A Bayesian Methodology for Project Issue Management: A Micro Economic Perspective

John M. Aaron Ph.D., PMP

Abstract: One of the most vexing project management challenges on large scale projects is to confidently close out a phase of work. This is particularly true on projects, such as new product development, application development or business transformation initiatives that bring significant change to an organization's technology and processes. In principle the process of closing out a phase milestone works easily enough in theory. Here the project manager simply ensures that all schedule line items for the phase are complete and yield the correct interim deliverables allowing the responsible team members to mark schedule line items 100% complete and enabling the team to move forward to a subsequent phase of the life cycle. Experience in managing larger scale projects, however, suggests a more complex set of closeout requirements are needed. Here, managers must formalize issue management and tie phase exit milestones to quality gate sufficiency criteria.

Achieving quality sufficiency on a phase exit milestone can be elusive as a multitude of lingering unanswered questions, decisions, risks, action items, and defects can remain open which cannot rightfully be closed until a later project phase. These kinds of "open issues" can obscure the true readiness for milestone closure and are a source of project adversity causing pressure on schedule and budgets. Open Issues can also lead to scope expansion.

In this paper the author shows how an evidence based issue management methodology can be integrated with a classic project management structure in order to help the project manager control quality and risk more effectively. The author argues that rather than being a project nuisance, issues become the lifeblood of a project carrying valuable insights toward project quality, scope and schedule adherence on development projects. The author lays out the project management framework from an economist's perspective and demonstrates Bayesian statistical techniques using Monte Carlo methods. The author shows how the combination of objective project evidence can be combined with subjective project team sentiment resulting in optimized decisions regarding milestone completion and phase exit readiness. The author also points out that Bayesian Monte Carlo methods may help move applied project management research forward in other key areas of the discipline. {Key words: Quality Gates, Stakeholder Management, Quality Management, Issue Management, Innovation Management, Bayesian, Monte Carlo, ERP Project Management, Application Development, PRIMMS®}

Issue Management Within the Project Management Context

Project managers must plan and control scope, schedule, cost and quality in an integrated fashion. They must also lead and overcome adversity to meet challenging project objectives. On larger scale, technology-based projects managers frequently have difficulty in managing emergent issues that can throw the intended balance of scope, schedule, cost and quality considerations out of alignment. Thus, issue management can be a crucial element in managing a project because it affects all other dimensions of project performance.

The overall framework for managing the traditional four objectives of scope (S), time (T), cost(C), quality (Q) subject to a risk (R) constraint begins with the assumption that stakeholders undertake projects to achieve a business outcome or capability, and that outcome can only be met by the attainment of a specific Scope (S) containing k elements on a work breakdown structure (WBS).

During the planning phase of a project, the targeted scope (S) is considered a fixed $\bar{S}$ consisting as a set of identified requirements placed under change control. Given the fixed scope, the project is then ready to finish planning by estimating baseline time (T), cost (C), quality (Q) for each of the k WBS elements.

On large scale development projects (such as new product development or ERP implementations), the project manager must consider the dynamics of the execution phases consisting of design, build test and deploy. At this point Cost (C) frequently becomes the dependent variable of consideration that is effected by potential changes in scope, time and quality. This can be viewed from an economic perspective as

$$dC = \frac{\partial C}{\partial S} dS + \frac{\partial C}{\partial T} dT + \frac{\partial C}{\partial Q} dQ \qquad (1.1)$$

In addition to leading the project team through task completion of k WBS elements, the project manager must enforce change control in an attempt to keep each of the above changes to a minimum. However, change control may not be perfect, and any required change in a parameter should be offset by a corresponding offsetting change in another parameter that keeps total cost unchanged. As an example, if schedule performance begins to slip, the project manager must consider an offsetting tradeoff in another area such as scope. By attempting to keep $dC = 0$, we consider the potential offsetting impact from a scope reduction:

$$-dT = dS$$

Here the amount of required scope reduction necessary to offset the change of schedule due to slippage is dependent upon the amount of schedule slippage as well as the ratio of partial derivatives defined above, or

$$-\frac{\partial C / \partial T}{\partial C / \partial S} dT = dS \qquad (1.2)$$

Having established the context of the interplay of the project management parameters in microeconomic terms, the emphasis of this paper shifts to examining the impacts of dQ and in particular the effect of *project issues on* dQ *and how to best control it*. The concept of quality on a project tends to defy the smooth, continuous functions that economists tend to assume. Yet some functional form must exist for quality. If quality control and quality assurance decline, the project manager faces negative impacts, and likewise as quality improves, costs decline or $\frac{dC}{dQ} \leq 0$, yet it is subject to the law of diminishing returns.

From a practical perspective difficulties in managing project quality become especially visible at times of planned milestone completion and especially at times of preparation for major phase transitions. To manage this properly larger projects require a complex set of quality gate validation requirements which include the measurement of open issue disposition (i.e. open questions, decisions, risks, action items and defects). To achieve effective quality management that truly balances all project performance parameters, it is typical to anchor phase exit events (i.e. milestones) in quality gate sufficiency criteria that are tied to both scheduled work completion and overall issue disposition of issues. While it is readily apparent how work completion is measured against the k WBS elements, it is often less apparent for practitioners to assess gate readiness when a substantial number of issues remain open.

