Protecting Software Development Projects Against Underestimation

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Abstract

When a project in progress has been seriously underestimated, it is essential to figure out how much additional effort is required to complete it within its original scope and delivery date. This paper posits that project contingencies should be based on the amount it will take to recover from the underestimation, and not on the amount that would have been required had the project been adequately planned right from the beginning, and that these funds should be administered at the portfolio level. A model to calculate the required funds is developed.

Introduction

According to the Project Management Institute (PMI), a "contingency reserve" is *"the amount of funds, budget, or time needed above the estimate to reduce the risk of overruns of project objectives to a level acceptable to the organization"* (PMI, 2004, p.355). Contingency funds are meant to cover a variety of possible events and problems that are not specifically identified or to account for a lack of project definition during the preparation of planning estimates. When the authority for the use of the funds is above the project management level, it receives the name of management reserve.

In practice, contingencies are added to projects using heuristics such as the 10% or 20% of the project budget or by accruing percentage points on the basis of responses given to a risk questionnaire. More mature organizations might even run Monte Carlo simulations to calculate expected values. Whatever the approach chosen, in deciding how much and how to administer the contingency funds, one cannot ignore the human and organizational considerations that dictate decision making in real-world projects. Specifically, one needs to consider management preference of schedule over cost, time preferences, and the money-allocated-is-money-spent behavior (Kujawski, Alvaro, & Edwards, 2004)

A good example of the preference for schedule over cost is given by Stephen Grey (1995): "While most people will be willing to accept that cost could exceed expectations, and might even take a perverse delight in recounting past examples, the same is not true for deadlines. This is probably due to the fact that cost overruns are resolved in house, while schedule issues are open and visible to the customer" (p.108). In other words, project delays and scope cuts are not great career builders, so when faced with a schedule overrun, management preferred course of action is not to re-plan to achieve the best economic outcome but to attempt to keep the schedule by adding people despite the fact that adding resources midway through a project will result in one or more of the following (Sim & Holt, 1998):

- Need to break down the work into additional segments, so that they can be allocated to the newcomers;

- Need to coach the new staff;

- Additional integration work; and

- Additional coordination effort.

This means that if we know that contingency funds will be used first and foremost to maintain a schedule and not just to pay for underestimated work, we should acknowledge in their calculation the extra cost incurred by the above activities.

Wishful thinking (Babad & Katz, 1991) and inaction inertia (Tykocinki, Pittman, & Tuttle, 1995) are examples of time preferences that result in postponing the acknowledgement of a delay until the last possible moment. Todd Little (2006) commented on the unwillingness to acknowledge project delays: "This is the result of the project manager holding on to a deadline in hopes that a miracle will occur and the software will release. Finally the day of reckoning occurs, with no miracle in sight. At this point, the project estimate is usually reset. In many cases, this cycle repeats until the software releases" (p.52).

The tendency to procrastinate should also be factored into the calculation of contingency funds because, other things being equal, the later the underestimation is acknowledged, the higher the number of people required and, consequently the higher the cost.

These two premises led us to postulate that:

$$ContingencyFunds = \iint RecoveryCost(u,t)\, p(t)\, p(u)\, dt\, du \qquad (1)$$

Equation 1 ascertains that contingency funds must equal the expected recovery cost of a project, that is, the effort necessary to recover from an underestimation of magnitude u upon which we act at time t by the probability of u and the probability of t.

Having considered management predilection for schedule over budget and the time preferences, it is time now to look at the third behavior that affects the use of contingency funds: The money-allocated-is-money-spent (MAIMS) (Gordon, 1997; Kujawski, Alvaro, & Edwards, 2004) behavior. The MAIMS behavior implies that, for a variety of reasons, once a budget is allocated it will tend to be spent in its entirety, and, as a consequence, cost underruns are seldom available to offset overruns. This negates the basic premise that contingency usage is probabilistic and so, managing the funds above the project level becomes the obvious and mathematically valid solution for its effective and efficient administration.

The remainder of the paper defines and provides a rationale for $RecoveryCost(u,t)$, $p(t)$, and $p(u)$ and explains how these functions can be calculated in practice. We also present a numerical solution to Equation 1 and explain why contingency funds should be administered above the project level.

The Recovery Effort

Figure 1 illustrates the effort makeup of a project under recovery assuming that the objective is to preserve the original scope and the delivery date to which a commitment has been made:

- The budgeted effort (E_b) is the amount of effort originally allocated to the project and is the product of the time budgeted (T_b) and the original staff (FTE_b).

- t is the time at which the underestimation is acknowledged and a decision to do something about it is finally made.

- T_a is the mean time between when the decision to bring in new people was made, and the time at which the new staff arrives.

- The additional effort (E_a) is the effort that will be contributed by the resources brought in to help recover from the delay. The sloped left side of the quadrilateral models the fact that there will be a certain time interval (T_l) before the new staff becomes fully productive.

- The overtime efforts (E_{ob} & E_{oa}) are the efforts contributed through overtime by both the original and the additional resources. Overtime efforts are affected by fatigue, as modeled by the dark triangles on the upper-right corners of the corresponding rectangles.

