Trade-offs in Organizational Architecture: Information Systems, Incentives and Work Design

Abraham Seidmann
William E. Simon Graduate School of Business
University of Rochester

Arun Sundararajan
Leonard N. Stern School of Business
New York University

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Abraham Seidmann and Arun Sundararajan[1]

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[1] Abraham Seidmann is the Xerox Professor and Area Coordinator of Computers and Information Systems, Operations Management and Management Science at the University of Rochester's William E. Simon Graduate School of Business Administration. Arun Sundararajan is Assistant Professor of Information Systems at New York University's Leonard Stern School of Business. The authors thank Marshall Freimer, Eugene Kandel and also Rajiv Banker, Anitesh Barua, Rajiv Dewan, Frances Frei, Harry Groenevelt, John Long, Leslie Marx, Roy Radner, Paul Schweitzer, Jerold Warner and Jerold Zimmerman, participants in a number of CIS/OMG seminars at the Simon School, and seminar participants at Carnegie-Mellon University, Dartmouth College, London Business School, New York University, Purdue University, University of Florida, University of Minnesota, University of Southern California, University of Texas and the Eighth Workshop on Information Systems and Economics for their feedback on earlier versions of various parts of this research.

2. Introduction

The last decade has witnessed a revolution in organizational design. Reengineering – a paradigm which called for radical change in the work systems, performance control and information systems infrastructure – was largely responsible. See Davenport and Short, (1990), Davenport, (1993), Hammer, (1990), Hammer and Champy, (1993), or Brickley, Smith and Zimmerman, (1997) for extensive discussion on some of the new organization design philosophies. The common theme of these ideas was to transform firms from *functionally specialized* organizations to *process oriented* organizations (illustrated by the definition of reengineering by Brickley, Smith and Zimmerman (1997) – *a change in the assignment of tasks, often involving the move from a functional to a process-oriented organization*[1]).

These new design principles were backed primarily by citing cases in which they worked. (Hammer and Champy, 1993 and Davenport, 1993 list many such cases – some others are described in Ballou, 1995, Byrne, 1993, Clark, 1995, Humphrey, 1995 and Zell, 1997). However, there has been little formal analysis of this new paradigm. Its results have been mixed at best; while a number of organizations have benefited, there has been an astonishing failure rate. Having transformed themselves, some firms find that they are unable to handle their workload (Boeing being a significant recent example). Other companies, such as Levi Strauss (King, 1998), have found that the new ideas of joint compensation and teamwork were markedly inferior to their prior system of functional specialization and piece-rate compensation.

We perceive two explanations for this reported variance in success. One is that some organizational transformation efforts fail due to inadequate change management. Resistance to change is inevitable, and firms may lack the management techniques required to successfully implement new organizational designs. The second explanation, which has not been investigated formally until now, is that some of the principles themselves lead to lower organizational efficiency in certain settings. In other words, they may not be universally applicable. However, if this is true, then which principles, if any, are universally applicable, and what factors determine whether a particular design is suitable for a specific organization?

The purpose of our paper is to answer these questions. Specifically, we ask:

1. When is process-oriented organization preferred to functional organization?
2. What mix of work systems, information systems and incentives are optimal in a particular organizational context?
3. What are the performance trade-offs between simultaneous changes *across* these organizational design factors?

We rigorously analyze the organization design principles that were motivated by business process reengineering, while *simultaneously* incorporating work system design, incentives and information systems variables into our models. We derive a number of interesting results, some of which support these principles, and others which do not. Our paper adds to the academic literature on process redesign (for instance, Caron and Stoddard, 1995, Clemons, Thatcher and Row, 1995, Davenport and Nohria, 1994, Davenport, Jarvenpaa and Beers, 1996, Teng, Jeong and Grover, 1998, Jarvenpaa and Ives, 1995, Jarvenpaa and Stoddard, 1995, Seidmann and Sundararajan, 1997 and Venkatraman, 1991), and also to the broader areas of information technology and organization design (for instance, Brynjolfsson, 1994, Gurbaxani and Whang, 1990, Huber, 1984, Malone and Smith, 1988, Markus and Robey, 1988, Orlikowski, 1994, Radner, 1993 and Sampler and Short, 1994), and the economics of queuing systems (Dewan and Mendelson, 1990, Lee and Cohen, 1985, Mendelson, 1985, Mendelson and Whang, 1990, and Whang, 1990).

Three articles from the academic literature are most similar to this paper, in either approach or in methodology. Buzacott (1996) develops a series of queuing models aimed at questioning the validity of Hammer and Champy's ten reengineering principles, and concludes, among other things, that a high degree of variability is necessary to justify their validity. This paper is comprehensive and rigorous. However, by isolating queuing effects, it ignores the crucial interactions between the design of work systems, and other motivational and technological factors. In the spirit of Milgrom and Roberts (1990), Barua, Whinston and Lee (1996) recognize that information technology and organizational changes may be complementary. They develop an axiomatic framework that captures this possibility, and show, under rigorous assumptions, that certain organizational changes may be complementary to information technology changes. More recently, Brynjolfsson and van Alstyne (1997) have developed a simple framework and software package which enables managers to study such complementary interactions.

What sets our research apart from these papers is our *interdisciplinary* approach that *simultaneously* capture the operational aspects of organizations, and the rich interactions caused by the increased employee component and the central role of information systems that characterize modern service organizations.

The rest of this paper is organized as follows. We describe our modeling framework in §2. In §3, we outline our model and state a lemma that enables us to solve agency problems in a variety of queuing systems. We then describe the details of functional and process-oriented organizations in §4 and §5, derive optimal contracts and cost functions for firms adopting one or the other form of organization, and state some results about the relation between information asymmetry and agency costs . In §6, we analyze these analytical results from the prior sections, graphically illustrate the trade-offs between functional and process organization, and describe the complementarity and substitutability between different organizational variables in each case. Finally, we discuss the managerial insights of our research in §7, and conclude in §8.

2. A Framework for Modeling Organizations

The first step towards successfully designing a organization is determining what parameters influence its performance. The next step is to recognize which of those parameters are variable, and which of those cannot be changed by the firm. For instance, both the level of customization demanded by a customer, and the level of skill-enhancing technology available to an empowered worker influence the performance of the organization. However, only the latter can be explicitly chosen by a manager. For those familiar with solving optimization problems, these steps correspond to identifying the parameters of the problem, and determining which of these parameters are variables. The parameters that can be chosen are termed *internal design variables.* The factors that are not controlled by the firm are classified into *job-specific factors* and *external factors*. The internal design variables fall into three broad categories: variables that determine the *information systems and architecture*, variables that describe *employee incentives*, and variables that describe *operational work design.* The framework is illustrated in Figure 1.

Information systems: Information systems that have the most significant impact on the performance of an organization cause at least one of three effects. They enable superior access to information, they expand worker skills and expertise, and they increase processing speed. Some information systems result in more than one of these effects. Others may have a positive effect on one dimension and a negative effect on others. The central point here is that managers and workers desire one or more of these effects when they acquire information systems. Therefore, we model these effects, rather than explicit hardware and software choices, since this will not only indicate what mix of technology is optimal in a particular setting, but will also predict and recommend the direction of future systems development and research.

Incentives: A striking difference between the organizational design and management in manufacturing and service firms is the relatively higher impact of performance measurement and control in service organizations. Modeling and optimizing performance in manufacturing processes is relatively easy — the machines that do the work in the process are much less reliant on human factors. This is probably one of the reasons why the philosophies of Adam Smith and Frederick Taylor that worked so well for assembling products were found lacking in service organizations. We explicitly consider the performance measures used by the organization, and the employee reward system that these measures form an input to. These variables are consistent with those commonly used in the performance control literature. See, for instance, Brickley, Smith & Zimmerman, (1997) or Eisenhardt, (1985)

Work Design: The final set of decision variables describes the architecture of work and information flows in the organization. We explicitly model task allocation and sequencing, and their associated information flows — whether tasks are done sequentially by different workers, or whether sets of tasks are allocated to a single worker or team of workers.