Project issues can be a major source of diminished quality and be used as a continuous variable proxy for project quality. To address project issue management within the context of quality, we need to discuss the nature of issues within the context of quality gate structures. A quality gate is a collection of completion criteria and sufficiency standards representing satisfactory execution of a phase of a project plan. Quality gates enable the project manager to structure projects in a way that allows the integrated reporting and control of schedule and scope progress against both quality criteria and completion criteria through the entire life cycle. A quality gate is a project management tool that enables project managers to ensure that first things are done first as well as to prevent unrealistic schedule performance reporting leading to runaway project execution. Reference: Read the PMI Quality Gate PMI Whitepaper by Aaron, Bratta and Smith 1993.

In practice quality gates anchor major milestones in sufficiency criteria. Figure 1 is a conceptual view of quality gate structure for a project containing super-milestones and sub-milestones on a project across the time dimension. For purposes of explanation we consider the standard waterfall life cycle methodology containing multiple execution phases and various organizational functions (tracks of work) that thread through the life cycle simultaneously. The smaller triangles shown reflect smaller sub-milestones which constitute the sufficiency criteria established for the phase. The phase exit points are considered super-milestones (large triangles) that slice vertically through the tracks of work and function as the quality gates. Using the quality gates as anchors all phase exits are tied to the attainment of criterion-based, cross track criteria that are deemed complete only when the sub-milestones (smaller triangles) are completed by the various teams (functions) performing the scheduled work at the prescribed level of sufficiency.

Attainment of each sub-milestone criterion within a phase contributes to the readiness for exit of the overall phase. Taken in totality the sub-milestones (i.e. the criteria) within the Figure 1 can be considered the phase exit criteria for the project. The phases are scheduled as super- milestones (the Quality Gates) reflecting their dependency upon summation of the sub-milestones. In practice, the whole must be equal to the sum of its parts. So, project managers cannot claim credit for a phase exit until sufficiency across all sub-milestones has been reached for the particular phase. Therefore when issues remain open at times of phase transition, a decision needs to be made which issues, if any, are tied to gate sufficiency criteria and are important enough to delay the closeout of the phase. Quality gates help raise the visibility of these exceptions which leads to an increase of focus on closing any lingering, remaining issues. It is this combination of visibility and pushback that forces sufficiency criteria to be met.

If we take our example a bit deeper we can consider the quality gate table shown in Figure 2 which is adopted from the original quality gates paper (Aaron, Bratta and Smith 1993). Here we see that the sample gate shown consists of a table listing the sufficiency criteria (i.e. analogous to the small triangles represented in Figure 1) needed for completing and exiting a project phase (the super-milestone QR7) on a development project (Alpha Project) in the telecommunications industry.

The sample table in Figure 2 contains a total of 10 sub-milestones that have been identified as being necessary criteria for exiting Phase QR7. Each criterion has an identified owner (shown by the initials of a department head); and has an associated number of sufficiency criteria (standards) required for its completion. Collectively the sub-milestones and their completion standards indicate the sufficient state

