A Quantitative Framework for Multi-Dimensional Risk and Opportunity Management

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Abstract

Many have recognized project management as the delicate task of balancing cost, schedule, and quality. Attributes in each of these dimensions contain uncertainty and consequences of positive or negative outcomes, which imply risks in the traditional sense but also opportunities. In current practice, risk management is often done separately from quality, performance, cost, and schedule management, and the relevant data reside in separate frameworks and information systems. Opportunity management is often not formally done at all. This paper defines four types of project risk and opportunity and proposes an integrative, quantitative framework for leveraging project cost, schedule, and quality risk and opportunity information. The framework highlights the key attributes of value to the customer and the level of risk and opportunity in each. It also calculates the level of overall risk and opportunity for a project and provides managerial guidance for projects with various combinations of high or low opportunity and risk. The framework is demonstrated with an extensive example.

Key Words

Project management, risk management, opportunity

1. Introduction

Project management is risk management. The job of a project manager is to produce a result that meets the project's stakeholders' expectations, typically by achieving satisfactory output performance within time and cost constraints. This spawns the classic tensions and tradeoffs between cost, schedule, and quality. But the benefits (quality) provided by the output and the sacrifices (time and money) required are uncertain at the beginning of a project. Plus, some cost, schedule, and quality outcomes bring positive or negative impacts. Risk accounts for both uncertainty and its impacts. Project managers must not only balance cost, schedule, and quality in congruence with stakeholder expectations but also manage the risks and opportunities in each of these areas. Risk of incongruency in one area forces compensation from other areas. And while most applications and methods focus on risks—the deleterious consequences or "down side"—project managers must also account for the opportunities, the rewarding consequences or "up side." This act of dynamically balancing cost, schedule, quality, and the risks and opportunities associated with each is a key task of project management.

Given this job description and the complexity of many projects, an integrative framework is needed to distill and organize a vast amount of information to support managerial decision making. Even if a project has good approaches to planning, budgeting, scheduling, monitoring, quality evaluation, and risk management, each of these is often done by separate individuals or groups, commonly using disparate approaches. Hence, incorrect assumptions may linger until later in a project, revealed as such only after a significant problem has occurred. Moreover, opportunities are unlikely to be systematically managed at all, or they are pursued without the support of sound analyses. Overall, the lack of a common, integrated approach makes it difficult to explore the impacts of potential changes in each area on the other areas.

In this paper, we discuss risk and opportunity in the context of projects. For example, there could be penalties for finishing late and rewards for finishing early; there could be a huge decrease in customer demand for a resulting product or service if it does not provide basic features; or there could be unplanned possibilities for a product or service that exceeds expectations. As a manager plans and controls a project, he or she needs the ability to explore the ramifications of "risk subsidies" and "opportunity costs" among the areas of project cost, duration, and quality.

This paper presents a practical approach to risk and opportunity management that is easily and obviously applicable to a variety of projects in industry. We provide a customizable, quantitative framework for planning and tracking projects to support managerial decision making. The framework accounts for cost, schedule, and technical performance (quality) risks and opportunities and provides a way to compare and trade off among these. Thus, the approach supports "what if" analyses and ongoing project monitoring and control.

The rest of the paper is organized as follows. In the next section, we provide foundational definitions of risk and opportunity as used in the framework. §3 presents the risk side of the framework and §4 the opportunity side. §5 then demonstrates the framework's implementation on an example project, and §6 discusses the issues and results. Finally, the Conclusion discusses additional insights, limitations, and next steps for research enabled by the framework.

2. Foundations

Risk entails both uncertainty and consequences. Just because an outcome is uncertain does not necessarily imply it is risky: one must also face some consequence should the event occur. Hence, the risk presented by an event is often quantified as the product of the probability of the event and its impact or consequence (e.g., PMI 2000):

$$\text{Risk} = \text{Probability} \times \text{Impact} \tag{1}$$

In decision analysis, this corresponds to the expected (adverse) value of an outcome. Thus, risk is typically measured in terms of the magnitude of the expected loss. If consequences are expressed in monetary terms (often termed "exposure" in the financial literature), the risk of an event is the expected monetary loss. Equation (1) pertains in the context of a set of risky events, where statistical averages become meaningful. (For a single event, it either occurs or does not, so knowing the expected loss is not as helpful.) Note that quantifying risk requires forecasting (of both probabilities and consequences), and that a "problem" or "issue" is a risk with a probability of one—i.e., an outcome that has occurred.

Projects face several categories of risks that threaten success, including cost, schedule, technical performance (or quality), market (or customer value), technology, and business risks. Here, we focus on the first four categories, which we define as follows:

Cost Risk is the uncertainty in the ability of a project to develop an acceptable output within a given budget and the consequences of cost overruns.

Schedule Risk is the uncertainty in the ability of a project to develop an acceptable output by a deadline and the consequences of schedule overruns.

Technical Performance (or Quality) Risk is the uncertainty in the ability of an output to satisfy technical performance requirements and the consequences of requirements shortfalls.

Market (or Customer Value) Risk is the uncertainty in the anticipated utility or value to the market of the chosen project targets and the consequences of failing to meet the right targets.

While some use the term "risk" in both a positive and a negative sense (Hillson 2002b; Hulett *et al.* 2002), for the sake of clarity here we use "risk" in a negative sense and "opportunity" in a positive sense. Thus, opportunity is quantified similarly to risk,

$$\text{Opportunity} = \text{Probability} \times \text{Impact} \tag{2}$$

except its impacts have the positive connotation of rewards.