Job-specific parameters: This set consists of the internal parameters that influence the performance of the organization, and are intrinsic to the work done in the process (they cannot be chosen). They include knowledge intensity (what skills and supporting information are required to complete the tasks), the magnitude of information that 'flows with the job' (how much customer-specific information does the job require), the characteristics of the workers (their preferences, risk aversion and effort aversion), the sizes of different 'pieces' of a job, and the technology responsiveness of the firm and its employees (how high the returns from the technology effects described are).

External characteristics: Organization design cannot be insulated from the characteristics of the customer; in fact, the concept of 'customer centered' processing is one of the focal points of modern organizations. Our framework includes customer characteristics such as variability in demand specifications (degree of customization required), time preferences (the magnitude of their delay costs), and the market demand at a particular level of service (the demand function)

3. Model

We model an organization with one principal and *n* identical agents. (See Jensen and Mecking, 1976, or Eisenhardt, 1985, for a discussion of agency theory in organizations). The principal attempts to maximize her net profit function by inducing certain effort levels from the agents. The effort levels of the *n* agents are not directly observable. However, they jointly influence a stochastic performance measure. It may not be possible to isolate the individual contribution of each agent to the performance measure. This performance measure affects the profits of the principal. A closed-form expression for the density function of the distribution of the performance measure is may not be known. However, the Laplace transform of this density function is known (see Smith, 1976, for an exposition of Laplace transform theory). The density function underlying the Laplace transform has moments that exist and are finite. This represents a general model of service organizations, where each agent controls the processing rate of a queue, and the overall cycle time of the process, which is the net sojourn time in the queuing network is the only observable performance measure that affects the profits of the firm. Some notation used is summarized below.

$U(x)$: Utility function of the agents in the process; the argument x is monetary compensation.

E: Set of possible effort levels.

$\mathbf{\Omega} = (\omega_1, \omega_2, \ldots, \omega_n)$: Effort level vector of the n workers; $\omega_i \in E \ \forall i$. A higher value of ω_i represents a higher effort.

$[\mathbf{\Omega}_{-i}, \omega_0] = (\omega_1, \omega_2, \ldots, \omega_{i-1}, \omega_0, \omega_{i+1}, \ldots, \omega_n)$: Effort level vector with the i^{th} component replaced by ω_0.

$c(\omega)$: Cost to each agent of exerting effort ω, measured in monetary units.

$f(\cdot \mid \mathbf{\Omega})$: Density function of observable performance measure if workers work at effort levels $\mathbf{\Omega}$.

$F^*(s \mid \mathbf{\Omega})$: Laplace transform of $f(\cdot \mid \mathbf{\Omega})$.

$m_i(\Omega) = (-1)^i \lim_{s \to 0} \frac{d^i}{dy^i} F^*(s \mid \Omega)$: i^{th} moment of $f(. \mid \Omega)$.

(a,b) = $(a_1, a_2, \ldots, a_n), (b_1, b_2, \ldots b_n)$: Contracts offered to the n agents.

U_0 : Reservation utility of the workers.

$\pi(y)$: Profits to the principal (excluding compensation costs) if observed performance measure is y.

An crucial assumption is made: *that the contracts offered to the agents are linear in the performance measure* i.e. if the observed measure is y, then agent i is paid $a_i + b_i y$. The utility function we use is contained in the class of functions for which linearity is optimal (as discussed in Ross, 1974), and the probability assessments of uncertainty are identical for both the principal and the agents, in that both have identical knowledge about the behavior of the random performance measure for a given set of actions. Besides, a non-linear contract, apart from being uncommon in practice, renders our problem intractable except when the agents are risk-neutral.. At this point, the principal's problem can be formulated.

$$\max_{a,b} \int_0^\infty \{\pi(y) - \sum_{i=1}^{n}(a_i + b_i y)\} f(y \mid \Omega^*) dy$$

$$s.t.$$

$$\int_0^\infty U(a_i + b_i y - c(\omega_i^*)) f(y \mid \Omega^*) dy \geq U_0 \quad \forall i \qquad \textbf{(P1)}$$

$$\omega_i^* \in \arg\max_{\omega \in E} \int_0^\infty U(a_i + b_i y - c(\omega)) f(y \mid [\Omega_{-i}, \omega]) dy \ \forall i.$$

The objective function of the principal is expected net profits (profits less compensation costs). The first constraint ensures that each of the workers get their minimum reservation utility. The second constraint ensures that, given the contract (a_i,b_i), each component ω_i* of the effort level vector Ω* induced provides each worker with the maximum possible utility, given the effort level of the other workers (thus yielding a Nash equilibrium solution for the inter-agent game). See Grossman and Hart (1983), or Holmstrom (1979, 1982) for more details on the assumptions and formulation of single and multi-agent principal-agent problems

The following lemma establishes that (P1) can be reformulated in closed form as a minimization problem. The proof of this lemma is not exposited. It follows directly from the definition of the Laplace transform, and the fact that profit maximization and cost minimization are equivalent for the profit function specified.

Lemma 1: If U(x) is identical and negative exponential for all agents, i.e. $U(x) = -e^{-\eta x}$, and $\pi(y)$ *is linear and decreasing in y, i.e.* $\pi(y) = \pi_0 - c_D y$, *then* **(P1)** *has the following closed-form formulation*

$$\min_{a,b} \left(c_D m_1(\Omega^*) + \sum_{j=1}^{n} [a_j + b_j m_1(\Omega^*)] \right)$$

$$s.t. \qquad \textbf{(P2)}$$

$$[-e^{-\eta\{a_j - c(\omega_j^*)\}} F^*(\eta b_j \mid \Omega^*)] \geq U_0 \ \forall j$$

$$\omega_j^* \in \arg\max_{\omega \in E} [-e^{-\eta c(\omega)} F^*(\eta b_j \mid [\Omega_{-j}^*, \omega])] \ \forall j.$$

A much more general form of this result is proved in a companion paper **(to ensure author anonymity, this paper is not cited. A copy of this result can be sent to reviewers upon request).**

In the subsequent sections, we place some more structure on our model of the organization, and use Lemma 1 to derive closed form solutions for optimal contracts and overall objective functions in functional and process-oriented organizations.

4. Functional Organization

In a functional organization, the *n* agents are modeled as specialists who perform the tasks in a job sequentially. Each job consists of *n* tasks, and each specialist is assigned one task. When the specialist receives responsibility over the job, it joins the queue of pending work for that specialist. After completing the relevant task, the specialist passes responsibility to the next agent, who receives it *immediately.* This immediacy is a reflection the advent of workflow automation software and intranet technology in today's workplaces, and allows one to focus on more subtle issues, such as the need for information transfers and the effects of specialization.

When a specialist begins to perform the required task, she must first spend time reading job specifications, inferring particular customer requirements and understanding the nature of what has already been performed by reading summaries of preceding tasks. After the nature of the job has been understood, the specialist performs the task. Finally, she may prepare information to be transferred and read by the succeeding workers. Our model divides the time taken for these activities into two categories. One of these is the *task processing time* of the agent. This is assumed to be exponentially distributed. When the worker works at effort level $\omega^i \in \mathbf{E}$, the parameter of this distribution is correspondingly μ_i. The workers chose from two levels of effort ω^L and ω^H (which correspond to processing rates of μ_L and μ_H) The other component is the *handoff delay* σ; this incorporates the pre and post processing activities. The *degree of customization* determines the value of σ, since higher levels of customization would correspond to lengthier and more complex customer specifications, and consequently, more pre-processing time. This is a widely documented drawback of functional organization (see Davenport, 1993, Hammer and Champy, 1993) -- it causes all workers to repeatedly have to incur a delay of σ. If all of the job's tasks were performed by the same worker, then there would be no need for these intra-job information transfers.