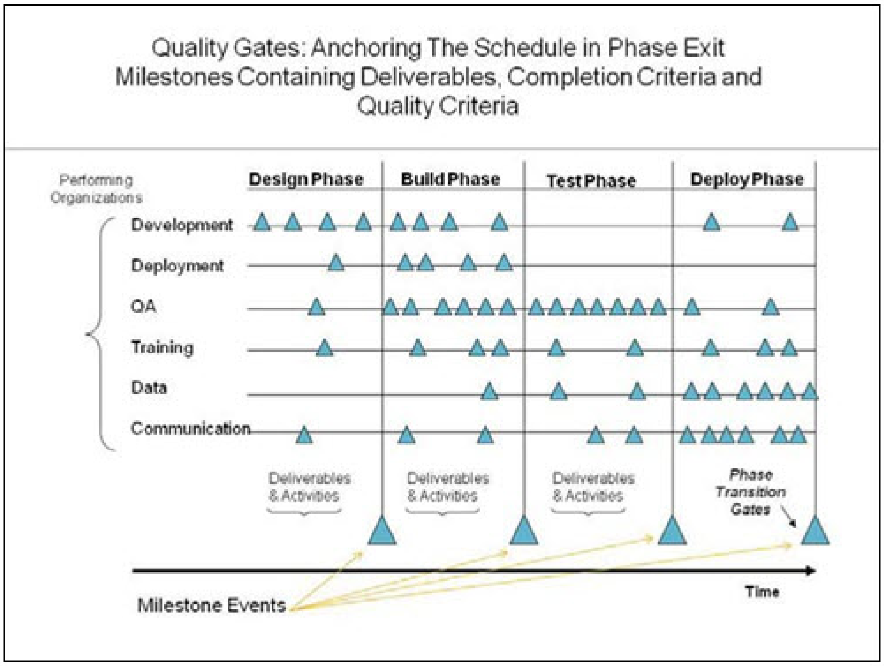

Figure 1

ALPHA PROJECT
QUALITY GATE QR7 STATUS REPORT

Milestones for Implementation Phase	Dept. Head	Total Sufficiency Criteria	Criteria	Total Criteria Met	Baselined Schedule	Forecasted Complete
Capital Expense Authorization Approved - OPS	VAC	1	Yes	1	1/03/93	1/05/93
Development Lab Facilities Available	TG	3	Yes	2	1/15/93	3/25/93
Prototype Hardware Available	TG	2	100%	0	2/01/93	3/20/93
SIT Test Plans Approved	DPS	20	95%	13	2/15/93	4/01/93
95% Pass Rate on Hardware Tests	TG	1	100%	1	3/01/93	3/01/93
Customer Letter of Intent Received	SS	1	Yes	1	3/15/93	1/02/93
Drawings and BOM's Released to Operations	TG	40	95%	38	3/15/93	2/16/93
Controlled Introduction Plan Reviewed & Issued	KC	2	Yes	2	4/01/93	1/02/93
Draft Source Materials to Technical Writing	JAM TG	8	100%	2	4/15/93	4/15/93
Code Inspections Complete	JAM	60	95%	30	5/30/93	5/30/93
	Total	138		90		

Figure 2

of readiness for the project manager to claim completion of the cross-functional, super-milestone QR7. Therefore any issue tied to these criteria has the potential of delaying a phase exit milestone.

The reader should notice that the naming of the sub-milestones (i.e. criteria) in this quality gate table contains both completion criteria and quality criteria. For instance, the sub-milestone *"Prototype Hardware Available"* references a completion criterion that can be tied to specific line items on a project schedule. Sufficiency is reached for this criterion once the corresponding activities on the project schedule have been completed. On the other hand, the criterion *"95% Pass rate on Hardware Tests"* references a quality criterion. It is only reached once a sufficient quality level on hardware testing has been met, and sufficiency at this level is less than 100% complete.

Quality gate sufficiency criteria must consider the disposition of open issues which are tied to the criteria. We classify open issues as *points of contention* that emerge on projects as falling into one of the following categories:

- Open action items/unanswered questions/general concerns/problems
- Open decisions
- Open risks without mitigation plans
- Open defects discovered in testing

The emergence of these types of issues can inhibit project stakeholders from closing out scheduled activities which can place stress on a schedule and budget in three ways. First, the baseline schedule and budget may not have allocated sufficient time and effort to close emergent issues. Second, the resolution of some of the issues may necessitate adding new deliverables to the baseline scope of the project. Third, there may be so many open issues that the team becomes overwhelmed and loses focus.

From a strict quality management perspective it would be very convenient if the project manager could take a hard line stance and simply insist that all open issues be closed before any phase milestone is closed out. But quality issues are subject to diminishing returns and project managers must lead through adversity by providing a perspective of balance and sensitivity to managing costs (C). Also, the nature of project issues is such that not all issues can be fully understood and closed within early phases of work. For various reasons some issues must be pushed to later phases[1]. So, while the hard line manager who insists on 100% closure of all open issues may be performing a vigilant quality management job, his overall management may be sub-optimal since schedule adherence and cost management may suffer.

What can project managers do to achieve the optimal balance of schedule and quality performance when open issues exist? As a common practice most managers attempt expediency and common sense by prioritizing the issues through the use of assigned severity ratings. Then, given these ratings the manager can insist that the most severe issues be closed before phase exit is authorized.

The prioritization approach to issues is helpful and necessary, but it is usually not sufficient alone. Several shortcomings exist. First, there is no guarantee that all of the severe issues can rightfully be closed in the current phase any more so than the lower severity issues can be. Secondly, it is not only the *severity* of open issues but the *number* of open issues as well as the *rate* of new issue identification that needs to be considered as well. Hence, an issue management approach that focuses solely on severity can leave a project vulnerable to missing a tsunami of open small issues that can overwhelm the team in a following phase of work even if the severity of each issue alone is rather low. The analogy of "death by a thousand cuts" is applicable to the naming of this risk.

It is with this very real project management dilemma in mind that we introduce a microeconomic framework toward dealing with project issue management. In the remainder of this paper we present the elements of the approach that includes:

1. An issue management framework in which project issues should be considered part of the overall production function for the project;
2. An issue management metric and analytical process that considers the number of open issues and rate of issue openings. The issue metric is reported in an integrated fashion with traditional project management metrics.
3. The blending of evidence based decision making with subjective team beliefs.

Issue Management Framework-An Economics Perspective

Over the last 20-25 years the inclusion of technology into business projects has shifted the paradigm of project productivity. This shift can be best explained by borrowing from economics the concept of the production function. In classic project management terms, project output Y is a function of the number of scheduled baseline activities (k) actually completed (AC), or

$$Y = f(\text{Activities Completed}) = f(\text{AC}) \tag{2.1}$$

On technology-based projects, in particular, we often find a new dependency added where project output becomes a function of the number of emergent issues opened (IO) and the number of issues

[1] The reader should note that the author intentionally omits discussion of the option to ignore all open issues.

closed (IC), shown as

$$Y = g(\text{Issues Opened, Issues Closed}) = g(\text{IO, IC}) \tag{2.2}$$

A positive change in project output is brought about not only through increased effort on completing the original baseline scheduled work AC, but also by achieving an increase in both issue discovery and issue closure which are typically unscheduled during the planning phase of the project. In mathematical terms, we get

$$dY = \frac{\partial Y}{\partial AC} dAC + \frac{\partial Y}{\partial IC} dIC + \frac{\partial Y}{\partial IO} dIO \tag{2.3}$$

Where all partial derivatives in the above equation are ≥ 0 and represent proxies for the overall concept of project quality (Q). Given equation (2.3) one can explain the need for budgeting a certain amount of time and resources for both issue discovery and issue closure[2].

