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Performance Evaluation Metrics for Information Systems Development: A Principal-Agent Model

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Abstract

The information systems (IS) development activity in large organizations is a source of increasing cost and concern to management. IS development projects are often over-budget, late, costly to maintain, and not done to the satisfaction of the requesting client. These problems exist, in part, due to the organization of the IS development process, where information systems development is typically assigned by the client (principal) to a developer (agent). The inability to directly monitor the agent requires the use of multiple performance measures, or metrics, to represent the agent's actions to the principal.

This paper develops a principal-agent model (based on information economics) that is solved to provide the set of decision criteria for the principal to use to appropriately weight each of the multiple metrics in order to provide an incentive compatible contract for the agent. These criteria include the sensitivity and the precision of the performance metric. After presenting the formal model, some current software development metrics are discussed to illustrate how the model can be used to provide a theoretical foundation and a formal vocabulary for performance metric evaluation. The model can also be used in a positive manner to suggest explanations for the current relative emphasis in practice on particular metrics.

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I. INTRODUCTION

The information systems (IS) development activity in large organizations is a source of increasing cost and concern to management. IS development projects[1] are often over budget, late, costly to maintain, and not done to the satisfaction of the requesting client. It has been suggested that these problems exist, in part, due to the organization of the IS development process, where information systems development is typically assigned by the client (principal) to a developer (agent) [Gurbaxani and Kemerer 1989, 1990] [Beath and Straub 1989] [Klepper 1990] [Whang 1990]. This agency relationship imposes the standard agency costs due to the goal incongruence of the principal and the agent and the imperfect monitoring of the agent's actions by the principal. The inability to directly monitor the agent requires the use of indirect performance measures, or metrics to represent the agent's actions to the principal. To appropriately represent information systems development, it will be necessary for the principal to employ multiple metrics to account for the multi-dimensional nature of the information systems development product [Bakos and Kemerer 1991] [Mendelson 1991]. The principal is then confronted with the problem of assigning individual weights to these multiple metrics in order to provide incentives for the agent.

The difficulties that principals have in assigning weights can be easily illustrated with a simple example. It is well-documented that the maintenance costs associated with information systems typically exceed the development cost over the system's useful life [Swanson and Beath 1990]. Yet, in practice, software developers are typically evaluated by criteria such as on-time and on-budget delivery of the initial system, and rarely, if ever, on the likely maintainability of the system that they have just delivered [Gode *et al.* 1990]. Izzo notes that, "Maintenance, long considered one of the most important product support services a business provides, is considered a secondary responsibility in information systems" [1987, p. 25]. It is apparent paradoxes such as this one that suggest that principals have difficulty with the multi-dimensional nature of IS development performance evaluation.

This paper develops a principal-agent model (based on information economics) that is analyzed to identify the set of decision criteria for the principal to use to develop the contract. These criteria are the *sensitivity* and *precision* of the performance metric. This formal model is developed and shown in Section II. The model provides a theoretical foundation and a formal vocabulary for

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[1]By "development" what is meant are all the activities that constitute the systems life cycle, including systems maintenance. Activities solely related to new systems exclusive of any maintenance activity will be referred to as "new development".

performance metric evaluation in the general context of a multidimensional performance contract. Section III first develops a simple framework of IS development project performance metrics. Then, two actual IS development organizations are described in terms of the performance metrics they have in current use. One of the IS development groups is internal to an organization and one is an external IS development services provider. The results of the model are applied to these organizations to illustrate the model's use in a positive manner to suggest explanations for the current relative emphasis in practice on particular metrics. Section IV presents a broader discussion of both the ramifications and limitations of the model outside the context of the two organizations studied. Finally, some concluding remarks are presented in Section V.

II. MODEL

Information systems (IS) development is modeled as a principal-agent problem, with the client (the principal) desiring information systems to be developed to meet her goals[2]. She contracts with an IS development manager (the agent) to perform this work, due to specialized expertise on the part of the agent. The normal principal-agent model assumptions are made, i.e., that the goals of the agent are assumed to be only imperfectly aligned with those of the principal (goal incongruence) and that the agent's actions can only be imperfectly observed by the principal (information asymmetries). Considerable prior work exists in this area, and the interested reader is referred to [Ross 1973] [Jensen and Meckling 1976] [Holmstrom 1979] [Harris and Raviv 1979] and [Holmstrom and Milgrom 1990].

The assumption is made that the principal is interested in the outcome along *n* dimensions, which are represented by the vector $\mathbf{x} \equiv (x_1, \cdots x_i, \cdots x_n)$. The agent can increase the likelihood of obtaining a better outcome x_i by devoting more effort, a_i, towards that outcome. More formally,

$$\partial m_i/\partial a_i > 0,\ \partial m_i/\partial a_j = 0,\ \ i,j = 1,2,\cdots n,\ \ j \neq i$$

where $m_i = E\,(x_i | a_i)$ = expected value of outcome x_i.

The outcomes cannot be observed jointly by the principal and the agent with perfect accuracy. The agent's efforts $\mathbf{a} \equiv (a_1, \cdots a_i, \cdots a_n)$ cannot be perfectly observed by the principal without incurring prohibitive monitoring costs. For performance evaluation purposes, therefore,

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[2]Following [Beath and Straub 1989], the use of "she/her" will refer to the principal, and "he/him" will refer to the agent in order to make pronoun references easier to follow. The model will focus on only these two parties, and excludes from consideration any possible agency relationship between the principal requesting the work and her superior, for instance, as suggested by [Gurbaxani and Kemerer 1990]. Therefore, it is applicable to situations involving either external or internal developers.

appropriate metrics, $\mathbf{y} \equiv (y_1, \cdots y_i, \cdots y_n)$ are developed to provide (imperfect) signals about the true outcomes.