The design of our model allows us to represent the cycle time at each worker as the sojourn time of an *M/G/1* queue[2]. The queues have an arrival rate equal to the rate of arrivals into the system (λ) and a processing time which is distributed as a *shifted exponential.* If the effort level of a worker is ω^I yielding a processing rate μ_i and the handoff delay is σ, then the processing time of each queue is has the density function

$$g(y;\mu_i) = \mu e^{-\mu(y-\sigma)}.$$

The corresponding processing time distributions in the queues are denoted $g_L(y)$ and $g_H(y)$ respectively. Also, define the cost of effort $c_j = c(\omega^j)$, $\omega^j \in \{\omega^L, \omega^H\}$

Two forms of information asymmetry are analyzed. The first, termed *complete asymmetry* is where the principal can only observe the cycle time of the *entire job*, and each agent can observe only the processing time of her task. The other, termed *partial asymmetry*, is where the principal can observe the cycle time of each agent individually — in this case, it is immaterial whether the agents can observe each others' cycle time, as the principal is free to contract with each agent individually. In either case, the value of σ is known to the principal and the agents before contracting. However, although the principal has full information about the value of σ, the best measure upon which a contract can be written is *the entire cycle time of the agent's task* as the presence of the handoff delay influences queuing time as well, and therefore, a measure based solely on μ cannot be separated out. Figure 2(a) depicts these information symmetry situations. Only each agent can see what is inside her box. All the agents and the principal can see what is outside the dotted box. An indicator variable q is used to represent information asymmetry. $q = 0$ represents partial asymmetry, and $q = 1$ represents complete asymmetry.

The following lemma characterizes the expected cycle time of each worker.

Lemma 2: If an agent works at an effort level that induces a processing rate μ_i *, and the arrival rate of jobs is* λ*, the expected cycle time for the agent is*

$$T_s(\mu_i,\lambda) = \frac{(1-\sigma\lambda+\sigma\mu_i-\frac{\sigma^2\lambda\mu_i}{2})}{(\mu_i-\lambda-\lambda\mu_i\sigma)}.$$

Proof: The processing time of each server is distributed as

$$g(x;\omega^i) = \mu_i e^{-\mu_i(x-\sigma)}; x \in [\sigma,\infty).$$

The Laplace transform of this distribution is

$$G^*[s;\omega^i] = \int_\sigma^\infty e^{-sx}\mu_i e^{-\mu_i(x-\sigma)}dx = \frac{\mu_i e^{-s\sigma}}{\mu_i+s}.$$

and the activity rate at each server is

$$\rho_i = \lambda(\frac{1}{\mu_i}+\sigma) = \frac{\lambda}{\mu_i}+\lambda\sigma.$$

By the Pollaczek-Khinchin transform equation (see Kleinrock, 1976), the system time at each server has a distribution whose Laplace transform is given by

$$G_S^*[s;\omega^i] = \frac{G^*[s;\omega^i]s(1-\rho_i)}{s-\lambda+\lambda G^*[s;\omega^i]},$$

which solves to

$$G_S^*[s;\omega^i] = \frac{s(\mu_i - \lambda - \lambda\mu_i\sigma)}{(s+\mu_i)(s-\lambda)e^{s\sigma} + \lambda\mu_i}.$$

The expected service time at each server is given by

$$\lim_{s\to 0} -\frac{\partial G^*[s;\omega^i]}{\partial s}.$$

Differentiating, and using L'Hospital's rule twice yields

$$\lim_{s\to 0} -\frac{\partial G^*[s;\omega^i]}{\partial s} = \frac{(1 - \sigma\lambda + \sigma\mu_i - \frac{\sigma^2\lambda\mu_i}{2})}{(\mu_i - \lambda - \lambda\mu_i\sigma)}.$$

The principal has the option of choosing to offer activity based compensation (a flat fee for each job completed). If this is the case, the workers all work at effort level μ_L This may occur if the cost of offering performance-based compensation outweighs its benefits. The principal chooses the contract that minimizes total costs.

The new notation introduced in this section is summarized below:

- μ_i Exponential processing rate of specialist at effort level $\omega^i \in \{\omega^L, \omega^H\}$.
- c_i: Cost of effort per task for a specialist at effort level $\omega^i \in \{\omega^L, \omega^H\}$.
- $g(y;\mu_i) = g_i(y)$: Server processing time density at effort level $\omega^i \in \{\omega^L, \omega^H\}$;

$g_i(y) = \mu_i e^{-\mu_i(y-\sigma)}$.

- $T_s(\mu_i, \lambda)$: Expected sojourn time in an *M/G/1* queue with arrival rate □ and

processing time distribution $g(y;\mu_i)$.

Propositions 1 and 2 characterize the incentive contracts and system performance of this organization design.

Proposition 1

In a functional organization with specialists, if a performance-based compensation scheme is chosen, the identical optimal contract (a,b) offered to all the specialists solves

$$\mathrm{a} = c_H + \frac{1}{\eta}\log\frac{-1}{U_0} + \frac{n^q}{\eta}\log[\frac{\eta \mathrm{b}(\mu_H - \lambda - \lambda\mu_H\sigma)}{e^{\eta \mathrm{b}\sigma}(\eta \mathrm{b} + \mu_H)(\eta \mathrm{b} - \lambda) + \lambda\mu_H}],$$

$$\frac{(\mu_L - \lambda - \lambda\mu_L\sigma)e^{c_L\eta}}{e^{\eta \mathrm{b}\sigma}(\eta \mathrm{b} + \mu_L)(\eta \mathrm{b} - \lambda) + \lambda\mu_L} = \frac{(\mu_H - \lambda - \lambda\mu_H\sigma)e^{c_H\eta}}{e^{\eta \mathrm{b}\sigma}(\eta \mathrm{b} + \mu_H)(\eta \mathrm{b} - \lambda) + \lambda\mu_H}.$$

Proof: There are two effort levels, and the agents seek pure strategy Nash equilibria. Therefore, the only rationale for having a performance-based incentive scheme is if it induces all the workers to work at ω^{H}. The agents have identical preferences, and identical job sizes, and hence, by symmetry, the optimal contracts offered to the will be identical, inducing identical effort levels. By Lemma 1, the contract *(a,b)* chosen must satisfy:

$$\omega^H = \underset{\omega\in\{\omega^L,\omega^H\}}{\arg\max} \ \text{-}\mathrm{e}^{\text{-}\eta[\mathrm{a}\text{-}\mathrm{c}(\omega)]}F^*[\eta \mathrm{b}|\,(\omega^H,\omega^H,\omega^H,..,\omega)],$$

$$\text{-}\,\mathrm{e}^{\text{-}\eta[\mathrm{a}\text{-}\mathrm{c}_H]}F^*[\eta \mathrm{b}|\,(\omega^H,\omega^H,\omega^H,..,\omega)] = \mathrm{U}_1.$$

Since ω can take only two values, it follows that *(a,b)* must solve

$$\text{-}\,\mathrm{e}^{\text{-}\eta[\mathrm{a}\text{-}\mathrm{c}_H]}F^*[\eta \mathrm{b}|\,(\omega^H,\omega^H,\omega^H,..,\omega^H)] \geq \text{-}\mathrm{e}^{\text{-}\eta[\mathrm{a}\text{-}\mathrm{c}_L]}F^*[\eta \mathrm{b}|\,(\omega^H,\omega^H,\omega^H,..,\omega^L)],$$

$$\text{-}\,\mathrm{e}^{\text{-}\eta[\mathrm{a}\text{-}\mathrm{c}_H]}F^*[\eta \mathrm{b}|\,(\omega^H,\omega^H,\omega^H,..,\omega^H)] = \mathrm{U}_1.$$

This is referred to as Condition 1.

Partial asymmetry: In this case, Condition 1 is equivalent to

$$\text{-}\,\mathrm{e}^{\text{-}\eta[\mathrm{a}\text{-}\mathrm{c}_H]}\mathrm{G}_S^*[\eta \mathrm{b};\omega^H] = \text{-}\mathrm{e}^{\text{-}\eta[\mathrm{a}\text{-}\mathrm{c}_L]}\mathrm{G}_S^*[\eta \mathrm{b};\omega^L],$$
$$\text{-}\,\mathrm{e}^{\text{-}\eta[\mathrm{a}\text{-}\mathrm{c}_H]}\mathrm{G}_S^*[\eta \mathrm{b};\omega^H] = \mathrm{U}_1.$$

where $\mathrm{G}_S^*[s;\omega^H]$ is as defined in the proof of Lemma 2. The first equation reduces to

$$\text{-}\,\mathrm{e}^{\eta \mathrm{c}_H}\ \mathrm{G}_S^*[\eta \mathrm{b};\omega^H] = \text{-}\mathrm{e}^{\eta \mathrm{c}_L}\ \mathrm{G}_S^*[\eta \mathrm{b};\omega^L],$$

which yields the equality for *b* when $\mathrm{G}_S^*[\eta \mathrm{b};\omega^H]$ and $\mathrm{G}_S^*[\eta \mathrm{b};\omega^L]$ are substituted for.