Yet a practical problem exists for the project manager. Only scheduled activities are *visible* to stakeholders during the initiation and planning phases, and there is no way to accurately predict the nature and number of issues that will emerge throughout the various phases of work. The iceberg analogy is relevant here in that scheduled baseline activities lie above the surface and remain visible as work to be performed. The emergent issues, on the other hand, fall below the surface and can remain hidden until discovered during the normal course of the project. Taken in totality both the baseline scheduled work and the emergent issues constitute the true required work required for phase and project completion.

Experience indicates that on large scale projects there is nearly always an underestimation of the time required for issue identification, issue resolution and issue administration. Finding and closing the inevitable emergent issues hidden beneath the surface typically constitutes more effort and time than estimated on the original baseline scheduled work. Moreover, the resolution of these issues may result in additions to scope. Hence an expanded equation for project productivity could be

$$dY = \frac{\partial Y}{\partial AC_1} dAC_1 + \frac{\partial Y}{\partial AC_2} \frac{\partial S}{\partial IC} dIC + \frac{\partial Y}{\partial IO} dIO \tag{2.4}$$

Where ∂S refers to required Scope (S) additions to the project WBS as a result of issue closure. AC_1 refers to execution of original baseline effort during a period of time. AC_2 refers to execution of new work brought about by the increased scope (S) of work. We assume, of course, that a change request process is in place to ensure that only required scope changes become authorized.

Equation (2.4) accounts for the reason why project budgets in mature project industries normally contain contingency with an understanding that estimation error plus or minus some percentage should be assumed to account for this unidentified but expected addition to the total cost of the project.

The implication here is that a tradeoff exists for the project manager. Issue discovery and resolution are key mechanisms to determine the true required scope of a development project. In fact one could

[2] The author fully acknowledges the possible existence of the chain calculation $\frac{dY}{dAC}\frac{dAC}{dIC}\frac{dIC}{dIO}$

argue that rather than being a project nuisance and source of adversity, issues are normal and become the lifeblood of a project carrying valuable insights toward project scope, quality and phase exit milestone readiness. Conversely, however, the manager must balance this benefit with the need for solid project change controls for scope, schedule and budget to prevent a flood of emergent project issues which can trigger the spiraling addition of new scope items and escalating costs. Good project managers must achieve this balance, and mature stakeholders understand the need for this balance.

On large scale development projects and especially on those that combine technology implementation, process changes and/or overall business transformation, the sheer number of emergent issues necessitates that issue status be tightly integrated with the traditional scope, schedule, budget, quality and risk measures and controls.

In our next section we will introduce issue management metrics that complement and integrate with classic project management tools and methods. Specifically we will discuss Bayesian weight of evidence calculations using Monte Carlo methods to track issue status and calculate an appropriate metric.

Foundational Bayesian Issue Management Metrics and Analysis

The term Bayesian Statistics is based upon the theorem first written by Rev Thomas Bayes in the 18th century. For project management purposes we use the term more generally to cover any analytical methodology where the probability $P(H \mid E)$ of a hypothesis H, given evidence E is meaningful. As we consider the universe of all possible ways to measure and manage project issues, a probabilistic, evidence based approach seems to offer the greatest usefulness in business settings.

In its proportionate form Bayes' theorem simply states:

$$P(H \mid E) \propto P(H)\, P(E \mid H) \tag{3.1}$$

In plain language it reads: the probability of H given E is proportionate to the probability of H times the probability of E given H.

For our purposes the "evidence" refers to the data (y) which is associated with the pool of issues that are collected for a given project. As we will see below our hypotheses (H) will take the form of a parameter θ which refers to our prior and posterior beliefs about these issues can take on various values affecting milestone readiness as we attempt to close out a phase exit milestone.

Issue collection is a practical consideration. A repository of issues should give us relevant insights to the issues including their type, severity, age, status and assignment of ownership. To satisfy this requirement for our analysis we use the PRIMMS® web-based project management tool www.myprimms.com . Originally developed in 2008 PRIMMS® is a multi-user project interaction center that contains, among other functions, an issue management repository and issue tracking/reporting capability. PRIMMS° offers the convenience of a multi-user, web database that is designed specifically as a project issue repository using a quality gate structure.[3]

PRIMMS® enables users to document, classify, rate severity, update and report status on project issues of various types including:

- Action items (to cover open questions, concerns, problems and items requiring follow up)
- Decisions
- Risks
- Defects found in testing (i.e. Test Problem Reports)

For our sample analysis we use a standard issue management report exported from PRIMMS® to Excel for each track of work containing the count of issues according to their type and status. Refer to Figure 3 below.