Paralleling the definitions of four categories of risk, we define four categories of opportunities:

Cost Opportunity is the uncertainty in the ability of a project to fully require a given budget to develop an acceptable output and the rewards of not spending an entire budget.

Schedule Opportunity is the uncertainty in the ability of a project to fully require a given schedule to develop an acceptable output and the rewards of beating a deadline.

Technical Performance (or Quality) Opportunity is the uncertainty in the ability of an output to exceed technical performance requirements and the rewards for exceeding required performance levels.

Market (or Customer Value) Opportunity is the uncertainty in the anticipated utility or value to the market of the chosen project targets and the rewards for exceeding the right targets.

These definitions cause some immediate insights. First, one should question the incentives or lack thereof for seizing opportunities. For example, not spending an entire budget is often not rewarded—in fact, it may even be penalized! Delivering an output ahead of schedule may also carry adverse consequences, such as if the recipient cannot itself take advantage of early delivery and must hold the product as inventory. Thus, the definitions of risk and opportunity should be seen as *usually* true. For greater correctness, we could change the definition of, for instance, cost risk (opportunity) to end with "and the consequences (rewards) of deviating from the planned budget." However, we chose the stated definitions to emphasize the typical cases where more or less is better. Both the definitions above and the framework to follow can also accommodate "nominal is best" cases.

3. The Risk Framework

We now provide a quantitative framework to evaluate the level of opportunity and risk in each category. Before presenting the framework by categories, we begin with a symbolism for the overall product and its value. Marketing and engineering design literature has found it helpful to represent a product as a vector of attributes for which various customers have particular preferences. For example, an aircraft's vector of attributes might include price, delivery date, operating cost, payload, range, max speed, reliability, etc. Customer value depends on how well the product meets preferences for these attributes. Here, we define $\boldsymbol{J}$ as a vector of m product attributes, $\boldsymbol{J} = (\varphi_1, \varphi_2, \ldots, \varphi_m)$, each with customer (or market) desirability or utility $\mathrm{U}(\varphi)$, $\boldsymbol{U} = (\mathrm{U}(\varphi_1), \mathrm{U}(\varphi_2), \ldots, \mathrm{U}(\varphi_m))$. We assume overall product value, Ω, can be expressed in terms of the utility of its individual attributes:

$$\Omega = f(\boldsymbol{U}) = f(\mathrm{U}(\varphi_1), \mathrm{U}(\varphi_2), \ldots, \mathrm{U}(\varphi_m)) \tag{3}$$

This overall value is reduced by the expected loss (risk) and increased by the expected gain (opportunity).

3.1 Quantifying Technical Performance (or Quality) Risk

During projects, many find it helpful to track the best estimates and measures of the product's key attributes of technical performance or quality. In this section, we begin with a subset of the attributes of interest to the customer, $\boldsymbol{J'}$, and refer to these m' attributes as *technical performance attributes* (TPAs) ($\boldsymbol{J'} \in \boldsymbol{J}$, $m' \leq m$). We refer to the measures and estimates of the

TPAs as *technical performance measures* (TPMs). (The term "measures of effectiveness" [MoEs] is also common.) To quantify the risk in each TPA, we elaborate upon a framework by Browning *et al.* (2002) called the Risk Value Method.

Utility functions provide one helpful approach for quantifying customer preferences for various TPA levels. Figure 1 shows an example (piecewise linear) utility function for aircraft range. The length of the *x*-axis is chosen to span the continuum from disgusting to delighting the customer or market. Perhaps the market (or a major customer) wants a new aircraft for a long-range route requiring a 9,000 nautical mile (nmile) range. Greater range is of marginally increasing value, to the point that a range of 11,000 nmiles would be delightful. The utility curve can be used to determine the impact of various range TPM outcomes in terms of customer utility or value.

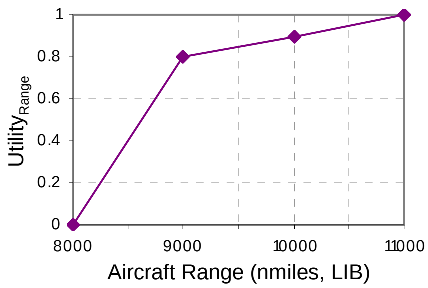

Figure 1: Example Utility Function for Aircraft Range

Until a project is finished, and especially early on, the performance level of each of the resulting product or service's TPAs is uncertain. Accordingly, Browning *et al.* (2002) define the purpose of product development processes as the reduction of these uncertainties through the creation of knowledge by executing design, verification, and review activities. The uncertainty in a TPA can be represented as variance in its TPM. Each TPA outcome has a relative probability, so the TPM can be modeled with a probability density function (PDF) noted as $f_{\varphi}(x_0)$, where x_0 is an outcome (a TPM level). For example, Figure 2 shows a triangle PDF for aircraft range TPM at an early point in a design project. We normalize the area under the PDF to equal one. (Alternatively, we could set it equal to, say, 0.9 to allow for 5% of outcomes to either side of the distribution.) Given a required or target level of performance (here, 9,000 nautical miles), it is then straight-forward to determine the probability of an undesirable outcome. Although any PDF could be used, we prefer triangle PDFs because they allow for skewness while requiring a minimal amount of data to specify (Williams 1992). (A minimal amount of data is typically all one has at a reasonable level of accuracy.)