- The process losses (P_l) include all the extra effort: ramp-up, coaching, and communication overhead imposed on the original staff by newcomers.

The simplicity of this makeup is deliberate. While other effort breakdowns are certainly possible, these would come at the expense of more complicated expressions, perhaps based on hypothesized parameters, which would make the model harder to explain.
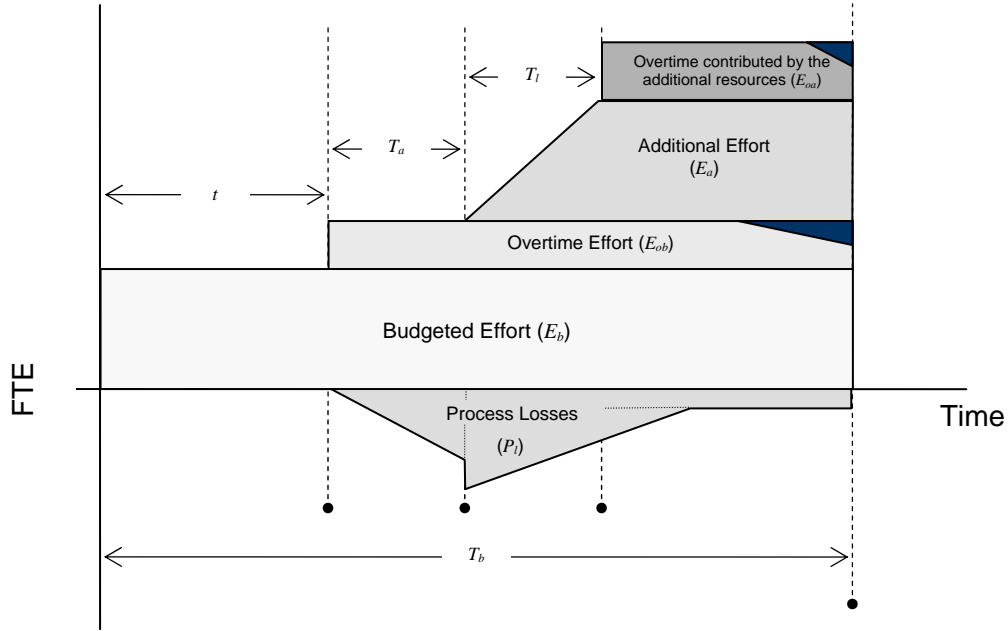
Figure 1: Recovery cost of an underestimated project (adapted from Grey, 1995)

Calculating the Number of Additional People – $FTE_a(t,u)$

Mathematically, the effort required to recover from an underestimation (u) would be equal to the effort that could be contributed through the overtime of the original staff (E_{ob}), plus the effort of those brought in to help (E_a) and their overtime (E_{oa}), less the effort necessary to compensate for the process losses (P_l).

$$u = E_a + E_{ob} + E_{oa} - P_l \tag{2}$$

The effort contributed by the additional staff would then be:

$$E_a = FTE_a \times (T_b - t - T_a) - \frac{FTE_a T_l}{2} \tag{3}$$

The term $\frac{FTE_a T_l}{2}$ accounts for the learning effort of the new staff.

The effort available through overtime is modeled as the percentage of the overall available effort less a productivity loss due to fatigue arising at a lag time after the decision to utilize overtime has been made:

$$E_{ob} = C_o FTE_b \left[T_b - t - \frac{C_d (T_b - t - lag)^2}{2} \right] \tag{4}$$

$$E_{oa} = C_o FTE_a \left[T_b - t - T_a - T_l - \frac{C_d (T_b - t - T_a - T_l - lag)^2}{2} \right] \tag{5}$$

The constants C_o and C_d stand for the maximum amount of overtime to be used in the project and the rate of productivity decay after lag weeks of working overtime respectively.

The process losses will be modeled as:

$$P_l = \frac{C_r \times FTE_a \times T_l}{2} + \frac{C_c \times FTE_a \times T_l}{2} + \frac{C_i \times FTE_a \left(FTE_a + 2 \times FTE_b - Teams \right) (T_b - t - T_a)}{2 \times Teams} \tag{6}$$

The constants C_r, C_c & C_i stand for the ramp-up, coaching, and interaction factors, respectively. $Teams$ is the number of groups into which the work is organized. Justification for these choices, together with that for C_d, will be given later.