Tracks of Work	Project Phase	Total Action Items	Action Items Closed	Total Action Items Open	Total Risks	Risk eliminated or plan in place	Total Risks Open	No of closed decisions	Total decisions	Total Decisions Pending	No of closed Defects	Total Defects	Total Open Defects
AfterSales	Execution	4	4	0	0	0	0	0	3	3	3	4	1
CRM	Execution	0	0	0	1	0	1	6	8	2	19	25	6
Customer Master	Execution	0	0	0	0	0	0	0	0	0	1	1	0
Data Migration	Execution	0	0	0	0	0	0	0	0	0	4	4	0
Finance	Execution	0	0	0	0	0	0	0	0	0	3	4	1
Global Data Goverance	Execution	0	0	0	1	0	1	0	1	1	2	2	0
Human Capital	Execution	0	0	0	2	2	0	5	5	0	1	1	0
Logistics	Execution	0	0	0	0	0	0	0	1	1	10	14	4
Material Master	Execution	0	0	0	1	1	0	0	0	0	9	14	5
Site IT	Execution	0	0	0	0	0	0	0	0	0	1	1	0
Product Data													

Figure 3

For our sample project we consider the issue pool to consist of both open and closed issues $y_1, \ldots, y_n$ where each y_i represents a single issue (i) in the total pool of n identified issues.

To start we consider simply merging issue metrics with project earned value metrics. An example of a ratio giving an adjusted percent complete would be

$$\frac{Actual\ Work\ Performed}{Total\ Budgeted\ Work + Open\ Issues} = \frac{Total\ Tests\ Passed}{Total\ Tests + Number\ of\ Open\ Issues}$$

Next, we identify a useful parameter θ which equates to the ratio of total closed issues to total issues in the pool. Or,

[3] PRIMMS® is a registered trademark of Milestone Planning and Research, Inc.

$$\theta = \frac{\text{Total Closed Issues}}{\text{Total Issues in the Pool}}$$

In a project situation this ratio will behave as a varying proportion ranging from 0 to 1 with a value depending upon the relative number of open issues to closed issues at any particular time on the project. The utility of θ is apparent as a metric when we think of it as an indicator of project health and readiness. Just as physicians use blood samples to evaluate the health pf patients, project managers can use θ as a project blood sample measurement. When θ takes on values that approach 1, it signals a good health and high readiness condition for phase exit. When θ takes on values that approaches 0, it signals poor health and low readiness condition for phase exit.

To be consistent with the Bayesian framework $P(H \mid E)$ we hypothesize any value or set of values for the ratio θ and then assess the likelihood $p(\theta \mid y)$ of a hypothesis being true based upon this evidence. For now we will consider the impact of our prior beliefs as being neutral, and thereby choose a non-informative prior. For now, we want to consider only the total evidence y consisting of the total number of issues and the status of each issue (i.e. being open or closed).

A classic Bayesian model for our purposes is the Beta distribution, where

$$p(\theta \mid y) = \frac{\theta^{a+y-1}(1-\theta)^{b+n-y-1}}{\int_0^1 \theta^{a+y-1}(1-\theta)^{b+n-y-1} d(\theta)}$$

with *y*= the evidence consisting of the number of closed issues, n= the total number of issues in the pool, n-y= number of open issues. In the Bayesian context the starting Beta parameters *a* and *b* are considered a non-informative prior (seed) values that can be assumed to *a*=*b*=1 at the start of the project. Then as we obtain evidence (i.e. issues) we increment the value of *a* for every closed issue, and we increment the value for *b* for every open issue.

The utility of the above formula becomes evident when we consider that we move the project forward in time and open/close issues and review them at recurring intervals. As part of the reviews we can simply add all closed issues to the parameter *a* and add all open issues to *b*. In addition, later on we will relax our assumption about using a non-informative prior (starting) values for *a* and *b* which will enable us to combine any starting subjective information with actual evidence obtained later. The combination of our prior times our likelihood functions produce the posterior function which is $p(\theta \mid y)$.

For our example the resultant output will be the posterior density function as shown in the example Figure 4 below. The distribution is generated using a Monte Carlo simulation using STATA with the above model where we generate possible values for θ (the x axis) and update *a* with our hypothetical 250 closed issues and update *b* with the hypothetical 25 open issues giving us a total pool of n=275 issues. Monte Carlo methods simulate draws from probability distributions using pseudo random number generators, and here the author chose a sample of 1,000,000 draws.

In this example the mean value for θ using the Beta-Binomial distribution is $\frac{a}{a+b} \approx 0.91$ which equals total closed issues divided by the total pool of issues.

The standard deviation equals $\sqrt{\frac{ab}{(a+b)^2(a+b+1)}} \approx .02$

Our next question relates to how we might interpret θ as a score in terms of project health and overall readiness to close out a phase of work at a point in time. So we ask what does the score of 0.91 really mean? To answer this question we must use operational judgment about expected utility. Refer to Figure 5.

Figure 5 shows two truncated normal distributions reflecting the assertion by the author (based upon experience) of the likelihood of success and the likelihood of failure across the range of possible values for θ on technology projects. The downward sloping curve (on the left) peaks at 0 and the upward sloping curve (on the right) peaks at 1. The distribution on the left gives the hypothesized likelihood of project failure for all values of θ if the project were to go live at any point in time. Conversely the distribution on the right is upward sloping and gives the hypothesized likelihood of success for all values of θ if the project were to go live at any point in time. The intersection of the two curves at $\theta =$ 0.7 is the point where the likelihood of success and the likelihood of failure are equal. Therefore, a value of θ going less than 0.7 reflects an increasing likelihood of failure, and a value of θ going greater than 0.7 reflects an increasing likelihood of success.