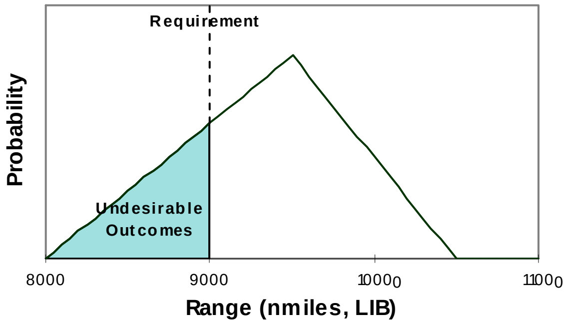

Figure 2: Example PDF Showing Relative Probability of Various Aircraft Range TPM Outcomes

An impact function expresses the loss in customer utility or value for failing to meet a required level of performance,

$$I = \kappa \left| \mathrm{U}(T) - \mathrm{U}(x_0) \right| \tag{4}$$

where T is the required (target) level of performance, U(•) is the utility function, x_0 are drawn only from the region(s) of adverse outcomes, and κ is a normalization constant (discussed below). That is, the impact of failing to meet a requirement is the difference in the utility of the actual level of performance and the required level of performance. Note that, if the utility curve is flat in some region containing the target, the impact may be zero for some "unacceptable outcomes"—meaning that a tolerance region exists around the target before impacts accrue.

Substituting the PDF and equation (4) into equation (1), we calculate a risk factor (expected loss of utility) for each attribute by integrating over the probabilistically weighted impacts of all adverse outcomes:

$$\mathscr{R}_\varphi = \kappa_\varphi \int_{-\infty}^{T_\varphi} f_\varphi(x_0)\left[\mathrm{U}_\varphi(T_\varphi) - \mathrm{U}_\varphi(x_0)\right]dx_0 \tag{5}$$

where here we show the case of a "larger is better" (LIB) TPA such as aircraft range, and therefore the adverse outcomes are ones that fall short of the target. (For "smaller is better" (SIB) TPAs, reverse the limits of integration. For "nominal is best" (NIB) TPAs, two integrands, a LIB and a SIB, must be summed.) In practice, equation (5) is typically a summation of a finite number of discrete outcomes rather than an integral. (To minimize error in the numerical evaluation of the integral via summation, it is helpful to divide the PDF or its cumulative distribution function (CDF) into bins equal in size to the units of measure for the TPM, rounded to some reasonable level [e.g., whole number].) Each risk factor is bounded by the range $0 \le \mathscr{R}_\varphi \le \kappa_\varphi \cdot \mathrm{U}_\varphi(T_\varphi)$, meaning that no more utility can be lost than the amount provided by the target level of performance. Thus, we have vectors of m' product technical attributes, $\boldsymbol{J'}$, their utilities, $\boldsymbol{U'}$, their targets, $\boldsymbol{T}_P$, and their risk factors (based on uncertainty and target), $\boldsymbol{\mathscr{R}}_P$.

Overall technical performance risk, $\mathscr{R}_P$, is a function of the m' risk factors in $\boldsymbol{\mathscr{R}}_P$:

$$\mathscr{R}_P = f\left(\mathscr{R}_{\varphi_1}, \mathscr{R}_{\varphi_2}, \ldots, \mathscr{R}_{\varphi_{m'}}\right) \tag{6}$$

The function can take any of several forms, each with advantages and disadvantages. For example, a weighted average,

$$\mathscr{R}_P = \sum_i^{m'} w_i \mathscr{R}_{\varphi_i} \tag{7}$$

where the $w_{\varphi i}$ are weighting factors and $\sum_i^{m'} w_i = 1$.

More sophisticated techniques, such as multi-attribute utility theory (MAUT) or a geometric mean, can also be used. Using the geometric mean as another example, let ξ_φ be an attribute's expected utility (target utility less expected loss of utility), raised to the power of its weighting factor:

$$\xi_\varphi = \left[\mathrm{U}_\varphi(T_\varphi) - \mathcal{R}_\varphi\right]^{w_\varphi} \tag{8}$$

where here we omit κ_φ from equation (5) when determining $\mathcal{R}_\varphi$. The geometric mean formula for overall technical performance risk is then:

$$\mathcal{R}_P = Max(\mathcal{R}_P) - \left(\prod_i^{m'} \xi_i\right)^{\frac{1}{\sum_i^{m'} w_i}} \tag{9}$$

where

$$Max(\mathcal{R}_P) = \left\{\prod_i^{m'} \left[\mathrm{U}_i(T_i)\right]^{w_i}\right\}^{\frac{1}{\sum_i^{m'} w_i}} \tag{10}$$

and $Max(\mathcal{R}_P)$ provides an upper bound on $\mathcal{R}_P$ based on the chosen targets $\boldsymbol{T}_P$. The geometric mean has the advantage of being sensitive to extreme values in individual TPMs: any one measure near zero causes the entire function to be near zero. Also, the weights, w_φ, do not have to sum to unity in equations (8) – (10).

Despite the advantages of the geometric mean, a single, best function to quantify composite technical performance has not been determined and is fraught with complications. We refer the reader interested in these problems to, e.g., (Bahill *et al.* 1998; Bell *et al.* 1992; Otto and Antonsson 1991; Wood and Antonsson 1989). In practice, the advantages of an easy-to-understand approach should not be underestimated, especially when introducing a new method. For this reason we use the weighted average in the examples in this paper.