More formally,

$$y_i = x_i + \varepsilon_i \,,\; i = 1, 2, \cdots n$$

where the ε_i represent random variations (noise) for each of the *n* outcomes of interest.

In order to provide incentives for the agent to exert greater effort to produce higher levels of the outcomes of interest to the principal, the principal bases the agent's compensation on the jointly observable metrics:

$$s = s\,(\mathbf{y})$$

where *s* represents the agent's compensation. The monetary value of the outcomes to the principal is represented by *w*, where *w* is a function of **x**, and therefore the risk-neutral principal seeks to maximize the expected value of $w(\mathbf{x}) - s(\mathbf{y})$. The agent is assumed to be risk and effort averse, and he must be compensated at the end of the contractual time period [Lambert 1983]. The principal understands the agent to be economically rational, and knows that a compensation contract based on **y** will influence the agent's actions **a**. The agent seeks to maximize the expected value of:

$$u(s) - v(\mathbf{a})$$

where $u(\cdot)$ represents his or her utility for compensation, $s(\cdot)$, and $v(\cdot)$ represents his or her disutility for effort, with $u'(\cdot) > 0$, $u''(\cdot) < 0$, and $v(\cdot) > 0$. The principal's problem can now be formulated as follows:

$$(1) \qquad \max_{s(\cdot),\mathbf{a}} \; E[w(\mathbf{x}) - s(\mathbf{y})]$$

subject to:

$$(2a) \qquad E[u(s(\mathbf{y})) - v(\mathbf{a})] \geq u_0$$

$$(2b) \qquad \partial\, E[u(s(\mathbf{y}) - v(\mathbf{a})] \;/\, \partial a_i = 0 \qquad \text{for } i=1, \ldots n$$

$$(2c) \qquad s \in [s_L, s_H],\; \mathbf{a} \in [\mathbf{a}_L, \mathbf{a}_H]$$

The objective function simply maximizes the expected benefit, $w(\mathbf{x})$, to the principal of the information systems outcomes, **x**, net of compensation, s, paid to the agent. The first constraint ("individual rationality") ensures that the contract guarantees the agent a minimum expected utility level, u_0, equalling at least his best alternative employment possibility. The next set of *n* constraints ("incentive compatibility") ensures that the agent's effort level choices, a_i, $i=1,2,\cdots n$ maximize his own expected utility level, and thus provide incentive compatibility. This set of first

order optimization conditions is assumed to characterize the optimal action choice for the agent [Rogerson 1985]. The final constraints specify a bounded feasible space to ensure the existence of an optimal solution to the principal's constrained maximization problem [Holmstrom 1979].

The Euler-Lagrange optimization conditions for the mathematical program above are given by the following:

$$(3)\ \frac{1}{u'(s)} = \lambda + \sum_{i=1}^{n} \mu_i \frac{\int [\partial f(\mathbf{x},\mathbf{y};\mathbf{a})/\partial a_i]d\mathbf{x}}{\int f(\mathbf{x},\mathbf{y};\mathbf{a})d\mathbf{x}}$$

$$(4)\ \frac{\partial^2}{\partial a_i^2} E[m(\mathbf{x}) - s(\mathbf{y})] + \sum_{j=1}^{n} \mu_j \frac{\partial^2}{\partial a_i^2} E[u(s) - v(\mathbf{a})] = 0$$

for each $i=1,\ldots n$

Here, λ and μ_i, $i=1,\ldots n$, are Lagrange multipliers for the $(n+1)$ constraints. The joint probability density function of the outcomes $\mathbf{x}$ and the metrics $\mathbf{y}$ is embodied in $f(\cdot)$, and $\partial f(\cdot)/\partial a_i$ denotes its partial derivative with respect to effort dimension, a_i. The condition in (3) reflects pointwise optimization for each observable value of the metric vector $\mathbf{y}$. Since the actual outcomes $\mathbf{x}$ are not jointly observable, the incentive contract cannot be based on it, and therefore integration is performed over all possible values of $\mathbf{x}$ in condition (3). Let

$$(5)\qquad f(\mathbf{x},\mathbf{y};\mathbf{a}) = g(\mathbf{x}|\mathbf{y};\mathbf{a})h(\mathbf{y};\mathbf{a})$$

where $g(\cdot)$ is the probability density function of $\mathbf{x}$ conditional on the observed value of $\mathbf{y}$, and $h(\cdot)$ is the marginal probability density function of $\mathbf{y}$. Now,

$$(6)\ \int [\partial f(\cdot)/\partial a_i]d\mathbf{x} = \int [\partial g(\cdot)/\partial a_i]h(\cdot)d\mathbf{x} + \int g(\cdot)[\partial h(\cdot)/\partial a_i]d\mathbf{x}$$

But, $\int g(\cdot)d\mathbf{x} = 1$ because $g(\cdot)$ is a probability density function, and therefore,

$$(7)\ \int [\partial g(\cdot)/\partial a_i]h(\cdot)d\mathbf{x} = h(\cdot)\frac{\partial}{\partial a_i}\int g(\cdot)d\mathbf{x} = 0$$