Taking this a step further we simulate a Bayes' Factor by dividing the two likelihood functions of Figure 5 resulting in Figure 6. The curve shown in Figure 6 is the result of a Monte Carlo simulation of 10 $\log_{10}$ ratio of the two truncated normal distributions yielding a composite upward sloping curve with a 0 reference point at even odds where $\theta =$ 0.7. The use of logarithms enables us to set the point of intersection of the two curves of Figure 5 at the 0 dP reference point.

From the author's perspective any θ value operating at a level less than 0.7 falls into a region of non-readiness prohibiting a milestone completion or a phase exit; whereas any θ value operating at a value greater than 0.7 falls into a region of potential readiness which could allow phase exit depending upon risk tolerance of project stakeholders. Further, as the actual value for θ increases the greater the weight of evidence pointing toward success. The implication is that the project stakeholders should be looking for at least even odds of success before considering any phase to be ready for exit, and any increase in likelihood ratio will yield a corresponding increase in the odds of success.

It will be up to management to decide upon and set the actual threshold of readiness based upon their own risk tolerance, yet it is useful to observe the overall curve shows diminishing marginal benefit in terms of risk reduction. We assume, of course, that the project manager will attempt to resolve the most severe issues first and as more and more issues become closed the risk of the "death by a thousand cuts" phenomenon becomes progressively diminished with the 0.7 benchmark as the minimum. As the value of θ increases beyond 0.7 the value on the curve increases, but at a decreasing rate. This suggests that management may choose a sufficiency value that falls between 1.0 and 0.7 for the value of θ .

From an economic perspective in terms of utility (U) for the project, we find that the following inequality generally holds true

$$\frac{dU}{d\theta} > 0 \text{ for all values of } \theta$$

But a more robust utility function would follow a profit maximization model that also considers the marginal cost of risk reduction in addition to the marginal benefit. The model being

$$\pi = U(\theta) - C(\theta) \tag{3.2}$$

Where π = profit
$U(\theta)$ = the benefit function from the level of risk reduction brought about by increasing θ.
$C(\theta)$ = the cost function from the level of risk reduction brought about by increasing θ.

With the point of profit maximization for θ found where the marginal benefit equals the marginal cost or

$$\frac{dC}{d\theta} = \frac{dU}{d\theta} \tag{3.3}$$

Where $0.7 \leq \theta \leq 1.0$

Hence, the optimizing project manager and project stakeholders should consider that not all issues require closure before milestones can be considered complete.