As each $\mathscr{R}_{\varphi}$ is bounded by the attribute's target amount of utility, $\mathscr{R}_P$ is bounded by the range $0 \leq \mathscr{R}_P \leq Max(\mathscr{R}_P)$, where $Max(\mathscr{R}_P)$ is a function of $\mathrm{U}(T_P)$ and depends on the type of function used to determine $\mathscr{R}_P$. If the geometric mean is used, $Max(\mathscr{R}_P)$ is defined in equation (10). For the weighted arithmetic mean,

$$Max\left(\mathscr{R}_P\right) = \sum_{i}^{m'} w_i \left[\mathrm{U}_i(T_i)\right] \tag{11}$$

$\mathscr{R}_P$ is "the expected loss of utility" or "units of utility at risk" based on the current estimates and/or measures of the product's TPAs. A normalization constant, κ_P, can be used to represent $\mathscr{R}_P$ in more meaningful units, such as units of product or dollars of sales at risk. Some may prefer to use κ at the composite level rather than for each TPM by omitting κ_{φ} from equation (5) and instead adding κ_P in equation (7) or (8) as follows:

$$\mathscr{R}_P = \kappa_P \sum_{i}^{m'} w_i \mathscr{R}_{\varphi_i} \tag{12}$$

$$\mathscr{R}_P = \kappa_P \left\{ Max(\mathscr{R}_P) - \left(\prod_{i}^{m'} \xi_i \right)^{\frac{1}{\sum_{i}^{m'} w_i}} \right\} \tag{13}$$

Thus, when including κ_P, $\mathscr{R}_P$ is bounded by the range $0 \leq \mathscr{R}_P \leq \kappa_P \cdot Max(\mathscr{R}_P)$. For example, if one desires $\mathscr{R}_P$ spread across the continuum [0,1], then κ_P can be defined as:

$$\kappa_P = \frac{1}{Max\left(\mathscr{R}_P\right)} \tag{14}$$

3.2 *Quantifying Cost and Schedule Risks*

In addition to a product's TPAs, the market or customer cares about non-technical performance attributes such as price, lead-time, and overall life cycle operating cost. Here, we focus on two non-technical attributes, price and lead-time, and furthermore make the (big) simplifying assumption that both depend entirely on development cost and duration, respectively. While the framework can accommodate more realistic relationships between a project's cost and the price of its output, and a project's duration and the timeliness of its output—including the effects of additional stages (such as production) prior to the end customer—detailing these relationships is outside the scope of this paper. In §4, however, we will also relate price to the TPAs. Thus, we have $m = m' + 2$, and $\boldsymbol{J} = [\ \boldsymbol{J'}\ \varphi_C\ \varphi_S\ ]$, such that the full vector of product attributes consists of the TPAs, price, and lead-time, where development cost and duration here serve as surrogates for price and lead-time, respectively.

To quantify cost and schedule risks, we use an approach similar to the one for technical performance risks, adapting and elaborating on other work by Browning and Eppinger (Browning and Eppinger 2002). Expressing cost as a distribution of possible expenditure level outcomes, $f_C(x_0)$, cost risk, $\mathscr{R}_C$, is then the sum of the adverse outcomes, each weighted by its probability and impact:

$$\mathscr{R}_C = \kappa_C \int_{T_C}^{\infty} f_C(x_0)\left[U_C(T_C) - U_C(x_0)\right]dx_0 \tag{15}$$

where κ_C is a normalization constant, T_C is the cost target (budget), and $U_C(T_C) - U_C(x_0)$ is the impact in terms of lost customer utility (from passing on the costs in product price). The limits of integration have been switched from equation (5) since cost is a "smaller is better" (SIB) performance measure—assuming no adverse outcomes from under-spending, as discussed in §2;

otherwise, an additional term must be added to equation (15) to account for these. $\mathscr{R}_C$ is bounded by the range $0 \leq \mathscr{R}_C \leq \kappa_C \cdot \mathrm{U}_C(T_C)$, meaning that no more utility can be lost than the amount provided by meeting the target budget (i.e., here, price).

If the lead-time is expressed as a distribution of possible durations, $f_S(x_0)$, then schedule risk, $\mathscr{R}_S$, is the sum of the adverse outcomes, each weighted by its probability and impact:

$$\mathscr{R}_S = \kappa_S \int_{T_S}^{\infty} f_S(x_0)\left[U_S(T_S) - U_S(x_0)\right]dx_0 \tag{16}$$

where κ_S is a normalization constant, T_S is the target lead-time (deadline), and $U_S(T_S) - U_S(x_0)$ is the impact in terms of lost customer utility from waiting. Equation (16) also assumes no adverse outcomes from early completion, although these could be accounted for by an additional term. $\mathscr{R}_S$ is bounded by the range $0 \leq \mathscr{R}_S \leq \kappa_S \cdot \mathrm{U}_S(T_S)$, meaning that no more utility can be lost than the amount provided by meeting the target deadline (i.e., here, lead-time).

3.3 Combined Effects

Equations (12 or 13), (15), and (16) express technical performance, cost, and schedule risks, respectively, in comparable terms. Over the duration of a project, it is useful to determine which attributes are contributing the most risk and to allocate resources accordingly. For example, if certain TPAs are problematic, additional time and money can be spent to increase performance and/or certainty about performance. This trades performance risk for cost and schedule risk. Or, if a project is behind schedule, additional money could be spent (to trade schedule risk for cost risk) or some planned activities to confirm technical performance could be sacrificed (to trade schedule risk for technical performance risk). The weighting factors must be used in such comparisons, and care must be taken to avoid extreme deficiencies in certain attributes, even when they have relatively low weights (more of an issue with the weighted arithmetic mean).