Solving the second equation for *a* yields

$$a = c_H + \frac{1}{\eta} log(\frac{-1}{U_0}) + \frac{1}{\eta} log\, G^*_S[\eta b;\omega^H].$$

Substituting for $G^*_S[\eta b;\omega^H]$ & multiplying by n^0 yields the result in its stated form.

Complete asymmetry:

$$F^*[\eta b,(\omega_1,\omega_2,..,\omega_n)] = G^*_S[\eta b;\omega_1]G^*_S[\eta b;\omega_2]....G^*_S[\eta b;\omega_n].$$

This result follows from the fact that the work system described is a product form queuing network with n servers in tandem. Condition 1 now reduces to

$$-e^{-\eta[a-c_H]}(G^*_S[\eta b;\omega^H])^n = -e^{-\eta[a-c_L]}(G^*_S[\eta b;\omega^H])^{n-1}\, G^*_S[\eta b;\omega^L],$$
$$-e^{-\eta[a-c_H]}(G^*_S[\eta b;\omega^H])^n = U_1.$$

Canceling terms and simplifying the first equation as in the case for partial asymmetry yields the equality for b. Solving for a yields

$$a = c_H + \frac{1}{\eta} log(\frac{-1}{U_1}) + \frac{1}{\eta} log(G^*_S[\eta b;\omega^H])^n$$

Substituting the expression for $G^*_S[\eta b;\omega^H]$ and using $\log(y^x) = x\log(y)$ yields the result for a in its stated form. *QED*

Proposition 2

The principal's cost per job is given by

$$C(\mu_L,\mu_H,\lambda,\sigma) = \min[\{nc_D T_s(\mu_L,\lambda) + n[c_L + \tfrac{1}{\eta}\log(\tfrac{-1}{U_0})]\},$$
$$\{nc_D T_s(\mu_H,\lambda) + n^{(q+1)} b T_s(\mu_H) + na]\}].$$

Proof: If the principal does not adopt an incentive compensation scheme, she must pay the agents their reservation wage. This is simply the wage that ensures their reservation utility. Let this wage be w. It is easily seen that

$$-e^{-\eta(w-c_L)} = U_1 \Rightarrow w = c_L + \frac{1}{\eta}\log(\frac{-1}{U_1}).$$

The agents work at rate μ_L, which yields an expected cycle time of $T_S(\mu_L, \lambda)$ per task. Hence, the total costs incurred are

$$C = nc_D T_s(\mu_L, \lambda) + n[c_L + \frac{1}{\eta}\log(\frac{-1}{U_i})].$$

On the other hand, if the principal uses an incentive scheme, the agents work at rate μ_H. The cycle time per task is therefore $T_s(\mu_H, \lambda)$ and the expected system cycle time is $n\,T_s(\mu_H, \lambda)$.

Partial asymmetry: The expected compensation per worker is

$$a + b\mathrm{E}(tasktime) = a + bT_S(\mu_H, \lambda).$$

Complete asymmetry: The expected compensation per worker is

$$a + b\mathrm{E}(systemtime) = a + bnT_S(\mu_H, \lambda).$$

Given that $q = 0$ under partial asymmetry, $q = 1$ under complete asymmetry and there are n workers, the total expected costs to the principal are:

$$C = nc_D T_s(\mu_H, \lambda) + nb[n^q T_s(\mu_H)] + na.$$

The principal chooses the compensation scheme that minimizes costs. The result follows. *QED.*

Proposition 1 describes the form of the optimal linear incentive contract. Note that the factor b has the same value, irrespective of the information asymmetry. This should not be misinterpreted as the variable component of compensation being the same in both situations. Under complete asymmetry, the performance measure is the cycle time of the entire job; hence the magnitude of the realized variable component of compensation (b multiplied by the observed cycle time of the entire job) is far higher than in the case of partial asymmetry (where it is b multiplied by the observed cycle time of a single task). This component increases approximately linearly with n, which is intuitively appealing, because as n increases, the problem of free riding becomes increasingly more difficult. The fact that b turns out to have identical values is due to a property of the Laplace transform of the density function of a sum of independent random variables.

Proposition 2 is easily explained in words. The first term inside the curly parentheses in each case is the total expected cost with an activity based compensation scheme. The second term is the total expected cost with a performance-based incentive scheme. Notice that in both asymmetry situations, the first term is the same - this is trivially true because with no incentive scheme, information asymmetry becomes meaningless.

We now state a corollary which distinguishes the relative impact of agency costs in each information asymmetry situation. Its proof is not detailed: it is evident from examination of the two propositions.

Corollary 1

(I) At a particular level of agent effort, costs due to delay are independent of the information asymmetry, and are linear in the number of workers.

(II) If it is optimal to use a performance-based compensation scheme, then

a) Under partial asymmetry, agency costs are linear in the number of workers.

b) Under complete asymmetry, agency costs are quadratic in the number of workers.

This corollary indicates the primary cost driver in a sequential system with complete asymmetry and a large number of workers is not only due to handoffs and queuing delays; in fact, as n grows, the impact of agency costs becomes increasingly more important. Two insights can be drawn from this result. The first is that agency costs are rarely cited as a driver of process redesign. The convexity of these costs in the number of workers may partially explain why long sequential systems are inefficient, even when specialization gains are significant. The second is that there is tremendous added value from an *information system* that moves a firm from complete to partial asymmetry. Workflow automation software is one example of such a system. Again, the gains from such information systems are always interpreted as being a result of reduced reconciliation costs and better co-ordination — however, reduction in agency costs is a potentially significant reason for adopting this expensive technology

It is difficult to interpret these results further using comparative statics, due to the complexity of the derived cost functions. However, using numerical optimization, a number of useful insights are derived from them; these are discussed in §6.

5. Process oriented organization

In this organizational architecture, the n agents are modeled as case managers who work in parallel. When a job arrives in the organization, it is sent to one of the n case managers, who performs all the n tasks of the job. This model depicts a common work system in process-oriented corporations (the most well-known example being that of IBM Credit from Hammer and Champy, 1993). Though this eliminates handoff delays, it presents the new problems. Due to a loss of specialization and barriers to accessing specialized information systems, at any given effort level, the processing rate per task of the case managers will not be as high as it was in the case of functional specialists. In addition, their skills are not broad enough for them to handle all the jobs that come to them; they need the intervention of an expert for the more difficult jobs. Typically, these problems are partially alleviated by using two types of information systems: *speed enhancing systems* (decentralized information access systems like regular client-server systems or intranets[3], and productivity tools) and *skill expanding systems* (expert systems and knowledge management systems). The level of technology in each of these types of systems is represented by θ_1 and θ_2 respectively.

These two effects – loss in productivity and skill reduction – are modeled separately. The parameter α represents the drop in processing rate per task when tasks are consolidated. α depends on α_0 (the reduction in productivity when there is no new IS support, representative of the *knowledge intensity* of the tasks), and *t,* the rate of returns from information technology. The explicit functional form of a assumed is $\alpha = 1 - \alpha_0 e^{-t\theta_1^2}$. The second parameter β represents the exception rate of the process, i.e. the percentage of arrivals diverted to an expert due to inadequate worker knowledge about all tasks. β depends on β_0 (the exception rate when there is no IS support), and θ_2. The functional form of β is $\beta(\theta_2) = \beta_0 e^{-t\theta_2^2}$. t is an absolute measures of the returns per dollar due to increased technology levels. θ_1 and θ_2 are representative of technology spending.

Since the workers are processing *n* tasks per job, their processing rate is also factored down by $1/n$. Hence, at an effort level ω^i, the processing rate per job of the generalist will be $\alpha\mu_i/n$. In addition, the workers need to examine job requirements, specific information pertaining to a particular customer as well. However, they need to do this *exactly once*, and this results in a delay of σ. The processing time distribution at each server is therefore a shifted exponential distribution with parameters $\alpha\mu_i/n$ and σ.