Substituting the terms $E_a, E_{ob,}, E_{oa}$ & P_l in Equation 2 by Equations 3–6 we obtain:

$$FTE_a^2 \left[\frac{C_i (t + T_a - T_b)}{2 Teams} \right]$$

$$+ \frac{FTE_a}{2 Teams} \left[-Teams \left[\begin{array}{c} 2\,t + 2T_a + T_l + C_c\,T_l + C_r\,T_l + 2\,C_o \left(t + T_a + T_l - T_b \right) \\ + C_d\,C_o \left(lag + t + T_a + T_l - T_b \right)^2 - 2T_b \end{array} \right] \right] \tag{7}$$
$$+ C_i \left(2\,FTE_b - Teams \right) \left(t + T_a - T_b \right)$$

$$- \frac{FTE_b \left[2C_o t + C_d C_o \left(lag + t - T_b \right)^2 - 2C_o T_b \right]}{2} - u = 0$$

Equation 7 is an equation of the second degree, the general solution of which is:

$$FTE_a = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

So, by renaming

$$a = \frac{C_i\left(t + T_a - T_b\right)}{2\,Teams}$$

$$b(t) = \left[\frac{-Teams\left[\begin{array}{l} 2\,t + 2T_a + T_l + C_c\,T_l + C_r\,T_l + 2\,C_o\left(t + T_a + T_l - T_b\right) \\ + C_d\,C_o\left(lag + t + T_a + T_l - T_b\right)^2 - 2T_b \end{array} \right] + C_i\left(2\,FTE_b - Teams\right)\left(t + T_a - T_b\right)}{2\,Teams} \right]$$

$$c(u,t) = \frac{FTE_b\left[2C_o t + C_d C_o\left(lag + t - T_b\right)^2 - 2C_o T_b\right]}{2} - u$$
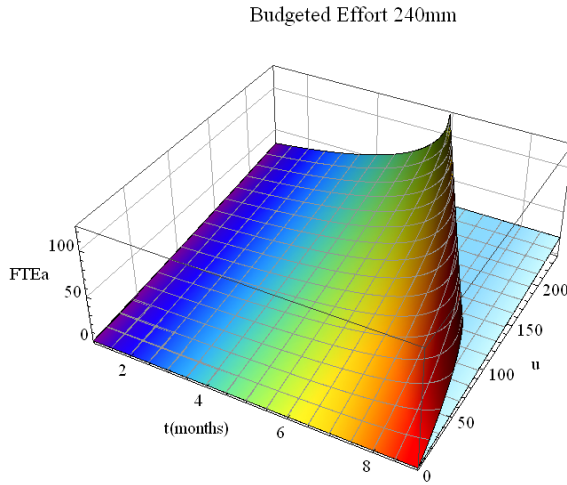
we obtain:

$$FTE_a\left(t,u\right) = \frac{-b(t) + \sqrt{b(t)^2 - 4a(t)\,c(u,t)}}{2a(t)} \tag{8}$$

This is the number of additional resources required to recover from an underestimation of magnitude u acknowledged at time t.

Project Example

The solution space for Equation 8 is illustrated in Figure 2. The vertical axis, $FTE_a\left(t,u\right)$, is the number of resources to be added to the project, the lower axis, t, corresponds to the time at which the underestimation is acknowledged, and the third axis, u, is the magnitude of the underestimation in man-months. The upper plane in the figure reflects the number of additional resources needed to recover from the underestimation while the lower plane shows the number of additional resources had the underestimated work be originally planned all of this on keeping, or at least attempting to keep, the same project completion date. All project parameters are listed on the right hand side of the figure.

The function is valid only if additional resources are required, that is, if the underestimation is greater than the extra effort that can be provided through the use of overtime alone and if the decision to bring in the additional resources is made on time, i.e., if the process losses are greater than the effort that could be generated in the remaining time $(T_b - t - T_a)$, then the equation has no real solution: it is an imaginary number, an indication that under the circumstances it would be impossible to maintain the schedule, no matter how many people are added.

Budgeted Effort 240mm

Note – Additional resources FTE_a required to recover from an underestimation of magnitude u acknowledged at time t. The lower front edge of the plane corresponds to a project that has not been underestimated ($u = 0$) and the lower left edge ($t = 1$) to a project that had been underestimated by u, but the underestimation was rectified when the project began. The truncation of the plane at the upper right corner indicates that the equation has no solution, meaning that the project cannot be recovered, no matter how many resources are added.

Figure 2: The cost of recovering from an underestimation

Process Losses

Frederick Brooks (1995) coined the well-known admonition that adding an extra person to a late project made it later, which even if a little extreme, has some element of truth. Adding people midway through a project creates additional work (the process losses) that would have not existed otherwise. The process losses are modeled by Equation 6. Its first two terms:

$$\frac{C_r \times FTE_a \times T_l}{2} \quad \& \quad \frac{C_c \times FTE_a \times T_l}{2}$$

correspond, respectively, to the ramp-up process leading to the incorporation of the newcomers and to the effort expended by the original staff coaching them. Both efforts are modeled as triangular areas.