We also look at the composite function for "value at risk." Overall product value, Ω, is decreased by the overall expected loss of utility due to risks in the product attributes, where

$$\mathscr{R} = f\left(\mathscr{R}_P, \mathscr{R}_C, \mathscr{R}_S\right). \tag{17}$$

Since we can treat φ_C and φ_S like individual TPAs, versions of equations (7) – (14) apply for $\mathscr{R}$ as well as $\mathscr{R}_P$. For the remainder of the paper, we will use the weighted arithmetic mean (equation (12)) as an example form of equation (17). We choose this form instead of a multi-attribute utility function or weighted geometric mean, both of which provide more realistic composite functions, purely for the sake of simplicity.

$\mathscr{R}$ represents the total customer "value at risk" in the project. This number is related to the financial idea of value at risk (e.g., Holton 2003; Jorion 2001) in that it combines known uncertainties and exposures into an aggregate metric. Figure 3 provides a stylized depiction of the customer value of a project's future outcome. The figure shows three of the *m* dimensions of overall value, aggregating *m*-2 dimensions as technical performance. The "value at risk" in each dimension is calculated using equations (12), (15), and (16), as applicable. The target product value, $Max(\mathscr{R})$, is an upper bound on "value at risk" and is determined akin to equation (11) but with the inclusion of κ. The opportunity values are discussed in the next section. Note that the shapes of these regions need not be pyramids or cubes: the actual shapes are determined by the choice of a form for equation (17). The shapes in Figure 3 are purely for illustrative purposes.

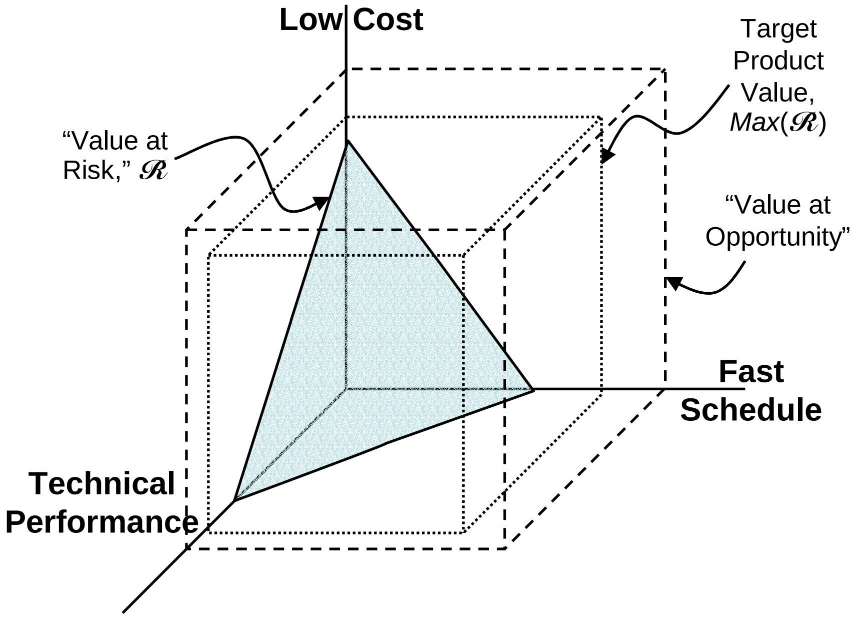

Figure 3: Stylized Comparison of Target Value, "Value at Risk," and "Value at Opportunity"

For example, a project to develop and produce widgets forecasts 1000 units will be sold at $1000 each if cost, schedule, and performance targets are met. They choose

$$\kappa = (\$1000 / \text{unit})(1000 \text{ units} / \text{target utility}) = \$1 \text{ million} / \text{target utility}$$

so $Max(\mathscr{R})$ equates to $1 million in potential sales. They simplistically assume a linear relationship between demand and overall value, such that a one percent increase in $\mathscr{R}$ translates to a one percent loss in sales. Then, if $\mathscr{R}$ increases by five, then $50,000 in potential sales are at risk. (Some call this "risk exposure" or "downside.") While this number is interesting, it is obviously sensitive to the assumptions about the market size and demand as a function of utility. Nevertheless, business cases regularly make assumptions about markets and demand, despite the problems with such forecasts. An organization with market savvy and historical data could choose κ so that $\mathscr{R}$ would provide useful support for business decisions. We develop a fuller example in §5, but first we present an opportunity framework to complement the risk framework.

4. The Opportunity Framework

The risk framework focuses on adverse outcomes: cost and schedule overruns and technical performance under-runs. However, since the utility functions span the range of outcomes from delighting to disgusting the customer, we can use the information provided by the utility curves on the other side of the targets—the area of desired outcomes—to evaluate rewards and opportunities. The impact equation for opportunity is the same as equation (4), except that the values of x_0 are drawn only from the region(s) of desired outcomes, expressing the increase in customer utility or value as a result of exceeding the required level of performance. The opportunity, $\mathcal{O}_\varphi$, equation is similar to the risk equation (5):

$$\mathcal{O}_\varphi = \kappa_\varphi \int_{T_\varphi}^{\infty} f_\varphi(x_0)\left[\mathrm{U}_\varphi(x_0) - \mathrm{U}_\varphi(T_\varphi)\right]dx_0 \tag{18}$$

where the expression applies to a LIB TPA and assumes no positive outcomes on the other side of the target (although these could be accounted for by an additional term). Each $\mathcal{O}_\varphi$ is bounded by the range $0 \le \mathcal{O}_\varphi \le \kappa_\varphi \times (1 - \mathrm{U}_\varphi(T_\varphi))$, meaning that the "utility surplus" that could be gained through proactive and effective management of opportunities is limited to the amount between the target level of performance and maximum utility. Of course, opportunities might stem from exceeding the "maximum" utility—i.e., what was originally determined to "maximally delight" the customer (where $\mathrm{U}(\varphi) > 1$). But because a utility function is defined in the region $0 \le \mathrm{U}(\bullet) \le 1$, it must be redefined in light of such new information (corresponding to resetting customer expectations).