There is only one information asymmetry situation; partial asymmetry. The principal can observe the cycle time of each agent, and therefore contracts with them individually. The cost per job to the agent is the sum of the costs of the *n* individual tasks[4], and is therefore nc_i at an effort level ω^i. To facilitate comparison between the systems, the expert is assumed to be external to the agency conflict. Normally, the expert is a person who is employed for the purpose of doing other value-adding work. Exception rerouting to this expert costs the firm at a rate equal to the value of her time. A clean way to model this scenario is to assume that the principal does this work; it is done at a rate μ_E, and at a personal cost proportional to the cycle time of the tasks. Since the information relating to the specific job instance has to be transferred to the expert every time a job is sent, the expert is delayed by σ per job, and has a resulting processing time which has a shifted exponential distribution with parameters σ and μ_E. The personal cost (due to spending time that could have been spent on other value-adding work) is measured at a rate c_E per unit time, and is over and above the delay cost borne by the firm.

The additional notation introduced is summarized below.

α	Reduction in the agent's processing rate due to loss of specialization.
β	Percentage of jobs rerouted to an expert.
α_0	Reduction in the agent's processing rate in the absence of supporting IS.
β_0	Exception rate in the absence of supporting IS.
t	Returns to information technology.
c_E	Additional cost per unit time of the jobs rerouted to the expert.
μ_E	Processing rate of the expert.
θ_1, θ_2	Spending on information systems for speed enhancing and skill expanding

The following proposition characterizes performance in the process-oriented organization:

Proposition 3

The optimal incentive contract (a,b) offered to all the case managers is

$$a = \mathrm{n}c_H + \frac{1}{\eta}\left(\log\frac{-1}{U_n} + \log\frac{\eta b(n\alpha\mu_H - n\lambda - \lambda\alpha\mu_H\sigma)}{e^{\eta b\sigma}(n\eta b + \alpha\mu_H)(n\eta b - \lambda) + \lambda\mu_H}\right),$$

$$\frac{(n\alpha\mu_L - n\lambda - \lambda\alpha\mu_L\sigma)e^{nc_L\eta}}{e^{\eta b\sigma}(n\eta \mathrm{b} + \alpha\mu_L)(n\eta \mathrm{b} - \lambda) + \lambda\mu_L} = \frac{(n\alpha\mu_H - n\lambda - \lambda\alpha\mu_H\sigma)e^{c_H\eta}}{e^{\eta \mathrm{b}\sigma}(n\eta \mathrm{b} + \alpha\mu_H)(n\eta \mathrm{b} - \lambda) + \lambda\mu_H}.$$

Proof: The processing rate at each case manager is $\alpha\mu_i/n$ and the arrival rate is λ/n. Analysis similar to that in Lemma 2 yields the Laplace transform of the system time at each case manager as:

$$G^*_P[s;\omega^i] = \frac{s(n\alpha\mu_i - n\lambda - \lambda\alpha\mu_i\sigma)}{(ns+\alpha\mu_i)(ns-\lambda)e^{s\sigma}+\lambda\mu_i}.$$

By Corollary 3.2.1, the optimal contract *(a,b)* must solve

$$\begin{gathered} -e^{-\eta[a-nc_H]}G_P{}^*[\eta b;\omega^H] = -e^{-\eta[a-nc_L]}G_P{}^*[\eta b;\omega^H], \\ -e^{-\eta[a-nc_H]}G_P{}^*[\eta b;\omega^H] = U_n. \end{gathered}$$

This is very similar in form to Condition 1 of Proposition 1 under partial asymmetry. The expression for b that results is

$$-e^{\eta nc_H}\, G^*_P[\eta b;\omega^H] = -e^{\eta nc_L}\, G^*_P[\eta b;\omega^L].$$

Similarly, solving the second equation for a yields

$$a = nc_H + \frac{1}{\eta}log(\frac{-1}{U_n}) + \frac{1}{\eta}log(G^*_P[\eta b;\omega^H]).$$

Substituting the expression for $G^*_P(.)$ in these two equations yields the desired result. *QED*

Proposition 4

The cost per job to the principal is

$$C(\mu_L,\mu_H,\mu_E,\lambda,\alpha,\beta) = \min\left\{\begin{array}{l} \left(\begin{array}{r} c_D[T_s(\frac{\alpha\mu_H}{n},\frac{\lambda}{n}) + \beta T_s(\beta\mu_E,\lambda)] + c_E\beta T_s(\beta\mu_E,\lambda) \\ + a + bT_s(\frac{\alpha\mu_H}{n},\frac{\lambda}{n}) \end{array}\right), \\ \left(\begin{array}{r} c_D[T_s(\frac{\alpha\mu_L}{n},\frac{\lambda}{n}) + \beta T_s(\beta\mu_E,\lambda)] + c_E\beta T_s(\beta\mu_E,\lambda) \\ + nc_L + \frac{1}{\eta}\log\frac{-1}{U_n} \end{array}\right) \end{array}\right\}.$$

Proof: If the principal does not adopt an incentive compensation scheme, she must pay the agents the wage that ensures their reservation utility. Let this wage be *w*. It follows that

$$-e^{-\eta(w-nc_L)}=U_n \Rightarrow w=nc_L+\frac{1}{\eta}\log(\frac{-1}{U_n}).$$

The expected cycle time is the expected time spent by the agent plus the expected time spent by the expert per job. This is simply

$$T_s(\frac{\alpha\mu_L}{n},\frac{\lambda}{n})+\beta T_s(\beta\mu_E,\lambda).$$

which follows from the definition of T_s, the arrival and processing rates of the agents and the expert, and the fact that a fraction β of the jobs are exceptions. The total non-compensation costs are therefore

$$c_D[T_s(\frac{\alpha\mu_L}{n},\frac{\lambda}{n})+\beta T_s(\beta\mu_E,\lambda)]+c_E\beta T_s(\beta\mu_E,\lambda).$$

where the third term is the cost of the expert's time per job. Adding this to the compensation cost yields the total cost without an incentive contract.

If the principal offers an incentive contract, the expected compensation costs per job are

$$a+bT_s(\frac{\alpha\mu_H}{n},\frac{\lambda}{n}).$$

The agents work at a rate $\alpha\mu_H/n$, and the arrival rate is λ/n. Analysis similar to that for the previous case yields the total non-compensation costs:

$$c_D[T_s(\frac{\alpha\mu_H}{n},\frac{\lambda}{n})+\beta T_s(\beta\mu_E,\lambda)]+c_E\beta T_s(\beta\mu_E,\lambda).$$

Computing total costs in each case, and recalling that the principal minimizes total costs yields the desired result. *QED.*

6. Analysis

The analytical results obtained in the previous section do not allow for significant comparative static analysis, as they are very complicated, and their first derivatives are not intuitively appealing. Hence, we have conducted extensive numerical optimization using these closed-form expressions as a starting point.

To examine *simultaneous* changes in different organizational parameters, two-dimensional projections of the parameter space are plotted. As these parameters vary, the regions in which different combinations of information systems, compensation schemes and work design are optimal are examined, and the points of *transition* from one optimal design to another are plotted. This provides a very intuitive graphical picture of how changes in parameter values affected design choices.

Without loss of generality, and for notational simplicity, we normalize the value of μ_L to 1 and μ_H to h. We also restrict the value of σ to lie in [0,1] and interpret this value as the handoff delay measured as a fraction of the expected processing time, $1/\mu_L$. While σ may actually be greater than 1, that interval is uninteresting, as it corresponds to situations with unduly large handoff delays, resulting in a clear case for process-oriented organization. λ is restricted to the interval $(0, 1/(1+\sigma))$ to ensure that queuing delays are finite under both the absence and presence of incentive compensation. We further normalize c_L to 1 (this is reasonable, since it simply represents a change in currency units, which can be accounted for by adjusting η) and assume that the cost of effort is linear in the effort; i.e., $c_H=h$. h can be interpreted as a measure of the difficulty of the task. Normalizing $\log[-1/U_0]$ to zero is equivalent to an identical linear shift in the expected cost under any process design. This leaves the results unaltered, since a cost of $\log[-1/U_0]$ is borne per employee irrespective of the nature of the organization design, and one is *contrasting* different organization designs. We then determine a level of information technology for the process-oriented organization, and solve for the optimal value of b for both the functional and process-oriented organizations respectively, given a certain set of parameter values. Next, the values of *a* and the cost functions for each work system are derivable. These figures are compared within each work system to derive the optimal level of θ_1 and θ_2. These optimal cost figures are compared across organization designs, and one of the four choices — (functional/process oriented, fixed/incentive compensation) is chosen. Varying the parameters two at a time enables us to plot *indifference cones* — lines that divided the 2X2 parameter space into regions where respective designs are optimal (this is done by seeing where they become equivalent — these sucessive points of equivalence define an indifference line).