The third term:

$$\frac{C_i \times FTE_a \left(FTE_a + 2 \times FTE_p - Teams \right)\left(T_b - t - T_a \right)}{2 \times Teams}$$

captures the extra effort expended coordinating the activities of the extended team. The equation[1] is derived from the findings of Thomas Allen (1984) while studying communications patters in research and development teams (see Figure 3) and on a previous work by Miranda (2001).
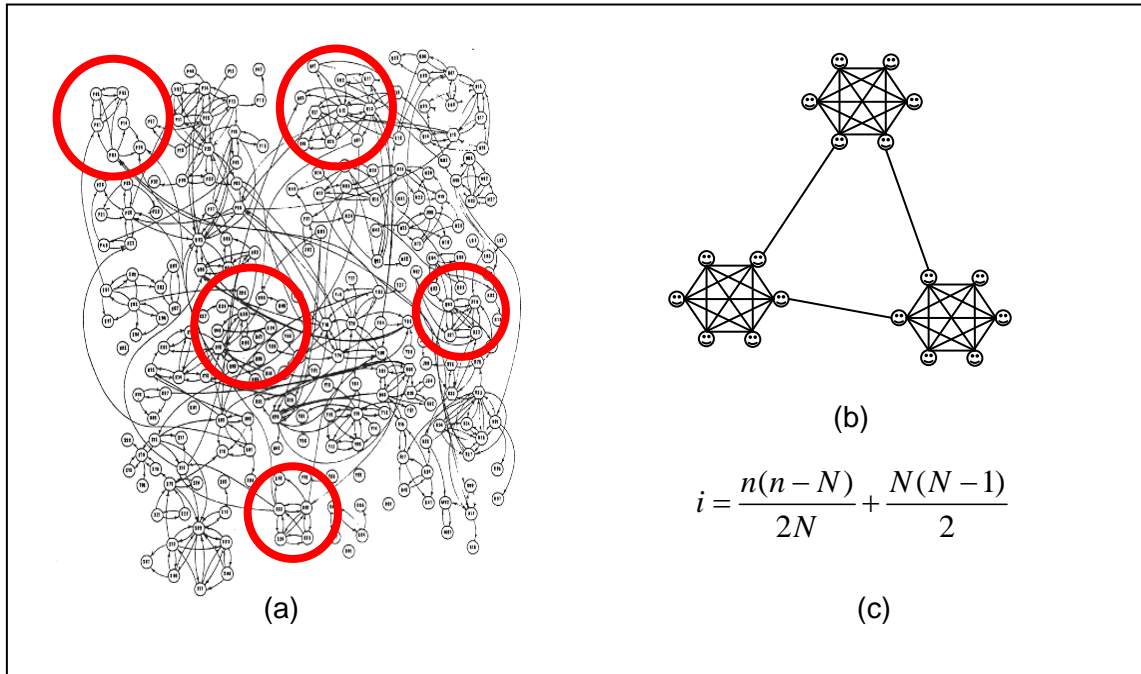
Note – (a) Patterns of communications in R&D teams, T. Allen (1984); (b) Stylized graph mimicking Allen's observations: everybody talks to everybody within a subsystem team while communications across subsystems are carried out by a few individuals; (c) Mathematical equation to calculate the number of communication paths

Figure 3: Communications in R&D teams

Allowing for Temporary and Permanent Staff Rates

The cost of recovery comprises the cost incurred through the overtime of the original staff and the cost, if needed, of additional resources and their overtime. Sometimes the additional staff is temporary, so for costing purposes, they might need to be considered at a different hourly rate from that of the permanent staff. The parameter *temp* in Equation 9 refers to the proportion of consultants or temporary workers employed in the project.

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[1] Notice that this equation yields a lower, but more realistic number of communication paths that the more well known $n(n-1)/2$.

Allowing for Liabilities and Opportunity Costs

Sometimes it may not be possible to recover from an underestimation within the original schedule. For example, if the decision to bring additional staff is made too close to the delivery date, the process losses incurred might be higher than the effort contributed in the time left and in consequence the project cannot be recovered. By not being able to deliver on time, the project could incur on liabilities and/or opportunity costs. These costs are accounted for in Equation 9 by the parameter *Penalty*

$$
RecoveryCost(u,t) = \begin{cases}
\begin{aligned}
&if\ u \le FTE_b\left[T_b + C_o\left(T_b - t\right)\right]\ \ then\ \text{- Overtime only}\\[2em]
&\quad R_o\left(u - T_b FTE_b\right)\\[2em]
&elseif\ b(t)^2 - 4a(t)c(u,t) > 0\ \ \text{- The project can be recovered}\\[2em]
&\quad R_o C_o \times FTE_b\left(T_b - t\right)\\[2em]
&\quad +\left[(1 - temp)R_n + temp \times R_t\right] \times FTE_a\left(u,t\right)\left(T_b - t - T_a\right)\\[2em]
&\quad +\left[(1 - temp)R_o + temp \times R_t\right] \times C_o \times FTE_a\left(u,t\right) \times \left(T_b - t - T_a - T_l\right)\\[2em]
&else\qquad \text{- The project cannot be completed on time}\\
&\quad Penalty\\
&endif
\end{aligned}
\end{cases}
$$

$$
\begin{aligned}
R_n &= \text{Normal Rate}\\
R_o &= \text{Overtime Rate}\\
temp &= \text{Proportion of temporary personnel to be employed}\\
R_t &= \text{Temporary personnel rate}\\
Penalty &= \text{Cost of not being able to complete the project on time}
\end{aligned}
\tag{9}
$$