It follows from (5), (6) and (7) that

$$(8)\quad \frac{\int [\partial f(\mathbf{x},\mathbf{y};\mathbf{a})/\partial a_i]d\mathbf{x}}{\int f(\mathbf{x},\mathbf{y};\mathbf{a})d\mathbf{x}} = \frac{[\partial h\,(\mathbf{y};\mathbf{a})/\partial a_i]}{h(\mathbf{y};\mathbf{a})}$$

Returning to the condition in (3):

$$(9)\quad \frac{1}{u'(s)} = \lambda + \sum_{i=1}^{n} \mu_i \frac{[\partial h(\mathbf{y};\mathbf{a})/\partial a_i]}{h(\mathbf{y};\mathbf{a})}$$

Differentiating (9) with respect to a particular y_j, $j=1,\cdots n$, yields

$$(10)\quad [-\frac{u''(s)}{(u'(s))^2}][\frac{\partial s^*(\mathbf{y})}{\partial y_j}] = \sum_{i=1}^{n} \mu_i \frac{\partial}{\partial y_j} \frac{[\partial h(\cdot)/\partial a_i]}{h(\cdot)}$$

In order to derive the distribution of the performance metrics $\mathbf{y}$, some additional structure is imposed. In particular, it is assumed that the stochastic variables x_i, given the agent's choice of efforts a_i, are statistically independent[3] and are normally distributed with means m_i and variances η_i^2. The measurement error ε_i in the metric y_i is also assumed to be distributed normally with mean zero and variance σ_i^2. The errors ε_i are assumed to be distributed independent of x_i, x_j and ε_j, $j \neq i$. It follows, therefore, that the metrics $y_i = x_i + \varepsilon_i$ are distributed independent of the other stochastic variables described above.

The distribution of each y_i, being a convolution of two random variables following a bivariate normal distribution, is itself normal with mean $E(y_i) = E(x_i) + E(\varepsilon_i) = m_i + 0 = m_i$ and variance $V(y_i) = V(x_i) + V(\varepsilon_i) = (\eta_i^2 + \sigma_i^2)$.[4] The probability density function $h_i(y_i|a_i)$ is then given by:

$$\ln h_i(y_i|a_i) = -1/2 \ln 2\pi V(y_i) - [y_i - m_i(a_i)]^2/2\,V(y_i)$$

Further, since the y_i are independently distributed,

$$h(\mathbf{y}|\mathbf{a}) = \prod_{i=1}^{n} h_i(y_i|a_i)$$

and

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[3]The agent will trade off allocations of efforts a_i to different activities i, and to that extent the model captures the interdependent nature of the outcomes. The statistical independence assumptions is maintained for expositional convenience; the principal results extend to the case of correlated stochastic variables.

[4]In the analysis presented here, it is assumed that only the mean $m_i(a_i)$ is affected by the agent's actions. However, this approach could be extended to address the case where the variance of x_i can be influenced by the agent's actions.

$$\frac{\partial h(y|a)/\partial a_i}{h(y|a)} = \frac{\partial \ln h(y|a)}{\partial a_i}$$

$$= \frac{\partial \ln h_i(y_i|a_i)}{\partial a_i}$$

$$= [y_i - m_i(a_i)]\,[\partial m_i(a_i)/\partial a_i] \;/\; V(y_i)$$

$$= [y_i - m_i(a_i)]\,[\partial m_i(a_i)/\partial a_i] \;/\; [\eta_i^2 + \sigma_i^2]$$

therefore,

$$\frac{\partial}{\partial y_j}\frac{[\partial h(y|a)/\partial a_i]}{h(y|a)} = 0 \qquad \text{for } j \neq i$$

and

$$= [\partial m_i(a_i)/\partial a_i]/[\eta_i^2 + \sigma_i^2] \qquad \text{for } j = i$$

It follows from equation (10) then that

$$(11) \qquad \frac{\partial s^*(y)}{\partial y_i} = \frac{-(u'(\cdot))^2}{u''(\cdot)} \cdot \frac{\mu_i\,[\partial m_i(a_i)/\partial a_i)]}{[\eta_i^2 + \sigma_i^2]}$$

Since the right hand side of the above equation (11) is independent of y, it follows that $s^*(y)$ can be written as $s^*(y) = s_1^*(s_2^*(y))$ where $s_2^*(y)$ is linear in y and can be interpreted as the aggregated performance evaluation metric. It also follows from equation (11) that

$$(12) \qquad s_2^*(y) = \sum_{i=1}^{h} \rho_i \xi_i y_i$$

where $\rho_i = [\eta_i^2 + \sigma_i^2]^{-1}$ is the *precision* of the metric y_i which is inversely related to $V(x_i)$ and $V(\varepsilon_i)$. Precision is a measure of the degree to which the agent can predict the value of the metric, given a set of actions. The lack of precision, or increase in the variance, can be seen as being due to two sources. The first is that the relationship between some outcome x_i and corresponding action a_i may be inherently *non-controllable* by the agent, due to the effect of factors outside his purview. A second source may be a *lack of accuracy*, or "noise" in measuring x_i, i.e., large variations in the values of ε_i. More formally, the inverse of the precision measure can be decomposed into its two constituent components, as follows:

$$var(y_i|\mathbf{a}) = var(x_i|\mathbf{a}) + var(\varepsilon_i)$$

where the first term on the RHS corresponds to the *controllability* component and the second term corresponds to the *accuracy* component[5]. A metric with higher precision will receive a higher weight in the aggregate since the metric will be more informative about the agent's action choice. This is true whether the greater precision results from greater controllability, greater accuracy, or some combination.