A few of these *indifference charts* are shown in Figures 3 and 4, and focus on the five parameters which we found to be the most significant determinants of organization design choice. Figure 3(a) and 3(b) illustrate the effects of level of customization (σ), the work intensity (λ/μ_L) and the returns to I.T. (t) on the optimal choice of organization. As shown, an increase in either the level of *customization* or the *work intensity* causes *process-oriented* organization to become optimal. However, this effect is *much more pronounced* when the returns to information technology t increase, as shown by a much larger area of optimality for process-oriented organization in Figure 3(b). Figures 3(c) and 3(d) plot similar results while varying the knowledge intensity (α and β)[5] , the work intensity (λ/μ_L) and the returns to I.T. (t). Note that an increase in *knowledge intensity* (represented by a decrease in α) results in *functional* organization being more desirable. Again, this effect is compounded by the increase in returns to I.T.

A very interesting result here is the relationship between *information technology* and *performance-based incentives.* As illustrated by Figure 3(a) and 3(c), when returns from I.T. are low, process oriented organization is often accompanied by incentive pay. The corresponding values of θ_1 and θ_2 (derived as described earlier) are low, corresponding to a *low level of I.T. investment*. These values of θ_1 and θ_2 increase significantly when the returns from I.T. are high

– there is a higher investment level in technology --- but this is accompanied by the *elimination of incentive pay* in process-oriented organizations, as shown in Figures 3(b) and 3(d). Therefore, *information technology and incentives appear to be* ***substitutes*** *in a process-based organization.* We discuss this further in §7.

Figure 4 strengthens the conclusions that higher customization and activity rates favor process-oriented organization, while higher knowledge intensity favors functional organization (note that this trend is illustrated in all four charts). In addition, surprisingly, at the same level of work intensity and customization/knowledge intensity, an *increase* in the *number of tasks* results in *process-oriented organization* being optimal in a larger number of cases. This counters the intuition that functional specialization is favored when there are a larger number of tasks in a job. The result is driven by the fact that longer 'chains' of tasks are affected more by handoffs. These charts illustrate the case of partial asymmetry – complete asymmetry would strengthen this result further (as discussed in corollary 1)

Our analysis yielded another significant result, which is also evident from a closer examination of Figure 3 and 4. Both *incentives* and *information technology complement* the move to process-based organization. The former can be seen clearly in figures 3(a), 3(c), and 4(a)-(d), where a majority of the area where process-based organization is favorable also features incentives as a part of the optimum. The latter follows from our result that when incentives don't feature (such as in 3.b. and 3.d.), information technology levels are high. As mentioned earlier, these two are almost mutually exclusive, suggesting a strong substitutability between technology investments and performance-based incentives.

7. Discussion and Managerial Insights

Perhaps the most significant result of our analysis is that *typical changes in work organization, incentive compensation and information systems do not always appear to be complementary.* In fact, in a very large number of cases, while the adoption of *process-oriented organization* and *information technology* appear to complement one another, as do the adoption of process-oriented organization and *performance-based incentives*, information systems and performance-based incentives appear to be *substitutable drivers* of process performance improvement. Most prescriptive essays on I.T. enabled design in service organizations (e.g. Hammer and Champy, 1993) consistently recommend *simultaneously* adopting a process orientation, introducing output based pay and using advanced information technology to enhance skills and productivity. However, as our results indicate, this approach is frequently not optimal, and that choosing on two out of the three is typically the best solution. While this does not constitute a formal proof of complementarity/substitutability, it is a testable hypothesis that our modeling results strongly support. .

Although this result seems very counter-intuitive, we can explain why it arises. There is a *fixed* cost of sorts to switching to performance-based incentives; it is not a continuous variable cost (you either have them, or you don't). If the returns from information technology are low, it is optimal to bear this cost, as its benefits are more cost-effective when compared to introducing advanced information technology. As the returns to technology increase, this option becomes relatively less favorable, until a breakpoint is reached, where it becomes sub-optimal to bear this cost. Now, given that one is not introducing incentives, the desirability of technology-based performance enhancers increases significantly; hence the optimal process design is characterized by high levels of information technology.

Another salient result is our demonstration of the *optimality* of *functional organization* in a number of situations. The reengineering revolution of the early 1990's has resulted in the almost absolute rejection of the value of functional specialization. However, it can be ideal in a number of situations; specifically, when work is knowledge intensive, when jobs have few tasks, and when work intensity is naturally low. Following the widespread move to process-based organization, many companies are currently wrestling with the problem of managing their knowledge, and are consequently implementing expensive *knowledge management information systems*. However, functional organization provides a natural environment for managing functional knowledge – an insight that could help many of these companies in their efforts in this direction.

A summary our the managerial insights from our models is presented below:

- Process-oriented organization is desirable when the typical job in the firm has a large number of sub-parts, when the firm's customers demand increased customization, and when there is significant information asymmetry between workers and management.
- Functional organization is desirable when jobs are knowledge intensive, when there are low returns from information technology, if seasonal variation requires low activity rates and when the typical process in the firm has few sub-parts.
- Performance based incentives are optimal in a process-oriented organization when jobs have a large number of parts , and the constituent tasks require lower specialization. They tend to be sub-optimal when returns from technology are higher. Also, as mentioned earlier, they tend to complement job redesign.

- In functional organizations, technology such as workflow systems which track where a job is at any given time have benefits beyond job control and co-ordination – the also significantly increase the cost-effectiveness of performance-based incentive compensation.

8. Conclusion and Future Research

This paper represents is the first comprehensive study of the trade-offs between specialized and process oriented forms of organization. It approaches an essentially interdisciplinary problem from an interdisciplinary perspective. In the light of the complementarity results that have been obtained, it is unlikely that subsequent single-dimensional models will have much predictive value. Towards this end, results like Lemma 1 contributes techniques that will aid future interdisciplinary research in information technology and organizational design.

The analysis of models that simultaneously incorporate queuing and agency theory can be extremely complicated. Some of the difficulty is overcome by using transform techniques and numerical methods; however, the tradeoff between realistic models and mathematical tractability is bound to cause difficulty. However, they still have immense potential as strategic guidelines. We have informally validated some of the results by case-based testing at a couple of Fortune 100 companies, and are working on testing them empirically.

Most importantly, our results finally gives managers concrete guidelines for organization design that are context specific. Instead of broad suggestions from popular books, process owners will have results that are applicable to their specific needs. Hopefully, we have provided the first building block of a comprehensive normative theory of IT-enabled organization design and implementation.