Probabilities of Underestimation and Its Acknowledgment

Project cost and lead-time estimates based on the limited information available in tendering documents are notoriously unreliable: They are typically based on the partial results of basic design and many assumptions about its execution. The best we can do in these circumstances is to identify a range of values (see Figure 4) within which the organization believes it is possible to achieve the objectives of the project with a defined probability. The range woud consist of at least of three values:

1. Best-case scenario, which is the lowest amount of effort, but with a corresponding low probability of occurrence;

2. Most likely scenario of some effort with the largest probability of occuring; and

3. Worst-case scenario with the highest amount of effort, but again with a low probability of occurrence.

Different budgets will lead to different project approaches and different behaviors. Choosing the the best-case scenario will almost certainly lead to a cost overrun and to people taking shortcuts (Austin, 2001) while choosing the worst-case scenario might result in failure to get the job and almost certain overspending (Miranda, 2003).
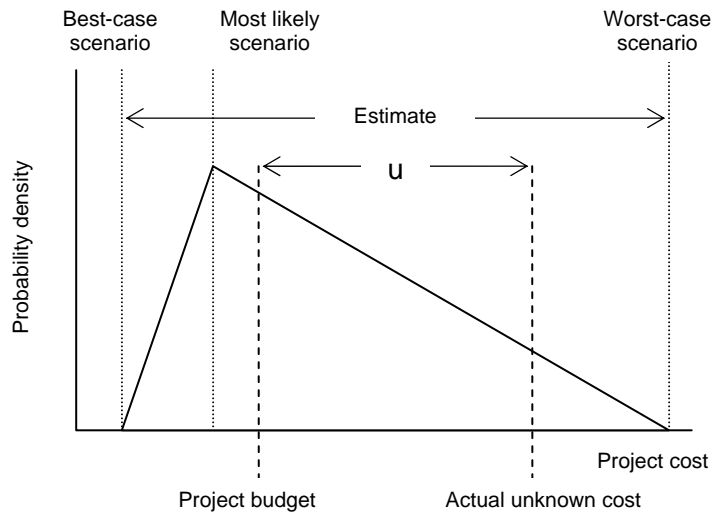
Figure 4: The probability distribution of an estimate

Probability of Underestimation - *p(u)*

The probability distribution of the underestimation u is identical to the effort distribution in Figure 1 shifted by the project budget. The selection of a right skewed triangular distribution is justified for three reasons: (1) the fact that while the number of things that can go right in a project are limited and in most cases have already been factored into the estimate, the number of things that can go wrong is virtually unlimited, (2) its simplicity, and (3) that since the actual distribution is not known this choice is as sensible as any other. Equation 10 gives the cumulative probabilities for $p(u)$.

$$
F(u) = \begin{cases}
if \quad u \le u_{min} \quad then \\[2em]
\quad 0 \\[2em]
elseif \quad u_{min} < u \le u_{ml} \quad then \\[2em]
\quad \dfrac{\left(u - u_{min}\right)^2}{\left(u_{max} - u_{min}\right)\left(u_{ml} - u_{min}\right)} \\[2em]
elseif \quad u_{ml} < u < u_{max} \quad then \\[2em]
\quad 1 - \dfrac{\left(u_{max} - u\right)^2}{\left(u_{max} - u_{min}\right)\left(u_{max} - u_{ml}\right)} \\[2em]
elseif \quad u \ge u_{max} \quad then \\[2em]
\quad 1 \\[1em]
endif
\end{cases}
$$

$$
\begin{aligned}
u_{mim} &= BestCaseEstimate - ProjectBudget \\
u_{ml} &= MostLikelyEstimate - ProjectBudget \\
u_{max} &= WorstCaseEstimate - ProjectBudget
\end{aligned}
\qquad (10)
$$

