Communications in Hierarchical Organizations and Standards Policies for Information Technology

by

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ABSTRACT: Corporate information systems standards are commonly used to coordinate key infrastructure decisions and to ensure compatibility across the increasing number of technology platforms that most businesses have to deal with today. In this paper, we investigate the economic merit of adopting a *delegated, mandated,* or *single technology standard* policy for interuser communication in a hierarchical organization. We show that a centrally mandated policy will always produce the "first best" results in terms of the net organizational benefits and that the voluntary choices made by managers and subordinates tend to converge as the span of control increases. On the other hand, the relative value of a delegated versus a mandated policy tends to be a unimodal function of the span of control. The most salient conclusion of our research is that there is a strong interaction between the choice of the optimal information systems standards and organizational architecture parameters such as the span of control, the direction of communication, the overall volume of communication, and the number of levels in the hierarchy. Contrary to the basic intuition, we also find that, as organizations become more decentralized and the span of control increases, the relative advantage of mandating a standard as a means of facilitating communication rapidly diminishes.

KEY WORDS AND PHRASES: electronic communication, hierarchical coordination, standardization.

> To contain costs and keep a handle on the "mishmash" of technologies thrown at them, information systems executives must standardize and force end users to adapt.
>
> —Colin Crook, Senior Technology Officer, Citicorp, New York (*ComputerWorld*, April 29, 1996)

The desirability of common business information has been taken for granted for many years. Consequently, modern management information systems are designed to link the diverse platforms that exist in organizations. In such information systems, the selection of appropriate technology standards facilitates communications, both vertically and horizontally. Vertical communication, the reporting of performance and status information to headquarters from the field, is critically dependent on the consistent flow of data from compatible platforms. Most organizations select certain technology standards by design or by default, and these choices affect the degree of incompatibility across the organization. The use of standards, a set of specifications to which every developer or purchaser of a system must adhere, reduces the cost of information systems and facilitates computer networking. They create value

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which is concave in x_m, so the first-order conditions will be necessary and This is an internal solution, as p_m and p_w are internal by assumption. sufficient for optimality provided that the solution is internal. The same is true for the subordinate. Taking the derivative of the manager's net benefit with respect to x_m and the derivative of subordinate's net benefit with respect to x_w, setting to zero and solving simultaneously for x_m and x_w, we get

$$x_m = \frac{1+v_w}{1+v_w+kv_m}p_m + \frac{kv_m}{1+v_w+kv_m}p_w$$

$$x_w = \frac{v_w}{1+v_w+kv_m}p_m + \frac{1+kv_m}{1+v_w+kv_m}p_w$$

Theorem 2: In a two-level hierarchy of a manager and k subordinates, the mandated choices for the manager and the subordinate, using the same notation as above, are:

Manager's choice:

$$\frac{1+v_m+v_w}{1+v_m+v_w+kv_m+kv_w}p_m + \frac{k(v_m+v_w)}{1+v_m+v_w+kv_m+kv_w}p_w$$

Subordinate's choice:

$$\frac{v_m+v_w}{1+v_m+v_w+kv_m+kv_w}p_m + \frac{1+k(v_m+v_w)}{1+v_m+v_w+kv_m+kv_w}p_w$$

Proof: We again use the first-order conditions. We take the derivatives of the organization's net benefit with respect to x_m and x_w and set them to zero to obtain two simultaneous equations. These are solved for the optimal choices and inspection shows that these are internal. All that remains is to show that the second-order conditions are satisfied.

To examine the second-order conditions, we compute the eigenvalues of the Hessian matrix of the organization's net benefit. The Hessian matrix is:

$$\begin{matrix} -2-2kv_m-2kv_w & 2kv_m+2kv_w \\ 2kv_m+2kv_w & -2k-2kv_m-2kv_w \end{matrix}$$

The two eigenvalues are

$$-(1+k)-2k(v_m+v_w) \pm \sqrt{(1-k)^2+4k^2(v_m+v_w)^2}$$

and they are both negative for all $k \geq 1$. Consequently, the organizational net benefit is strictly concave in x_m and x_w. The first order conditions with internal solutions are therefore necessary and sufficient.