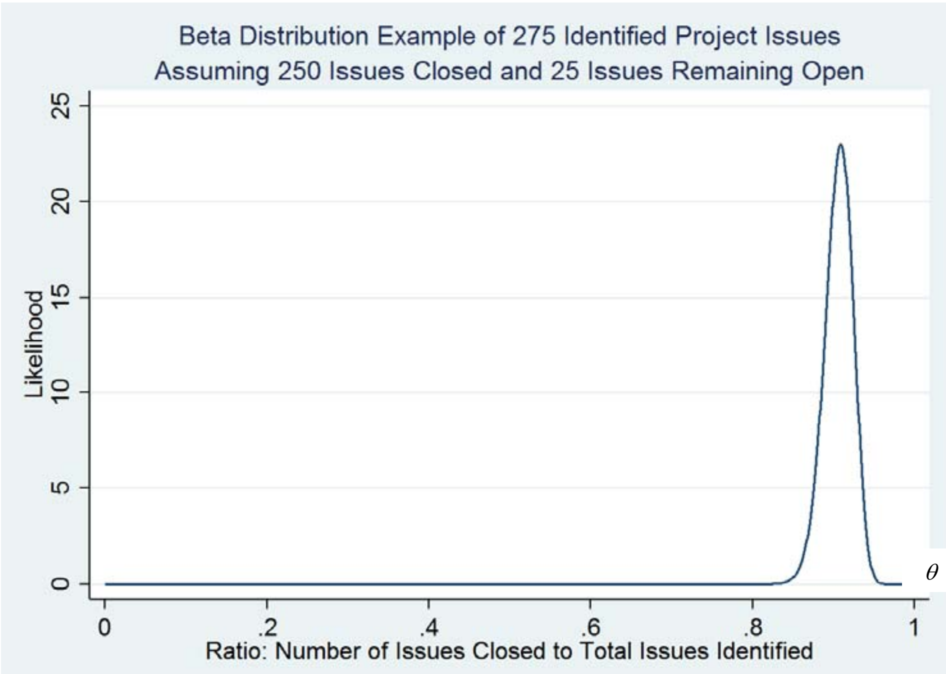

Figure 4

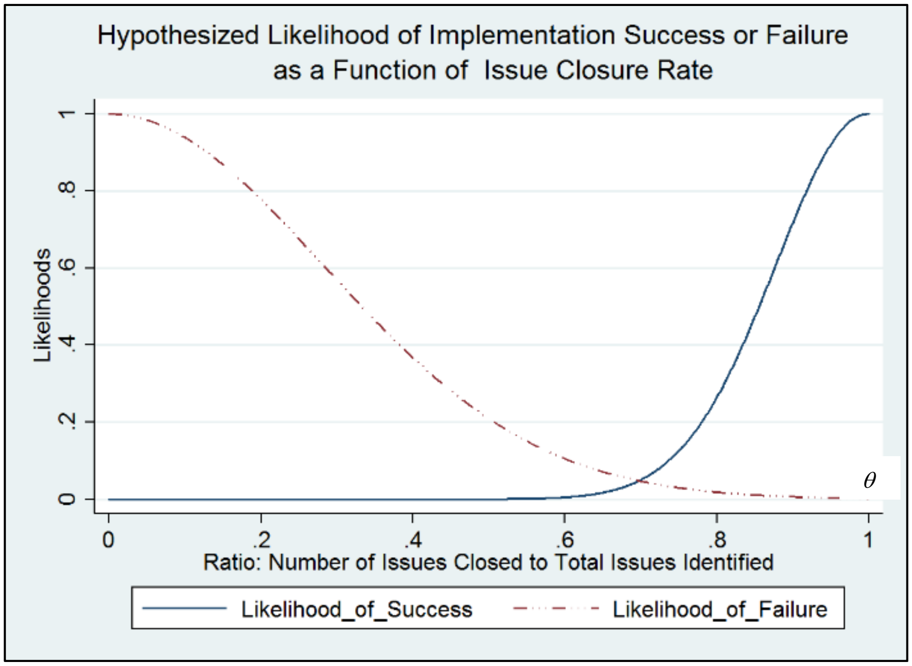

Figure 5

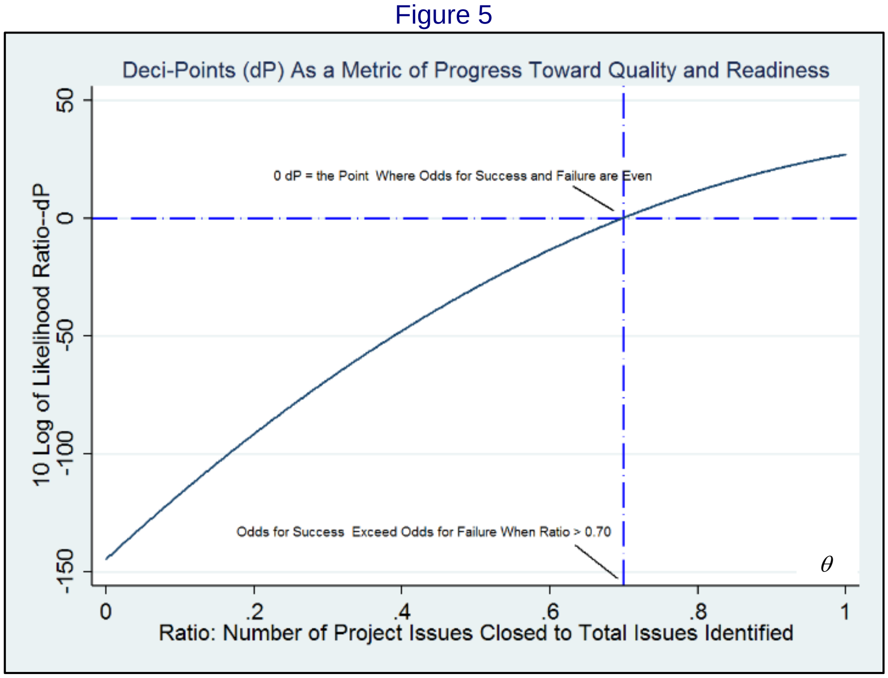

Figure 6

Using Team Beliefs as the Prior in Bayes' Theorem

We are now ready to build upon the Bayesian framework further by using the prior component of Bayes' theorem to our advantage. As mentioned above Bayesian statistics allows us to use two sources of information about the parameter θ : our prior belief and the observed evidence. So, let's suppose that instead of starting the analysis with the observed evidence on successes of closing issues (*y*) as described above, we start instead with the team's subjective beliefs (gathered from surveys) about their sentiments regarding the project's readiness to close a milestone. We assume that the team's beliefs about readiness are gathered independently from the analysis of issues described above.

For the sake of example let's further suppose there are 50 total stakeholders surveyed on the project and only 5 of the 50 (10%) indicate that the project is ready to exit a phase (or milestone such as go live). The PRIMMS® web enabled project management tool provides us with the functionality to gather team sentiment, and Bayes' theorem enables us to combine this prior subjective information of team sentiment from the survey data with the evidence related to actual issue closures.

To utilize Bayes' theorem we describe a prior density $f(\theta)$) that is based upon survey responses which will be multiplied by our likelihood function $g(\mathrm{y} \mid \theta)$ that is based upon the evidence of y issues closed out of a total n identified issues. The product of prior times likelihood yielding a posterior distribution $g(\theta \mid y)$. Using Bayes' theorem we perform the following calculation to generate the posterior:

$$g(\theta \mid y) = \frac{f(\theta) \quad g(y \mid \theta)}{\int_0^1 f(\theta) \quad g(y \mid \theta) \; d(\theta)} \tag{4.1}$$

Resetting the example described above we now assume that project issue management begins with a survey of stakeholder sentiment taken from PRIMMS® which indicates that only 10% of stakeholders (i.e. 5 out of 50) believe the project is ready to exit the phase milestone.