Overall $\mathcal{O}$ is "the expected increase in utility" or "customer value at opportunity" for the project as a whole and is a function of the $\mathcal{O}_\varphi$ terms. Using the weighted arithmetic mean,

$$\mathcal{O} = \kappa \sum_{i}^{m} w_i \mathcal{O}_{\varphi_i} \tag{19}$$

Continuing the example from §3.3, the project to develop and produce widgets, with *Max*($\mathcal{R}$) equal to \$1 million in potential sales, still assumes a linear relationship between demand and overall value, such that a one percent increase in $\mathcal{O}$ translates to a one percent gain in sales. Hence, if $\mathcal{O}$ increases by five, then \$50,000 in potential sales are "at opportunity." (Some prefer the term "upside.") Given the current knowledge about customer preferences, *Max*($\mathcal{O}$) = 1 - *Max*($\mathcal{R}$).

Finally, as an aside, note that when certain opportunities are mutually exclusive, "opportunity cost" refers to the value of the opportunity not taken.

5. Example Application

We now demonstrate the framework's application using the example of an information technology (IT) installation project. This example is based on an actual project in a county government circa 2002; however, the data are hypothetical (yet realistic). The purpose of the project is to install Active Directory software as a precursor to an enterprise resource planning (ERP) implementation. Two TPAs are (1) the number of user installations and (b) the time each user cannot use their computer for other work (user down time). Project duration and cost are also important to IT executive management, the internal customer.

In pre-project discussions with IT executives, the project manager (PM) elicited the utility curves in Figure 4. (For more information on eliciting utility curves, see, e.g., (Bell *et al.* 1988; de Neufville 1990; Keeney and Raiffa 1976).) For number of installations, he found it was expected that five departments (177 users) would receive the installation prior to ERP. The project would still be of some value if three key departments (84 users) could be made ready, but readying only 50 or fewer users would be unacceptable. Readying all 265 eventual users would be outstanding. Regarding user down time, it would be great if the installation only took about 15 minutes. Of course, taking no time would be ideal. However, the PM estimates that each installation will take about five hours (300 minutes) and had been hinting to the executives ahead of time that this amount of down time per user would be realistic. The executives were roughly indifferent to this amount of down time, although they stated that anything that affects a user for more than a day (480 minutes) is unacceptable. To accomplish the installations, the PM and the executives discussed their estimates, expectations, and data from comparable projects to arrive at the utility curves for project cost and duration. An outcome approaching a million dollars would be untenable, and going over 90 days would drive the critical path of the ERP enabling activities and thus also would be unacceptable. Finally, they discussed the relative importance of each of these four attributes of the result and agreed on the following weightings: (a) 0.3, (b) 0.2, (c) 0.2, and (d) 0.3. Given these utility curves and estimates of the project's capabilities, the project manager and the IT executives agreed on the following targets: (a) 177 installations, (b) 300 minutes of down time per installation, (c) a $600,000 budget, and (d) a 75 day schedule.

As the project began, and in the context of a robust risk management process (see, e.g., Chapman and Ward 1997; Hall 1998; Smith and Merritt 2002), the project team met to discuss risks and opportunities. Taking risks first, they asked, "What could go wrong?" Then, for opportunities, they asked, "What could go even better than we expect?" The key answers to both questions are summarized in Table 1.

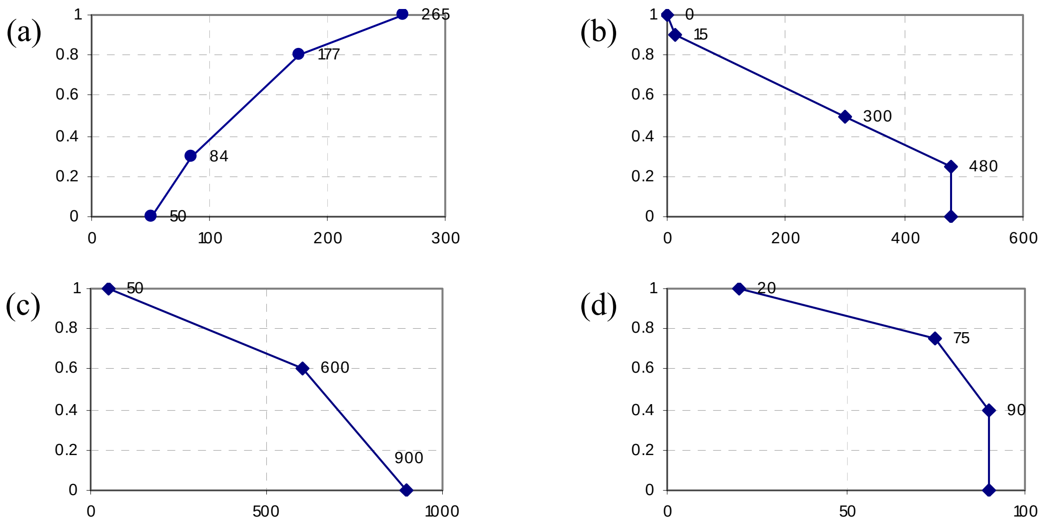

Figure 4: Example Utility Curves for IT Installation Project

(a) Number of installations
(b) User down time per installation (minutes)
(c) Project cost (in $thousands)
(d) Project duration (working days)