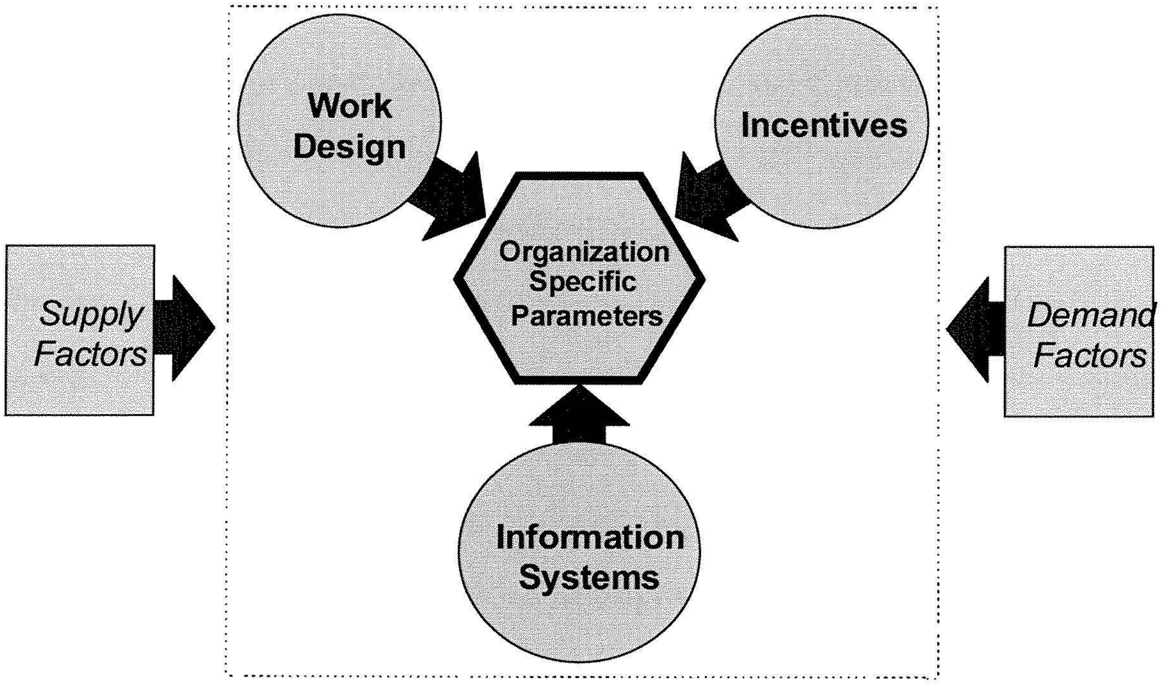


Figure 1 Modeling framework

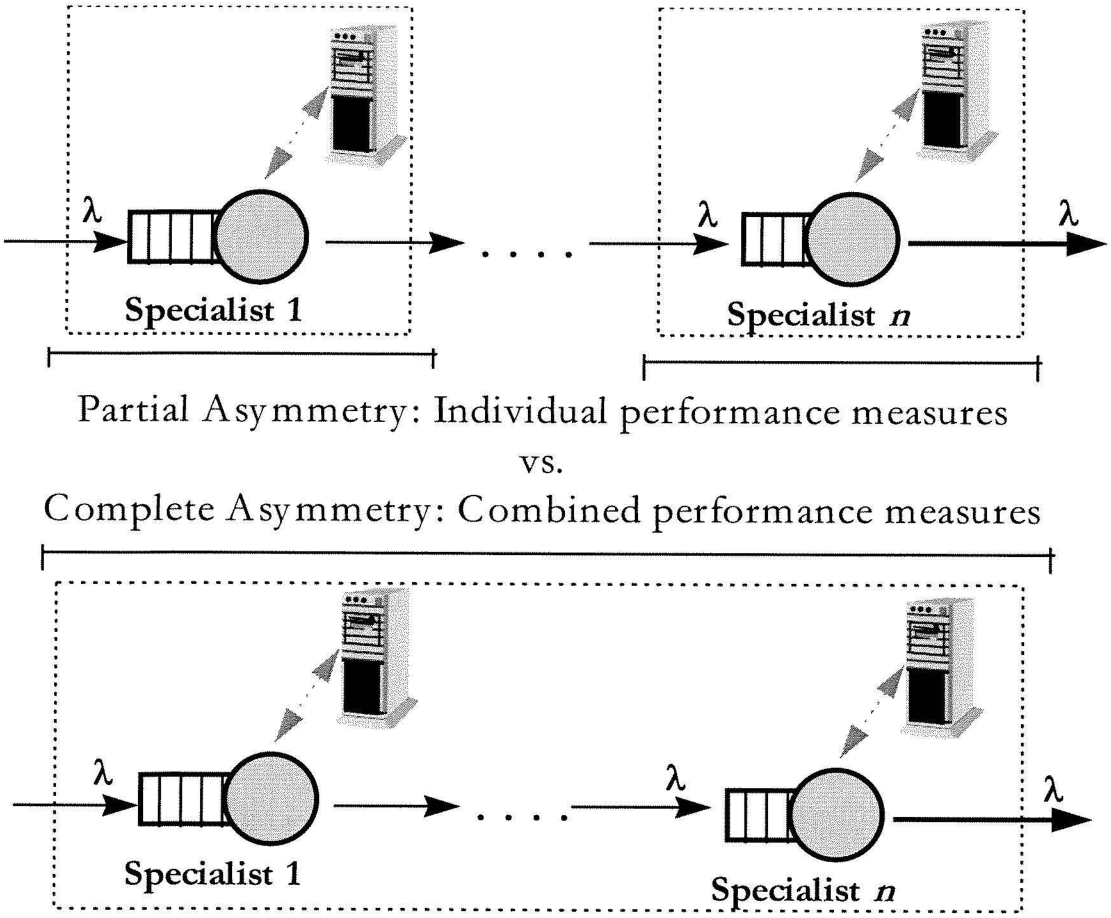
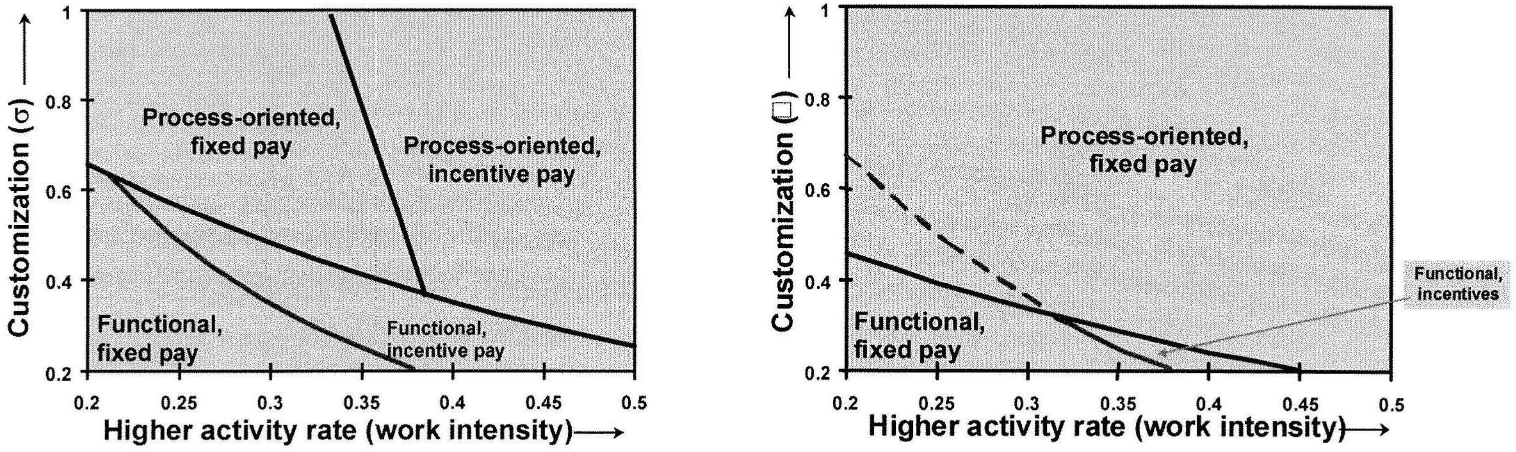
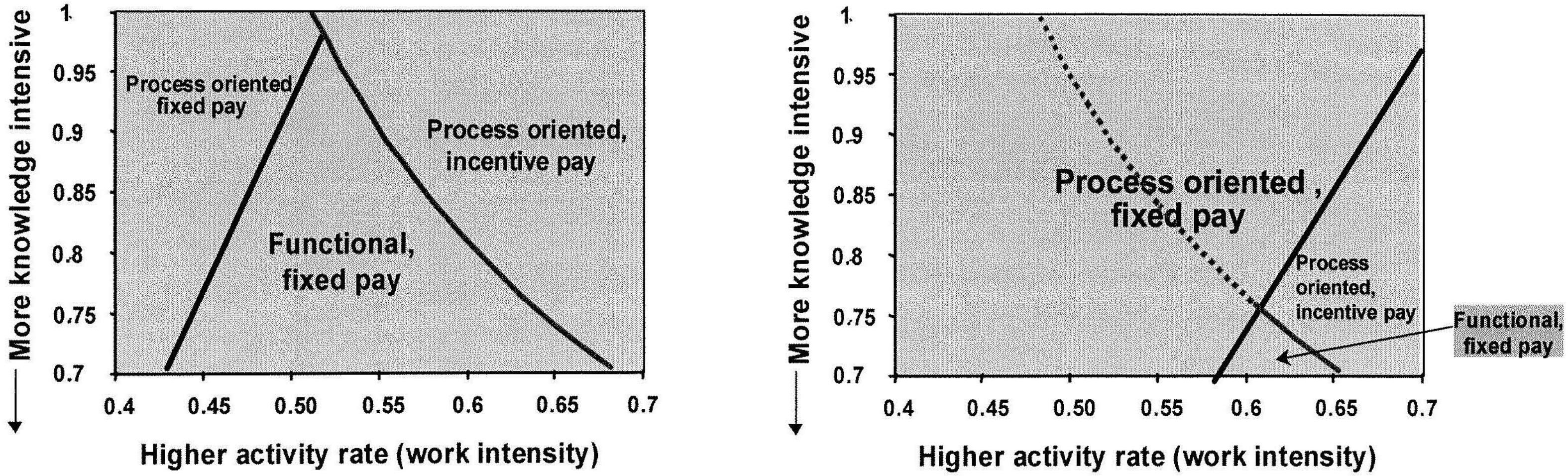