In equation (12), $\xi_i = \mu_i \partial m_i(a_i) / \partial a_i$ is the *sensitivity* of the outcome x_i (and the metric y_i) to the agent's action a_i. Using standard sensitivity analysis in optimization theory [Ioffe and Tihomirov 1979, pp. 292-298] the ξ_i is seen to correspond to the change in the principal's expected utility relative to the change in the agent's expected utility when, at the optimal solution, the agent's incentive compatibility constraint for the choice of a_i is perturbed marginally. In other words, ξ_i is the marginal value to the principal of providing the incentive to the agent to increase his effort a_i by a marginal unit. The principal will want to encourage agents' actions that most increase the final payoff to the principal, and therefore metrics that correspond to these "high payoff" activities that are most sensitive to the agent's actions will be more highly weighted relative to those with less impact[6].

For a metric to exhibit high sensitivity it must exhibit significant changes during the evaluation period in response to the agent's actions. A very sensitive metric would show a large change in the value to the principal, on average, for even a small additional amount of disutility to the agent resulting from an increase in effort. In terms of the optimal contract, more weight will be placed on metrics with high sensitivity relative to those with low sensitivity [Banker and Datar 1989][7].

Since the true levels of the agent's efforts, **a**, are unobserved, for incentive contracting purposes the principal and the agent agree on a set of performance evaluation metrics, **y**, that can be observed. This multi-dimensionality poses a dilemma for the principal: how to establish a contract that maximizes the agent's efforts appropriately across dimensions; in particular, which metrics to emphasize most in the agent's performance evaluation.

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[5]Precision is the reciprocal of the sum of the variances, which is generally not equal to the sum of the reciprocals of the variances.

[6]With multi-dimensional tasks the agent has tradeoff possibilities and it is therefore possible that a particular μ_i could be very small. Therefore, it would be optimal at the margin to not devote additional effort to that task. In the event that the precision and sensitivity of the associated metric are low, effort devoted to that dimension is likely to become extremely small. This result is complementary to that of Holmstrom and Milgrom [1990].

[7]This extends the work of Banker and Datar (1989) to the case of imperfect performance metrics for multiple outcomes of interest.

In order to effect the appropriate behaviors, the principal will base the agent's compensation in part upon the value of the performance metrics **y**.[8] Since the **y** are likely to be imperfect surrogates for the **x** and underlying effort choices **a**, some uncertainty is present. Therefore, an extreme form of compensation contract involving total reliance on performance evaluation metrics is unlikely, since this places extreme risk on the agent, who is assumed to be risk averse. Conversely, however, the opposite extreme of zero reliance on the performance evaluation metrics is also unlikely, as this does not allow the principal to offer any incentives for appropriate behavior.

However, within the range of likely contract forms, there is still room for considerable variation in terms of the choice of individual metrics (the y_is) and the weight that is to be assigned each metric in the compensation scheme. A final potential issue is the mapping of the weighted performance evaluation metrics to the actual rewards. However, as shown above in equation {12}, this third step is straightforward in this analysis, as the rewards will depend directly upon the weighted aggregate of the individual y_is. Therefore, the critical decision problem for the principal is assigning the relative weights.

III. APPLICATION OF THE MODEL TO MIS DEVELOPMENT

In this three part section the model developed in Section II is applied to the domain of Management Information Systems (MIS) development. Section A describes the overall dimensions of performance evaluation in MIS development, while Section B presents metric operationalizations of these dimensions gleaned from two mini-case studies. Section C then interprets the case study data in light of the model results.

A. Performance Evaluation in IS Development

The principal will seek to motivate the agent to take actions that will increase gross benefits and to decrease costs.[9] It is assumed that higher effort on the part of the agent increases the expected value of the gross benefits to the principal. Going beyond a general cost-benefit framework, in an IS development context the costs and benefits have both long term and short term components. On

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[8]The emphasis here is on the use of a set of metrics to evaluate performance. The form of the actual reward, be it cash, stock options, promotion, time off, etc., will clearly vary due to individual preference, prevailing industry norms, etc., and will not be considered here.

[9]Cooper and Mukhopadhyay, in a recent review and analysis of potential IS effectiveness evaluation approaches, note that only three approaches, cost/benefit analysis, information economics, and microeconomic production functions are suitable for use in performance evaluation, and that of these, only the first is of current practical applicability [Cooper and Mukhopadhyay 1990, p. 5 and Figure 1]. Therefore, for illustrating the model in terms of current practice, the focus is on the cost/benefit approach to performance evaluation.

the cost side the short term costs are primarily those associated with systems development, most prominently the labor costs. However, there is also a longer term *maintenance* cost associated with each system. Numerous studies have shown that over half of all systems moneys are spent on maintenance [Elshoff 1976] [Lientz and Swanson 1980] [Boehm 1987] and, most recently, that for every dollar spent on development, nine will be spent on maintenance [Corbi 1989]. While many factors (including exogenous factors such as future changes in the business environment) may effect maintenance costs, for information systems development contracting purposes the principal can only attempt to ensure that the system developed by the agent can be maintained at the least possible foreseeable cost.