14. Gordon, S. Standardization of information systems and technology at multinational companies. *Journal of Global Information Management, 1,* 4 (1993), 5–14.
15. Greenstein, S.M. Invisible hands and visible advisors: An economic interpretation of standardization. *Journal of American Society for Information Science, 43,* 8 (1992), 538–549.
16. Gurbaxani, V., and Whang, S. The impact of information systems on organizations and markets. *Communications of the ACM, 34,* 1 (1991), 59–73.
17. Huber, G.P. A theory of the effects of advanced information technologies on organizational design, intelligence and decision making. *Academy of Management Review, 15,* 1 (1990), 47–71.
18. Markus, L., and Robey, D. Information technology and organizational change. *Management Science, 34,* 5 (1988), 583–598.
19. Myerson, R. *Game Theory, Analysis of Conflict.* Cambridge, MA: Harvard University Press, 1991.
20. Pfeffer, J., and Leblebici, H. Information technology and organizational structure. *Pacific Sociological Review, 20,* 2 (1977), 241–261
21. Radner, R. Hierarchy: The economics of managing. *Journal of Economic Literature, 30* (September 1992), 1382–1415.
22. Urwick, L.F. The manager's span of control. *Harvard Business Review,* 34 (1956), 39–47.
23. Williamson, O.E. Hierarchical control and optimum firm size. *Journal of Political Economy, 75,* 2 (1967), 123–138.

Appendix

Theorem 1: In a two-level hierarchy with a delegated system choice policy, the manager with a preference for system p_m and k subordinates with a preference for system p_w pick the following systems:

$$\textit{Manager's choice: } \frac{1+v_w}{1+v_w+kv_m}p_m + \frac{kv_m}{1+v_w+kv_m}p_w$$

$$\textit{Subordinate's choice: } \frac{v_w}{1+v_w+kv_m}p_m + \frac{1+kv_m}{1+v_w+kv_m}p_w$$

where v_m and v_w are the volume of communication received by the manager from each subordinate and the volume received by each of the subordinates from the manager, respectively.

Proof: In the delegated system, the manager and each subordinate pick systems to maximize just their own net benefit. First consider the manager. The manager's net benefit is

$$b-((x_m-p_m)^2+kv_m(x_m-x_w)^2),$$

and setting standard policies. The recommendations detailed above identify the conditions for which the different standards policies (mandated, delegated, or single common system) are best from an overall organizational standpoint.

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REFERENCES

1. Aach, J.D. So you want to have corporate standards? *Journal of Systems Management, 15,* 8 (1994), 28–31.
2. Aoki, M. Horizontal and vertical information structure of the firm. *American Economic Review, 26* (1986), 971–983.
3. Banker, R.D.; Datar, S.M.; Kemerer, C.F.; and Zweig, D. Software complexity and maintenance costs. *Communications of the ACM, 36,* 11 (1993), 81–94.
4. Bensen, S.M., and Saloner, G. Compatibility standards and the market for telecommunication services. In T.J. Allen and M.S. Scott Morton (eds.), *Information Technology and the Corporation of the 1990s.* Oxford: Oxford University Press, 1994.
5. Bolton, P., and Dewatripoint, M. The firm as a communication network. *Quarterly Journal of Economics, 109* (November 1994), 810–839.
6. Brickley, J.A.; Smith, C.W.; and Zimmerman, J.L. *Organizational Architecture: A Managerial Economics Approach.* Burr Ridge, IL: Irwin, Times-Mirror Higher Education Group, Inc., 1996.
7. Brynjolfsson, E., et al. Does information technology lead to smaller firms? *Management Science, 40,* 12 (1994), 1628–1644.
8. Clemons, E.K.; Reddi, S.P.; and Row, M.C. The impact of information technology on the organization of economic activity: The "move to the middle" hypothesis. *Journal of Management Information Systems, 10,* 2 (1993), 9–35.
9. Cremer, J. A partial theory of the optimal organization of bureaucracy. *Bell Journal of Economics, 11* (1980), 683–693.
10. David, P.A., and Greenstein, S. The economics of compatibility standards: an introduction to recent research. *Economics of Innovation and New Technology, 1* (1990), 3–41.
11. Dewan, R.; Seidmann, A.; and Sundaresan, S. Strategic choices in IS infrastructure: corporate standards vs. best of breed systems. *Proceedings of ICIS 95,* Amsterdam, 1995.
12. Farrell, J., and Saloner, G. Standardization, compatibility, and innovation. *Rand Journal of Economics, 16* (1985), 70–83.
13. Geanakoplos, J., and Milgrom, P. A theory of hierarchies based on limited managerial attention. *Journal of the Japanese and International Economies, 5* (1991), 205–225.