Key Risks	Key Opportunities
• Additional hardware and/or software upgrades may also be needed for some users. • User training may not be synchronized with the installations. • A lack of network standards may cause even more of the installation process to be done manually. • Team members may get pulled to work on other projects or issues.	• Consultants claim they can probably find a faster installation process using scripts and overnight down time. • May be able to tap other funding for additional/other hardware and software upgrades, if needed • Could seek to protect team members from getting pulled to other duties

Table 1: IT Project Key Risks and Opportunities

With these sources of risk and opportunity in mind, the team pooled their data and expertise to determine the optimistic (best case), most likely, and pessimistic (worst case) estimates for each major value attribute. The first column ("Day 0") of Table 2 shows the results, along with the resulting risk and opportunity factors calculated using equations (12) and (19), omitting κ. The utilities of the targets and the weights were used to determine the overall utility of the targets, Max($\mathscr{R}$) = 0.685, and therefore Max($\mathscr{O}$) = 0.315, again omitting κ. Out of that overall utility, 0.107 was at risk according to the current estimates of uncertainties and impacts as the project began. Also, there was 0.019 of utility "at opportunity" out of the 0.315.

While the project would be a challenge, the project team felt the executives gave them a reasonable combination of targets and saw these amounts as the most likely outcomes for the project's value attributes. The PM decided to hire the consultants to pursue the opportunity of a much faster installation process, which if successful would positively affect all of the project's value attributes.

			Day 0	Day 15	Day 30
Number of installations	Weight: 0.3 Target: 177 users	Optimistic	265	265	265
		Most Likely	177	220	265
		Pessimistic	84	84	220
		$\mathscr{R}$	0.084	0.058	0
		$\mathscr{O}$	0.034	0.055	0.167
User down time	Weight: 0.2 Target: 300 min.	Optimistic	180	15	15
		Most Likely	300	180	15
		Pessimistic	480	300	15
		$\mathscr{R}$	0.052	0	0
		$\mathscr{O}$	0.022	0.189	0.4
Project cost	Weight: 0.2 Target: $600k	Optimistic	500	400	200
		Most Likely	600	550	210
		Pessimistic	800	650	250
		$\mathscr{R}$	0.091	0.007	0
		$\mathscr{O}$	0.008	0.049	0.276
Project duration	Weight: 0.3 Target: 75 days	Optimistic	60	50	40
		Most Likely	75	65	45
		Pessimistic	100	80	50
		$\mathscr{R}$	0.177	0.047	0
		$\mathscr{O}$	0.008	0.044	0.134
Overall Project		$\mathscr{R}$	0.107	0.033	0
		$\mathscr{O}$	0.019	0.077	0.225
		Max($\mathscr{R}$)	0.685		
		Max($\mathscr{O}$)	0.315		

Table 2: Example IT Project Data at Various Times

By 15 days into the project, the team had learned the following. First, some additional hardware and software upgrades were indeed required as precursors. While funding for these was available from outside the project budget, project team members would have to spend their time facilitating the changes on an accelerated basis. Second, the consultants were working more hours and costing more than anticipated, but they had designed a dramatically quicker installation process. In fact, they claimed that the process would cut user down time to a mere 15 minutes! If so, then the target number of installations would be very easy to meet. Meeting again to discuss opportunities and risks, the team agreed on the revised estimates at “Day 15” in Table 2. The most likely number of installations was revised to include another department, and the potential posed by the new process shifted the user down time distribution dramatically to the left—although the team was cautiously optimistic about the consultants’ new process until it could be further verified. But the risk of meeting the target of five hours per installation went to zero and the opportunity increased significantly. The new approach also looked very promising in terms of its effect on project cost and duration. Overall, the new developments cut project risk by roughly 70% and provided about a four-fold increase in opportunity.

On day 30, the team met again to review the project status. The consultants’ new process was working very well and in fact provided a 15 minute installation time. It was looking like the project would finish a month early, spending only 35% of its budget, and making all 265 installations. Because of the amazing success, the PM sought approval from the IT executives to use the project’s remaining budget to expand its scope. Another software package would also be needed for about other users prior to ERP installation. Permission was cheerfully granted to take on this new assignment. (At this point, the utility curves and targets were rebaselined.) Indeed, the project manager remarked that this was the best project he had ever been involved in.

6. Discussion

The preceding example yields several discussion points. First, one notices the way targets are chosen has a significant impact on risk and opportunity. Low risk and high opportunity can result from choosing conservative targets. The framework organizes the information needed to propose and negotiate targets and quantifies the project’s value and levels of risk and opportunity. Second, looking specifically at opportunities during project planning helps distinguish them from the “likely” situation, and thus ameliorates the problem of the plan being too optimistic. Third, opportunities often relate to ways to mitigate risks. For instance, there is somewhat of a “barrier-to-enabler” relationship between the items listed in the two columns of Table 1. (But opportunities need not correspond to specific risks.) Fourth, the risks and opportunities listed in Table 1 were accounted for by the framework in terms of their effect on the project’s key value attributes, which differs from a traditional risk management quantification scheme in which the risks themselves are quantified separately from the value attributes. But these are tightly linked, and we submit that treating them separately in project management methodologies is a problematic source of project dis-integration. On the other hand, just asking what could positively or adversely affect the project’s key value attributes could miss some significant opportunities and/or risks. If one really thought of all the things the customer cares about (dimensions of customer value) and all of the things that could make one or more of these turn out worse (better) than desired, then theoretically he or she could cover the waterfront of project risks (opportunities). However, we recommend using both perspectives—attribute-by-attribute and general risk-opportunity—and letting them complement (and help verify) each other.