Similarly, the benefits side of the equation has both a short and long term component. The principal requesting the system clearly can begin to benefit only when the system is completed. Further, the business use of the new system has to be coordinated with several other business activities, and considerable other resources have to be committed at the anticipated implementation time for the system. Therefore, if the system is delivered on time, the principal is likely to be better off, *ceteris paribus*, than if it were delivered late. This corresponds to the notion of *timeliness*, the ability to deliver the system on or before the deadline. However, in the long term, the ultimate value of the system may be due to the provision of user-desirable functionality. This is the notion of *effectiveness*, which can only be interpreted in a longer term context.

Therefore, for model illustration purposes, the focus is on four outcomes for the principal to apply the efforts of the agent, represented as x_1 (negative of development cost), x_2 (maintainability), x_3 (timeliness), and x_4 (effectiveness)[10]. These are perhaps best presented by means of a 2x2 matrix:

	SHORT TERM	LONG TERM
COST	Initial Development Cost	Maintainability
BENEFIT	Timeliness	Effectiveness

Table 1: Classification Matrix of IS Development Project Outcomes

[10]Note that the research problem of interest here is the measurement of project results, which are the principal's typical concern, especially in the case of an external agent. These organizational level effects, (e.g., the degree to which a project furthered the professional development of the project staff (in order to possibly increase their value on future projects) or the degree to which a project followed site technical standards (in hopes of increasing future inter-operability and hence productivity)) are only secondary effects in terms of an individual project and therefore are not considered here.

Table 1 presents four outcomes (**x**) of interest to the principal requesting the information system. The principal and the agent must jointly agree on a set of performance evaluation metrics, **y**, for the compensation contract. If the **x** are observable by both the principal and the agent in the contractual period, then these may serve as the **y**. However, if that is not the case, then the principal and the agent must determine surrogate metrics that are jointly observable.

B. Performance Evaluation Metric Operationalizations

Two sites were selected as mini-case studies to determine the type and extent of measurement used, one an internal development organization and one an external firm. While the two sites represent a convenience sample, they are believed to be representative of typical current practice in information systems development[11].

The internal organization is located within a large commercial bank. The information systems development group consists of approximately 450 professional staff members who work at developing and maintaining financial application software for the bank's internal use. The applications are largely on-line transaction processing systems, operating almost exclusively in an IBM mainframe COBOL environment. The bank's systems contain over 10,000 programs, totalling over 20 million lines of code. The programs are organized into application systems (e.g., Demand Deposits) of typically 100 - 300 programs each. Some of the bank's major application systems were written in the mid-1970's and are generally acknowledged to be more poorly designed and harder to maintain than more recently written software. The bank has made some attempts to upgrade its systems development capability. These steps include the introduction of a commercial structured analysis and design methodology, the institution of a formal software reuse library, and the piloting of some CASE tools.

The external organization is a major systems consulting and integration firm that operates nationally. Their staff consists of over 2000 systems development professionals who are recruited from the leading colleges and universities. They develop custom applications and sell customizable packages to a variety of public and private clients. Their various divisions are organized around a small number of specific industries, such as financial services. These divisions tend to focus on software and hardware platforms that are widespread in their respective market segments, although there is some firmwide commonality across divisions via a standardized development methodology and toolset. An emphasis is placed on very large systems integration projects that are often multi-

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[11]See Section IV.A for some external validation of this assumption.

year engagements. A state of the art development environment is maintained, with the firm being an early adopter of most software engineering innovations.

At the bank, development cost is tracked through a project accounting system that is used to chargeback systems developer hours to the requesting user department. Hours are charged on a departmental average basis, with no allowance for the skill or experience level of the developer being incorporated into the accounting system. Mainframe computer usage is also charged back to the user, at a 'price' designed to fully allocate the annual cost of operating the data center to the users. However, labor costs are generally believed to constitute eighty percent of the cost at this organization [Kemerer 1987]. At the consulting firm, development costs are tracked through a sophisticated project accounting and billing systems, with the main entry being the bi-weekly timesheets of the professional staff, who may be simultaneously working on multiple projects for different clients. Other direct project charges are also administered through this system, especially travel. Development is typically done at the client's site, and therefore hardware chargeback is often unnecessary.

Long term maintenance costs are, in part, a function of the maintainability of a system [Banker *et al.* 1991a]. While there are many factors outside the control of both the principal and the agent that can affect maintenance costs (e.g., changes in external business conditions such as regulatory changes), the principal desires that the agent deliver a system that can be maintained at the least possible cost. Therefore, the outcome that is desired is a high level of maintainability. Unfortunately, even the growing recognition of the significant magnitude of maintenance efforts has not yet produced a well-accepted metric for maintainability. The closest approximation to such a notion are the class of software metrics known as complexity metrics [McCabe 1976] [Halstead 1977] [Henry and Kafura 1981] [Banker *et al.* 1991c]. The general notion is that, as systems become more complex over time (so-called "system entropy", [Belady and Lehman 1976]), they become more difficult to maintain. The various complexity metrics provide a means of measuring this complexity, and therefore can be used both to predict maintenance costs, and as an input to the repair/rewrite decision [Gill and Kemerer 1991] [Banker *et al.* 1991a] [Banker *et al.* 1991b].