Figure 2: Work design and information asymmetry in functional/process oriented organizations



3(a) When the returns to information technology are low

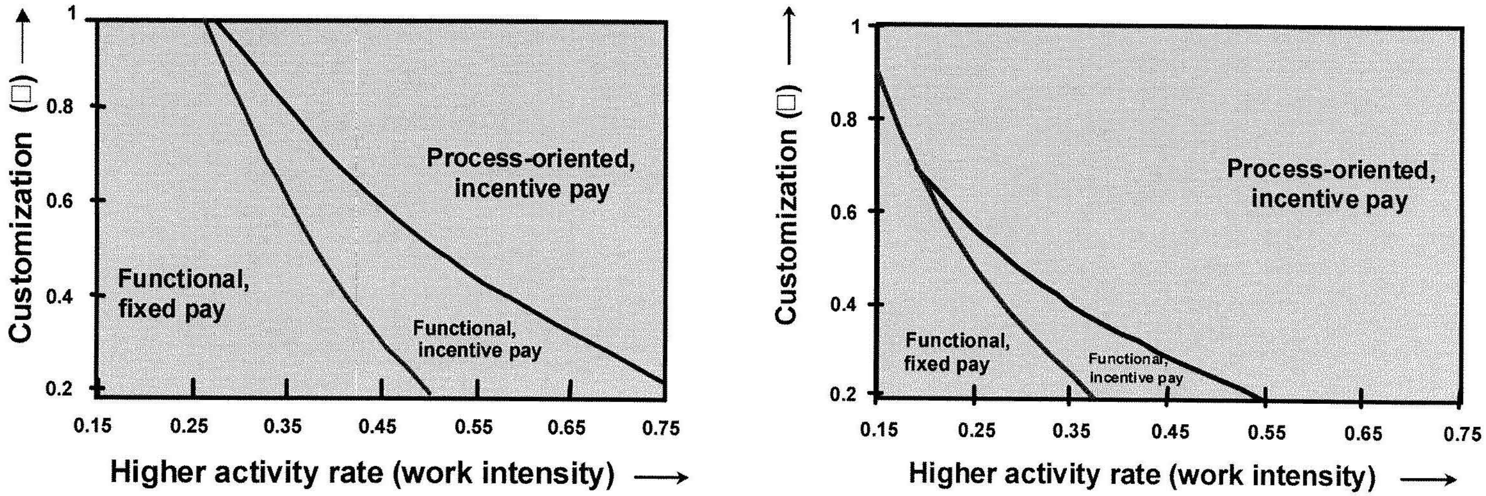
3(b) When the returns to information technology are high



3(c) When the returns to information technology are low

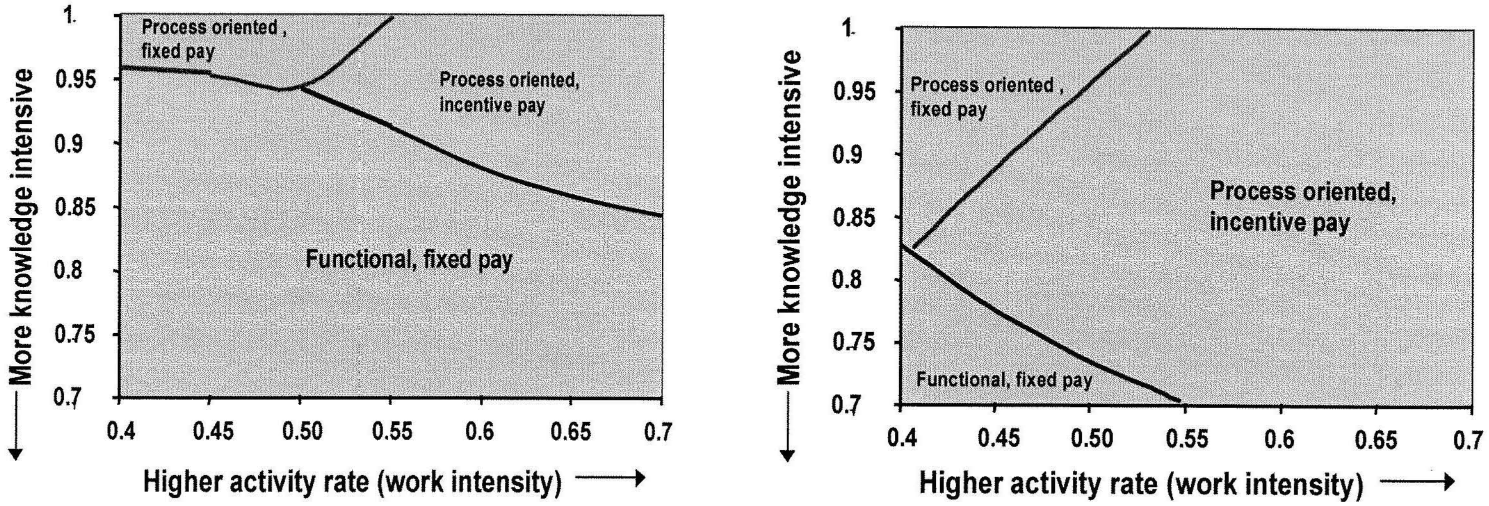
3(d) When the returns to information technology are high

Figure 3: Optimal organization – work intensity, knowledge intensity, customization and returns to I.T.



4(a) When the number of tasks is low

4(b) When the number of tasks is high



4(c) When the number of tasks is low

4(d) When the number of tasks is high

Figure 4: Optimal organization – work intensity, knowledge intensity, customization and # of tasks

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[1] Hammer and Champy (1993) define a process as a *related group of tasks that together create value for the customer.* Davenport (1993) defines a process as *a specific ordering of work activities, with a beginning, an end, and clearly identified inputs and outputs: a structure for action.* We model processes in organizations in the spirit of these definitions.

[2] Unfortunately, the departure process of an M/G/1 queue is not Poisson. However, we are not explicitly modeling a specific physical system here; we are modeling cycle time at each processing station as the sojourn time of a widely used queue.

[3] The barriers to information access are modeled as reducing the effective rate at which the tasks are processed; hence information access systems here have the effect of increasing processing rates.

[4] It is easy to be misled into thinking that this is equivalent to assuming a linear cost structure. However, this is not the case. The convex nature of the cost of effort is based on the amount of work done in a fixed time period, and the personal cost increases at an increasing rate in the amount of work an agent does *in a working day*. In this case, the agent does the same volume of work in a given time period – instead of doing n instances of the same task, she does n potentially different tasks. Hence the cost of doing these n tasks remains the same. There may be a cost associated with switching between tasks; this can be assumed to balance the reduction in cost due to lowering of monotony.

[5] While both α and β are inverse measures of knowledge intensity, the results obtained from varying β were highly sensitive to the processing rate of the expert μ_E. (an increase in β causes both μ and λ to reduce by a factor of $(1-\beta)$, which does not change agent activity rates). We can therefore conclude that a slow expert causes functional organization to be optimal and vice versa. The more interesting parameter was α, and hence the graphs plot variations in α for a fixed β.