Probability of Acknowledging the Underestimation on a Given Month - *p(t)*

Figure 5 shows the ratio of the actual remaining duration to the current estimated remaining duration plotted as a function of relative time (the ratio of elapsed time over total actual time) for each project at each week. Under a schedule overrun condition, the estimated remaining duration will be smaller than the actual duration, and as time passes by, the estimated remaining duration will grow towards zero and the ratio will grow towards infinity. The convex pattern proves that project managers, or at least these ones, waited until the last possible minute to update the impaired schedule.
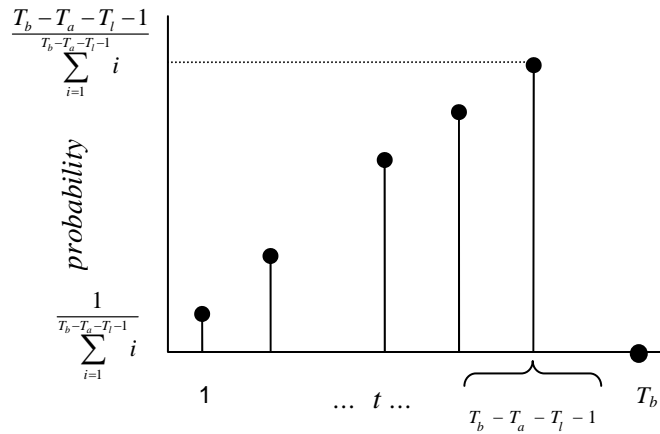
The implication of this finding for our model is that $p(t)$ must be an increasing function of t. One of such functions is Equation 11 (see Figure 6).
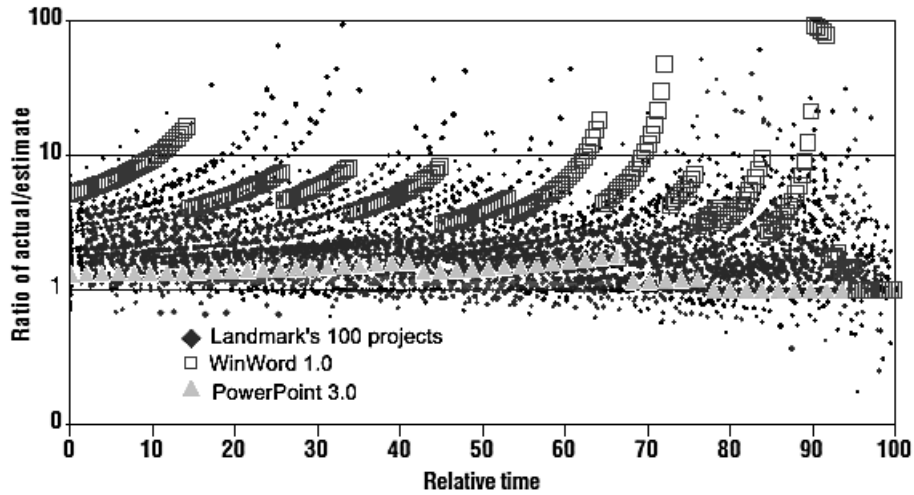
Figure 5: Procrastination as a function of project time (Little, 2006)

This, of course, is not the only possibility, but it resembles the patterns in Figure 6 and it is simple. Other possibilities for the probability function would include the use of Bayesian probabilities to model the effect of the underestimation, e.g., larger underestimations will be easier to notice than smaller ones, but this treatment is outside the scope of the present work.

$$p(t) = \frac{t}{\sum\limits_{i=1}^{T_b - T_a - T_l - 1} i} \qquad (11)$$

$$\frac{T_b - T_a - T_l - 1}{\sum\limits_{i=1}^{T_b-T_a-T_l-1} i}$$

probability

$$\frac{1}{\sum\limits_{i=1}^{T_b-T_a-T_l-1} i}$$

1   ... t ... $T_b - T_a - T_l - 1$ T_b

Note – The probability function does not extend to T_b, as the time to recruit, the time to learn, and at least one month to do some work must be taken into account

Figure 6: Probability distribution for t.

Numerical Solution

Equation 1 postulates to set the level of contingency funds at the expected value of the recovery cost.

Although the integral could be resolved analytically, the resulting expression is complex because of the piecewise continuity of the two triangular probability distributions and the need to decompose the function in order to consider whether or not the project could be recovered through the use of overtime alone or if additional resources need to be added. Consequently, the integral will be approximated by a sum of its parts according to the following algorithm.

1. For *budget* = u_{min} To u_{max}

    $FTE_b = budget / T_b$

    $\delta = 1$ *- This is the integration step*

    1.1. For *u* = *budget* to u_{max} Step δ

         1.1.1. For *t* = 1 To $\left(T_p - T_a - T_l - 1 \right)$

         1.1.2. If $u - budget \leq C_o \times FTE_b \left(T_b - t \right)$ then   *- Could we recover with overtime alone?*

    $$RecoveryCost = R_o \left(u - budget \right)$$

         1.1.3. Elseif $b(t)^2 - 4a(t)c(u,t) > 0$ then   *- Recovery is possible*

    $$RecoveryCost = R_o C_o \times FTE_b \left(T_b - t \right)$$
    $$+ \left[(1 - temp) R_n + temp \times R_t \right] \times FTE_a (u,t) \left(T_b - t - T_a \right)$$
    $$+ \left[(1 - temp) R_o + temp \times R_t \right] \times C_o \times FTE_a (u,t) \times \left(T_b - t - T_a - T_l \right)$$

         1.1.4. Else   *Recovery on time is not possible*

    $$Recovery = Penalty$$

         1.1.5. End if

         1.1.6. $Contingency = Contingency + RecoveryCost \times p(t) \times \left[F(u) - F(u - \delta) \right]$