At the bank, while maintenance projects are recognized as the primary information systems development activity, no attempt is currently made to measure and control for the maintainability of the applications. Similarly, at the consulting firm no maintainability measures are tracked, even though the ongoing maintenance of the developed system by the firm is a requirement of many projects.

On the benefit row of Table 1, the short run benefit is provided by delivering the system on schedule, what is referred to as system timeliness. Of course, the appropriate duration of a systems development project is very much dependent upon such factors as the size of the system and the productivity of the development staff. Therefore, the timeliness metric is generally stated in relative terms, rather than absolute terms, most typically in relation to a deadline. Thus, a system is delivered "on time" or "2 months late". Of course, this metric is really a difference result, and therefore an agent seeking to minimize the difference can direct effort both towards maximizing the time period (deadline) allowed during the project planning stage, as well as towards actually developing the system in such a way as to minimize the delay from the delivery date. However, a tendency on the part of developers to estimate or propose excessively long development times will be mitigated by other controls, *i.e.*, an external developer is unlikely to be awarded such a contract, and an in-house developer may find that the principal chooses not to do the system at all. Therefore, a timeliness metric can be assumed to provide at least partial motivation to develop the system promptly.

At the bank, project schedules are published and the larger projects are tracked via a regular status meeting chaired by the most senior vice president in charge of the information systems function. Project adherence to intermediate milestones is checked, and late projects are flagged for discussion. At the consulting firm, adherence to schedule is monitored through use of a development methodology with standardized milestones. Deliverable deadlines are an important part of many contracts, with clients' desire to implement systems by certain fixed dates a key contributor to their decision to use an external developer.

The fourth and final cell in Table 1 is long term benefit, or effectiveness. Effectiveness metrics are much sought, but little or no general practitioner agreement has been reached on such metrics. Crowston and Treacy note that: *"Implicit in most of what we do in MIS is the belief that information technology (IT), has an impact on the bottom line of the business. Surprisingly, we rarely know if this is true"* [1986, p. 299]. They go on to review the existing literature in this area for the previous ten years and conclude that until more progress is made in identifying performance variables, that the best current metrics can only test whether systems engender user satisfaction or usage. Therefore, commonly accepted effectiveness metrics tend to take the form of surveys of user satisfaction [Bailey and Pearson 1983] [Ives *et al.* 1983] [Jenkins and Ricketts 1985]. This work has been criticized as not being theoretically based [Chismar *et al.* 1986] [Melone 1990] and the results of these surveys will be subject to the users' prior expectations about the system. Newer work proposes 'user satisfactoriness' as a theoretically-based alternative metric surrogate for system effectiveness [Goodhue 1986].

At the bank, no formal mechanisms are in place to measure user satisfaction, although occasional efforts are made to interview key users about their needs. At the consulting firm, while user satisfaction is deemed to be highly relevant in terms of its linkage to follow-on contracts, until very recently, no standardized mechanism existed to capture this information. Of course, contractual provisions typically guarantee some minimum level of performance. Beyond this, a small number of newer projects are experimenting with a user satisfaction survey.

C. Application of Model Results

The results of the previous sections are now combined by applying the measurement criteria from the model to the commonly used operationalizations of IS performance evaluation metrics. From this application some observations are made with regard to the model criteria about the relative emphasis on the current operationalizations in practice.

C.1 Precision

The first criterion is the precision of the performance evaluation metrics. Precision's two principal component parts, lack of controllability, as defined by $Var(x_i|a)$, and lack of accuracy, as defined by $Var(\varepsilon_i)$ are considered.

The relative controllability of the four performance evaluation criteria are fairly clear. The agent has strong control over the development costs through his actions to manage them. Timeliness and maintainability are less under the agent's control, as the relationships between efforts taken and the results achieved are less well-understood than those of costs [Abdel-Hamid and Madnick 1991]. Finally, least controllable of all from the IS development agent's perspective is the system's effectiveness. The system may have been poorly conceived initially by the requestor, and therefore, the delivered system, while perhaps meeting the agreed upon technical specifications, may not prove to be valuable. Or, the principal may do an inadequate job making the organizational changes necessary for the success of the new system, e.g., re-assignment of tasks, re-training, and adjustment of compensation systems. In support of these notions there is a growing body of descriptive research that suggests that many completed systems are never used [Rothfeder 1988] [Kemerer and Sosa 1991]. Finally, if user satisfaction metrics are used, it may be in the interests of the user to not report satisfaction as high, in order to extract additional effort or attention from the developer.

In the accuracy component, the short-term measures clearly allow for more accuracy than the long-term measures. Project management systems routinely track project expenditures and deadlines,

and these provide metrics that are relatively objective and accurate versus either maintainability (subject to limitations in measurement and the impact of the unknown nature of future change requests) or effectiveness (subject to the lack of reliability of the measurement instrument and the unknown impact of future changes in the business). The problems with maintainability and effectiveness introduce a large degree of noise into the process, thus reducing the precision of metrics for those performance evaluation variables.

Summing these two components of precision, controllability and accuracy, it can be seen that development cost scores relatively the best on both components, while effectiveness scores relatively the worst. Timeliness and maintainability rate in the middle of these two extremes in terms of their precision.