Having this information the project manager then considers the available evidence from the issue pool. We further assume that project manager finds the issue pool to now contain n=350 issues with 280 issues closed and 70 issues remaining open resulting in a closure rate of 80%. By carrying out Bayes' theorem using Monte Carlo methods as described in the equation above, we combine the prior and likelihood functions resulting in the posterior which is the Beta distribution.

Figure 7 below shows the resultant prior, likelihood and posterior outputs. It is useful to see that the consideration of evidence regarding issue status has shifted the mean θ value of the posterior to approximately 0.7. The calculation of the posterior reflects a blend of both prior and likelihood, but overall the evidence from the likelihood function dominates the team sentiment. A rational project manager would go with the posterior for purposes of decision making, but would explore the reason for low team sentiment.

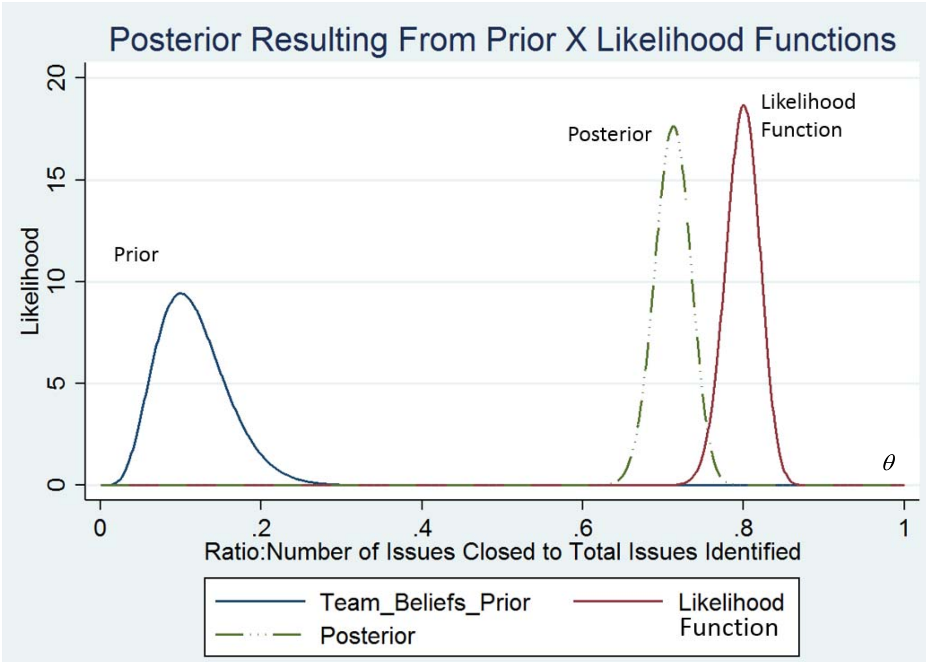

Figure 7

In the calculating the posterior the effect of likelihood function outweighs the effect from the prior because the number of issues is greater than the number of survey respondents. Because we are using the Beta, each positive survey response adds to the value of *a*; whereas each negative survey response adds to the value of *b*. Therefore, the shape and location of the posterior would be an additive composite of both issues from the likelihood function and the survey respondents in the prior. The posterior can be considered a Beta (285,115) where the weight of each survey respondent is weighed equally with the weight of an issue. Since the number of issues exceeds the number of respondents, the posterior is pulled more toward the likelihood function than toward the prior.

Various schemes exist to raise or lower the effect of the prior on the posterior relative to the effect on the posterior from the likelihood. In general, however, most would argue that the evidence is what is most important. This suggests that the likelihood dominate the prior. For this reason we will make no adjustments in the relative weights between prior and likelihood.

Conclusions

Most project managers perform issue management in some fashion, yet in practice many are challenged by the adversity and complexity that comes with it. This is especially true when the number of issues becomes quite large. The need for effective project issue management becomes most visible during times of phase transition or other major milestones.

This paper presented a project management framework from an economic perspective. It examined the role of quality and especially the impact of issues on quality on overall project success. The paper showed how Bayesian methods and Monte Carlo methods can be used for evidence based issue tracking as part of the overall project management performance reporting. The paper highlighted several key points:

1. Project issues are normal. There is no such thing as problem-free projects, at least for larger projects and first time development projects. All stakeholders need to be made aware of this point.
2. It is important to have access to a repository of all project issues. A single, multi-user tool such as PRIMMS® can make these kinds of analyses possible.
3. Bayesian methods enable the project manager and all stakeholders to gain a more holistic understanding of milestone readiness. The combination of team beliefs along with issues based evidence add greater practicality to the quality gate framework which has remained the cornerstone of project quality management over the last 20 years.

A critical point worth noting is the interesting potential that Bayesian Monte Carlo methods holds for the future practice of project management and project management research. Disciplines such as forensic science and epidemiology already use these approaches to a great extent. Why not project management as well? This paper has demonstrated only a very basic use of Bayesian Monte Carlo methods related to the Binomial and Beta distributions. Tools such as Markov Chain Monte Carlo (MCMC) may unlock the door to an understanding of useful topics related to advanced scheduling methods beyond the critical path approach, modeling stakeholder interactions, ROI causation, and advanced risk management to name a few.

Finally, it is important to highlight the close connection between project management and mathematical economics. Hopefully, this paper will raise the interest in project management among economists. There is much work to be done in the area of project management *optimization* where economists could contribute greatly.

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