   1.1.7. Next *t*

    1.2. Next *u*

    $Contingency = 0$

2. Next *budget*

Figure 7 shows the contingency amounts required by each level of funding for a project with an optimistic estimate of 200 man-months, a most likely estimate of 240 man-months and a pessimistic one of 480 man-months. As expected, when the project is budgeted at its most optimistic estimate, the contingency is at its maximum, and when the project is budgeted at its most pessimistic level, the contingency is zero. In the example, the minimum total cost is achieved for a budget allocation of 320 man-months. The location of the minimum would depend on the amount and the cost of overtime, temporary resources that might be employed on the recovery actions, and the penalty associated with the late delivery of the project.
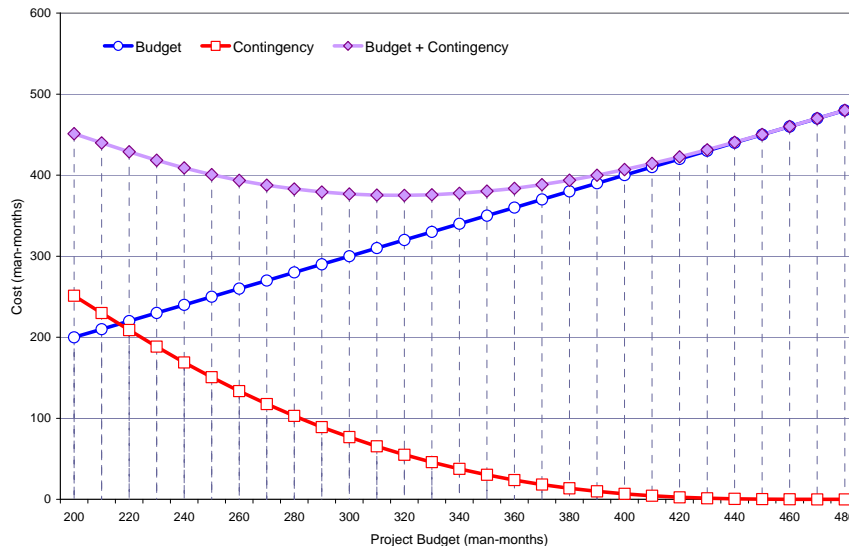
Figure 7: Breakdown of total project costs (budget + contingency) as a function of the budget allocated to the project

Managing the Contingency Funds

The MAIMS behavior could be explained by Parkinson's Law (Parkinson, 1955) and budget games like expending the entire budget to avoid setting precedents (Churchill, 1984; Flyvbjerg, 2005). If the MAIMS behavior is prevalent in an organization, all the budget allocated to a project will be spent irrespectively if it was needed or not, and as a consequence, there are never cost underruns only cost overruns. This negates the basic premise that contingency usage is probabilistic. The obvious and mathematically valid solution for the effective and efficient management of the funds is to maintain them at the portfolio level distributing them to the individual projects on as-needed basis. This is explored in the following paragraphs by means of a Monte Carlo simulation of a portfolio consisting of three projects identical to the one in the example in Figure 7 under four different budget allocation policies.

Figure 8 shows the probability of delivering on time and the expected portfolio cost for each scenario. The portfolio cost includes the allocated budget for the three projects plus their recovery costs or, whenever it is not possible to recover from the underestimation, the penalty cost.

Scenario 1 shows the result of the simulation when projects are allocated a budget equal to the most optimistic estimate (200 man-months). This is probably the worst policy of all. Not only does it yield the second highest portfolio cost but also has the most late projects. Despite the projects being allocated the minimum budget, recovery costs and penalties drive the cost up.

Scenario 2 corresponds to a budget allocation equal to the most likely estimate (240 man-months). In this case, the portfolio cost is lower than in the previous scenario and the probability of delivering on time is higher. Scenario 3 corresponds to a budget allocation that minimizes the total project cost (budget + contingency) as shown in Figure 7.
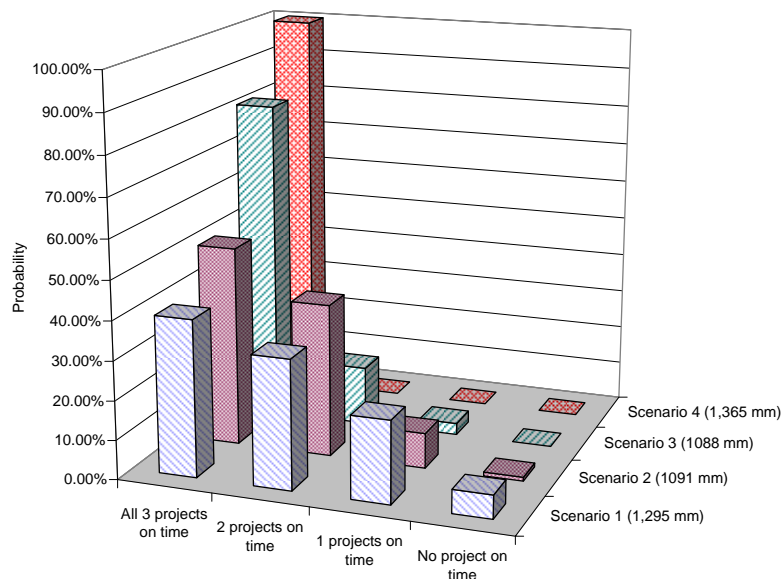

Note – The numbers between parentheses show the expected portfolio cost.