C.2 Sensitivity

Development cost, operationalized at both sites primarily as labor work months, is a sensitive metric, that is, it possesses a relatively high value for $\mu_1 \partial m_1(a_1)/\partial a_1$. A project manager can change the expected development cost by deciding which staff members are to be assigned[12] and how they are to be deployed, and by providing leadership and supervision during the development process. In addition, a manager may also influence project cost by under-reporting his own hours, as a means of adding value to a project without exceeding the budget.

The other short term measure, timeliness, as operationalized by the degree to which the deadline was met, is relatively less sensitive than cost to the agent's increased effort. While assigning less or more expensive personnel directly affects the project cost, the influence on timeliness is less direct. Brooks's research has been summarized into the aphorism that "adding staff to a late project makes it later," denying the ability of the agent to move the timeliness metric in the desired direction in a substantial way [Brooks 1975]. In essence, given the current state of practice in software project management, small efforts at the margin on the part of the agent cannot effect as large a change in the timeliness metric as could similar efforts directed toward the development cost metric. This result depends in part upon the project specification being sufficiently concrete as to disallow the possibility of significant "gaming", i.e., undocumented reduction in scope that allow the appearance of on time delivery of what in reality is significantly reduced functionality. This is the situation at both of the case study sites, particularly the external consulting firm where formal contracts are the norm.

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[12]This assumes that different levels of staff are charged at different rates, a typical approach, but one that is not universal, particularly among internal IS development groups.

In terms of the longer term metrics, the cost side is reflected by maintainability, possibly operationalized by complexity metrics, (although not done at either site) and the benefit side is referred to as effectiveness, possibly operationalized by user satisfaction (although not done at either site). Maintenance, despite its growing economic importance, is a relatively unstudied and therefore poorly understood phenomenon. Metrics for measuring maintainability are in their infancy, and therefore the relationships among agents' efforts and their impact on maintainability or the complexity metrics are even less well understood. The project manager's ability to influence maintainability is, therefore, limited. Thus, the sensitivity of maintenance metrics can only be described as low.

Conversely, the user satisfaction metrics used to indicate effectiveness should show relatively high sensitivity. Often, the inclusion of a seemingly small feature can greatly improve the user's perceived or even actual value for the application. If the IS development agent is aware of user needs and preferences, particularly regarding user interface issues, he is often able to greatly influence user satisfaction.

In summary, the relative sensitivity of the commonly used metrics are as follows. Development cost and user satisfaction will exhibit relatively high sensitivity, with timeliness being less sensitive than either of them. Finally, maintainability, with the current poor understanding of the relationship between complexity and maintenance, is relatively the least sensitive of the four.

C.3 Summary

In examining all of the performance evaluation metrics relative to the criteria defined by the model, it can be seen that development cost as a metric ranks high in terms of both its sensitivity and precision. Timeliness as measured by meeting deadlines is also sensitive, but somewhat less precise. Effectiveness seems sensitive, but fares poorly in terms of its precision, while maintainability is only moderately sensitive and moderately precise. Therefore, using the result from Equation 12, an ordinal ranking of performance evaluation metrics would list development cost and deadlines a close first and second, followed by user satisfaction and then followed by maintainability, as shown in Table 2.

Metric	Sensitivity	Precision		Ordinal Score
		Control	Accuracy	
Budget performance	High	High	High	1a
Schedule performance	High	Medium	High	1b
User Satisfaction	High	Low	Medium	2
Maintenance complexity	Low	Medium	Medium	3

Table 2: Relative Metric Values

To summarize, this ranking is based on observations at the two sites. In practice, both sites emphasize measurement on two dimensions, cost and timeliness, that are seen to possess relatively the most precision and sensitivity, as predicted by the model. How these dimensions might fare at other sites, or at these same sites in the future, are discussed in Section IV.

IV. DISCUSSION

In this section the generalizability and implications of the results shown in Section III are discussed. Limitations of the model and possible extensions to it are also presented.

A. Generalizability and Implications of the Results

In examining the results presented in Section III one possible concern might be with the representativeness of the two mini-case studies. Even though their practices are in line with what the model would predict, to what degree are they believed to be representative of current practice?

Three other sources of data on the current state of measurement suggest that the two mini-cases are quite typical of current practice. In a survey of over 140 medium to large IS departments conducted in 1988, managers were asked what measures they currently used [Howard 1988]. By far the leading measures were work-hours per project, a measure of development cost (78% of managers surveyed), and adherence to delivery dates, a measure of timeliness (72%). The third most used measure was computer resource usage, which was only mentioned by 27% of the respondents. All other measures were less frequently reported, and, in particular, "module size", a potential measure of maintainability, was reported by only 8% of the respondents.

Another independent source is some descriptive data from the forthcoming text by Jones [1991]. His reports about the status of software measurement in various industries are worth quoting in full:

> *"Companies such as Exxon and Amoco were early students of software productivity measurement , and have been moving into ... user satisfaction as well...The leading insurance companies such as Hartford Insurance, UNUM, USF&G, John Hancock, and Sun Life Insurance tend to measure productivity, and are now stepping up to ... user satisfaction measures as well...In the manufacturing, energy, and wholesale/retail segments the use of software productivity measurement appears to be proportional to the size of the enterprise: the larger companies with more than a thousand software professionals such as Sears Roebuck and J.C. Penney measure productivity, but the smaller ones do not....user satisfaction measurement are just beginning to heat up within these industry segments...Companies such as Consolidated Edison, Florida Power and Light, and Cincinnati Gas and Electric are becoming fairly advanced in software productivity measure. Here too, ... user satisfaction measures have tended to lag behind."* [1991, pp. 22-24]

Finally, Watts Humphrey, in his work on software process maturity, notes that the first measures adopted by organizations are cost and schedule metrics. It is not until stage four of the five stage model that more comprehensive measures are expected to be implemented [Humphrey 1988, p. 74].