The example also begs a question about the framework user’s attitude towards risk and opportunity. Prescribing an optimal solution would require an assumption about risk attitude. One PM may follow a conservative (risk and opportunity averse) strategy to minimize the probability of an outcome other than the desired one. A liberal (opportunity seeking) PM may seek to maximize the probability of the best outcome. A typical but somewhat conservative strategy is to maximize the probability of an acceptable outcome. Should the goal of a project be risk minimization, opportunity maximization, or both?

The answer seems to be *both*—yet without mixing them, since this could allow opportunities to obscure risks. Hence, we do not mix opportunity and risk directly in the framework, even though both are defined in terms of expected utility gained or lost. Areas of high opportunity often hint at ways to compensate for certain risks, but typically these must be negotiated with a customer prior to surprising him or her. (It seems to take a much greater exceeding of expectations in other areas to compensate for a breach of expectations in one area.) Opportunity is not merely the absence of risk. (Health is not the absence of disease. Peace is not the absence of war. Happiness is not the absence of sadness.) Of course, some opportunities are created when risks are removed (e.g., "if the union does not take industrial action we can introduce an incentive scheme"), and other opportunities are simply the inverse of related risks (e.g., instead of productivity being lower than planned, it might be higher). But there are also "pure opportunities" unrelated to risks: uncertain events or circumstances which would produce real additional benefits or value, if they could be captured proactively and exploited (e.g., it may be possible to recruit exceptionally skilled staff onto a project). As well as identifying and addressing risks, it is equally important to seek and maximize opportunities, in order to optimize achievement of objectives (Hillson 2002a; Hillson 2003).

The key is to determine the optimum balance between positive and negative uncertainty given a particular project or business situation. Clearly a project with low risk and high opportunity is in a good position, and this should be reinforced and protected wherever it occurs, seeking to consolidate the low-risk profile and aggressively exploit as much opportunity as possible. The converse is true for the high-risk/low-opportunity project, where aggressive risk management action is required in order to stay on target (noting that such action needs to include both risk reduction and opportunity enhancement). The situation where both risk and opportunity are high also calls for focused risk management action to reduce the threat, but proactive opportunity management is also required in order to capture and exploit the available upside. Projects with low risk and low opportunity may appear stable, but management should remain vigilant to ensure that previously unforeseen risks do not occur, and that possible opportunities are not overlooked. Table 3 summarizes these managerial guidelines.

		Opportunity ($\mathscr{O}$)	
		Low	**High**
Risk ($\mathscr{R}$)	**Low**	• Remain vigilant against unforeseen risks and emerging opportunities	• Reinforce and protect position • Aggressively exploit opportunities • Maximize probability of best outcomes
	High	• Aggressively manage risks • Minimize probability of adverse outcomes • Seek to enhance opportunities • Consider project re-scoping or cancellation	• Allocate significant effort to identify, assess, and manage risks and opportunities • Retain agility to respond to sudden developments, negative or positive

Table 3: Risk and Opportunity Management Guidance

7. Conclusion

This paper has shown how projects can use an integrated, quantitative framework to proactively manage both opportunity and risk. Since risk is uncertainty that could adversely affect achievement of one or more objectives, and opportunity is uncertainty that could beneficially affect achievement of one or more objectives, both can exert a significant influence on the ability of projects to meet their goals. If projects only address risk minimization, this creates a one-way street where actions are only considered which seek to overcome potential negative effects and bring the project back on target. Since no risk response plan will be 100% effective and there will always be residual risk, this one-way street can lead to failure to achieve objectives to a greater or lesser extent. (This situation is similar to the one noted by Goldratt (Goldratt 1997) where cost and time overruns are passed along from one activity to the next but savings are not.) However, if management attention is also given to proactive management of upside opportunities, the realization of additional value as a result of captured opportunities can offset the downside effect of some risks, thus improving the chances of achieving targets.

The framework applies to a variety of projects, although it becomes especially valuable as project size and complexity increase. Since it emphasizes a systematic approach to project value, risk, and opportunity, it is one of several useful tools for moving a chaotic or ambiguous project to a merely uncertain one (De Meyer *et al.* 2002). As chaos and ambiguity are undone, new customer value attributes and their utility curves will be discovered and can be added to the model, and included utility curves and weighting factors may need to be rebaselined. The framework can also be used to evaluate projects comparatively in a portfolio, seeking a minimization, maximization, or balance of risk and opportunity.

Thus, the main contribution of this paper is a framework for organizing, integrating, and distilling project knowledge as it evolves. The quantified amounts of value, risk, and opportunity in a project are only as accurate as the data upon which they are based. However, those data—albeit from disparate methods, groups, and information systems—are what projects currently use as a basis for their decisions. Integrating the data provides new insights and also highlights missing information. The framework provides a practical tool for assessing the degree of influence of both risk and opportunity, and facilitates making balanced judgments and tradeoffs. It is important to realize, however, that any calculation of utility or value is not an infallible, deterministic statement of the future. Instead, it gives valuable insight to decision-makers, allowing proactive focus on areas requiring the most attention.

In closing, we point out that the focus of the paper has been on project value from the customer's perspective. But projects have value to a variety of other stakeholders as well—e.g., employees, suppliers, shareholders, society, etc. Additional research is needed to explore the drivers of utility or value to these stakeholders. However, as such attributes are determined, the framework proposed in this paper can expand to include them.

8. References

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