Figure 8: Probability of delivering on time under for different budget allocation scenarios.

With a total cost of 1,088 man-months, this scenario offers the lowest expected total cost with a high probability of delivering the three projects on time. The budget allocation for Scenario 4 is set at 455 man-months, the 99% quartile of the estimate distribution. In this scenario, all projects are completed on time but the cost is the highest.

Figure 9 shows the distribution of portfolio costs for each of the scenarios. What is important to look at here is the steepness of the curve. Steeper curves are the result of a smaller variance of the portfolio costs for a given scenario. Scenario 4 has the lowest variance since the large budgets allocated to the projects preclude underestimations. Scenario 1 is the opposite. It has the largest variance as a result of each project been underestimated at one simulation iteration or another. The importance of the curves' steepness is that the steeper the curve the highest the safety per dollar or man-month added to the project budget.
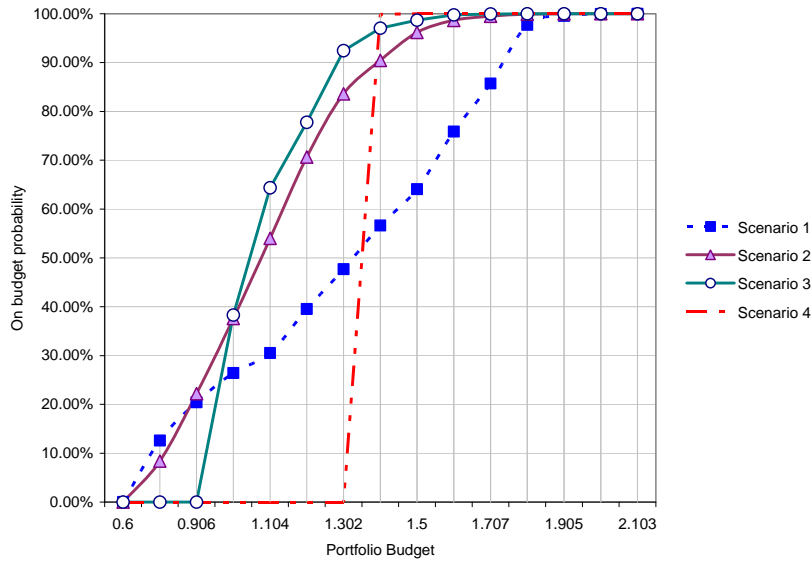
Figure 9: Distribution of the portfolio costs for each scenario

The results of the discussion are summarized in Table 1.

Table 1: Summary of budgeting policies

Scenario	Expected portfolio cost (from simulation) (man-months)	Budget for the three projects (man-months)	Contingency funds (man-months)	Portfolio budget (man-months)	Probability of not exceeding the portfolio budget (Fig. 9) ($\cong$)
1	1,295	3 x 200 = 600	3 x 251 = 753	600 + 753 = 1353	55%
2	1,091	3 x 240 = 720	3 x 150 = 450	720 + 450 = 1170	68%
3	1,088	3 x 320 = 960	3 x 55 = 165	960 + 165 = 1125	71%
4	1,365	3 x 455 = 1365	3 x .5 = 1.5	1365 + 1.5 = 1366	99%

The most efficient policy is thus the one corresponding to Scenario 3, which guarantees a 71% probability of being on-budget for a portfolio budget of 1,125 man-months. It is important to emphasize that, since we did not include for simplicity reasons, the use of temporary personnel and overtime for extended periods in the examples, the recovery costs are not as high as they would be if it was necessary to resort to any of these two sources of additional effort.

Summary

In this paper, we postulate that a project estimate is a range of values, within which an organization believes it is possible to achieve the project's objectives with a defined probability. A budget is the result of a political decision and consists on the allocation to the project of an amount of money or effort within the estimated range. A low budget will have a large probability of underestimating the actual effort required. A large budget will result in almost certainly gold-plating and over-engineering. As organizations tend to privilege schedule over cost, when projects are underestimated management first course of action will be to maintain the delivery date by adding resources to the project. This requires that project contingencies be calculated on the basis of the amount it will take to recover from the underestimation and not on the amount off the missed work have this been initially planned.

The proposed model takes into account the magnitude of the underestimation, the time at which the underestimation is acknowledged, and the consequences of not delivering on time and can be used to either calculate contingencies in actual projects or for education purposes.

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Appendix A: Model Parameters

C_i = Effort expended attending to one interaction (%)

C_o = Maximum overtime to be employed (%)

C_r = Effort to be expended in preparation
for the arrival of the new comers (%)

C_c = Effort expended in coaching a newcomer (%)

C_d = Decline in performance due to fatigue (%)

FTE_b = Budgeted full-time equivalents

lag = Time after which overtime productivity
starts to decline due to fatigue

T_a = Average time for newcomers to arrive

T_l = Average time for newcomers to get up to speed

T_b = Budgeted project duration

$Teams$ = The number of teams (subsystems)
into which the project is organized

$Penalty$ = The amount to be used as cost of
recovery when the project cannot
deliver on time