These independent observations document what is predicted by the model. Productivity measures, be they cost or time-related, are in wide use, while effectiveness measures in the form of user satisfaction or quality metrics, are less widely adopted. Measures of maintainability are completely absent from these discussions, which is consistent with the results in Table 2 which suggest that they are the least likely of the four to be adopted.

The implications for this choice of adoption are worthy of managerial concern. The emphasis on short-term results will tend to produce decisions on project planning, staffing, and technology adoption that are sub-optimal for the organization in the long-term. For example, the total lack of measurement of the maintainability impacts of project decisions implies that only minimal effort will be devoted towards, for example, useful design and code documentation or adherence to structured coding precepts, to the extent that these activities are viewed as costly or otherwise compete for resources with different activities that are measured. Similarly, an emphasis on schedule and budget measurements in preference to effectiveness measures implies an emphasis on delivering any product on-time, rather than a better product later, where this latter option might be the preferred alternative for the organization.

B. Limitations and Possible Extensions to the Results

The discussion so far has been limited to application of the results of the model to examples in traditional information systems development that are currently observed. Two obvious extensions to this analysis would be to apply the model to (a) different development environments, and (b) speculate as to future trends that may have some impact on these results.

Different environments may have available metric operationalizations that exhibit higher precision or sensitivity or both versus their counterparts in traditional information systems. For example, the effectiveness dimension is traditionally perceived as difficult to quantify. However, in another environment this may not be the case. For example, in a safety critical application, such as real-time control of a nuclear power plant, software reliability may be the overwhelming criteria, and therefore the degree to which the software has been tested and can be 'proven' correct may swamp all other possible effectiveness considerations. To the degree that metrics for reliability exhibit higher control and accuracy relative to the equivalent user satisfaction metric of traditional information systems, and to the degree that reliability is a highly valued outcome dimension, it will be weighted more heavily. Another example might be the effectiveness of a real-time military fire control system which may depend almost solely on the operational performance (speed) at which it operates. This may lend itself to easily definable metrics that possess desirable properties.

One change that may occur over time within the information systems environment is greater recognition of the ability to measure and improve software maintainability. While the importance of the maintenance activity has been recognized for over a decade [Lientz and Swanson 1980], it is only recently that research has linked measures of complexity to maintainability [Gibson and Senn 1989] [Gill and Kemerer 1991] [Banker *et al.* 1991a] [Banker *et al.* 1991b]. This realization has been accompanied by the commercial availability of automated tools that deliver the metric values [Babcock 1986] [McAuliffe 1988]. To the degree to which these static analysis tools are delivered within CASE environments, rather that having to be justified and purchased as stand-alone tools, their use can be expected to increase. Therefore, over time a greater understanding of software complexity metrics as operationalizations of the maintainability dimension may improve the relative sensitivity of this metric.

A further interpretation of the results from the model would be to move beyond the positive or descriptive aspects and interpret the results in a normative manner, i.e., where current metrics are deficient indicates where further effort is needed. This would argue for greater emphasis on metrics for both effectiveness and maintainability, as these are the two dimensions least well represented by current metrics. It should be noted that this result which is derived from the agency theory perspective matches well with some current calls from practitioners for better measures of the 'business value' of IS development [Banker and Kauffman 1988]. For example, the effectiveness dimension would be likely to be measured more often if there were a metric that possessed better characteristics than the current user satisfaction metric.

A more general result that follows from this same line of reasoning is that, given the poor qualities of the currently available outcome metrics, it is not surprising to see an emphasis in practice on behavior-based metrics (e.g., tracking of hours-not-to-exceed-n; timebox management). This has a number of implications, particularly for the viability of outsourcing. Given the impossibility of directly monitoring outsourced development, for contracting purposes the principal would be greatly aided by the availability of outcome metrics with desirable properties such as sensitivity and precision. The current deficiency in this area may slow the growth of adoption of systems development outsourcing.

V. CONCLUDING REMARKS

This paper has developed a principal-agent model, grounded in information economics theory, that provides a common conceptual framework to illuminate current and future practice with regard to performance evaluation metrics for information system development. Given the principal-agent nature of most significant scale IS development, insights that will allow for greater alignment of the agent's goals with those of the principal through incentive contracts will serve to make IS development both more efficient and more effective. An important first step in this process is gaining a better understanding of the behavior of the metrics used in contracting for IS development. The insights available from the model both suggest explanations as to the current weighting of the dimensions of IS development performance, and provide insights into where better metrics are needed if the current largely unsatisfactory situation is to be remedied.

In terms of future research, a natural follow-on would be to perform an empirical validation of the proposed relative weightings given a set of performance evaluation metrics. This will require the development of an instrument to measure the model's sensitivity and precision constructs.

The ultimate value of such research will be in an increased understanding of how best to evaluate current systems development performance, so as to provide guidance to managers on how best to improve that performance. Given the key role played by systems development in enabling strategic uses of information technology, such improvement is of critical importance to the management of organizations.

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