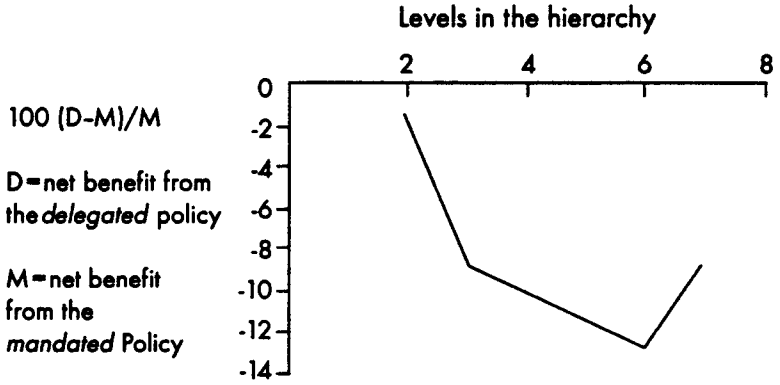

Figure 8. The Impact of the Number of Levels in the Hierarchy on the Desirability of Delegated or Mandated Policies

from mandated policies for either very small or large spans of control.

3. As the span of control increases, the managers and their subordinates voluntarily converge towards similar information systems. The observed change in system preferences is much more pronounced for the manager.
4. The optimal single standard is a convex combination of the optimal system choices centrally mandated for the manager and the subordinates. This is not the case when the choices are delegated to the users.
5. The relative advantage of mandating a standard decreases as the intensity of information exchange between managers and subordinates increases.
6. A delegated policy could be superior to dictating a single standard for all users when the span of control is small. Beyond a certain threshold, a single standard policy could again be superior. This threshold is a function of the volume of communication and relative cost factors.
7. The advantage of mandating a standard peaks for an intermediate number of levels in the hierarchy.

The evidence is clear that changes in the structure of hierarchical organizations have a profound impact on the relative advantage of the different standards policy options for management of information systems. General managers responsible for making policy choices affecting several departments will find that our results can be useful in dealing with technology choices

optimal and the difference in the range between mandated and delegated policy choices decreases. The incompatibility cost between the users is therefore decreased, but, on the other hand, the number of interactions has increased. The balance between these two effects determines the value of mandating a standard.

As modern organizations flatten their hierarchies, the value of mandating a standard varies in a non-monotonic manner. Eliminating the intermediate layers will increase the differences in tasks and information requirements between adjacent levels, thereby increasing the potential incompatibility. At the same time, reducing the number of levels decreases the total amount of interlevel communications, which in turn reduces the potential incompatibility cost for the organization as a whole. The net managerial effect depends on the sum of these two competing forces and on the starting point of the organization. Flattening the organization structure does not necessarily mean that information systems choices should be decentralized.

Conclusions

Given the observed increase in overall IT expenditure, the current trend of cross-functional integration arising from corporate reengineering, and the increased variety of sophisticated and powerful hardware and software systems, managers are looking for ways to analyze the implications of corporate technological policy choices systematically. This paper integrates the growing body of research on the business aspects of standardization and provides a framework for determining the key tradeoffs involved in the adoption and development of IT products for intra-networking in hierarchical organizations.

The benefits of standards depend on the organizational structure; we identify the types of hierarchies that benefit more from mandated standards than others. We also show how the span of control and the number of levels in the hierarchy influence the value of standards. Organizations that have a greater imbalance of information flows between individuals benefit more from standards policies. Moreover, those portions of the hierarchy that have very small or very large spans of control may be left to their own devices to pick information systems. A similar effect is observed with very small or very high numbers of levels. In contrast, those units that do not fall in the above classifications deserve a closer examination and active intervention to mandate IS standards.

Our research models and analysis provide the following key insights:

1. A centrally mandated policy will always produce the "first best" results in terms of the organizational net benefit. In practice, however, implementing this policy requires that users divulge the true cost and benefits of the different information systems presented to them. Hence, the mandated policy is impractical in most organizations.
2. The value of delegating the system choices is a unimodal function of the span of control. Delegated policies come closer to the benefit

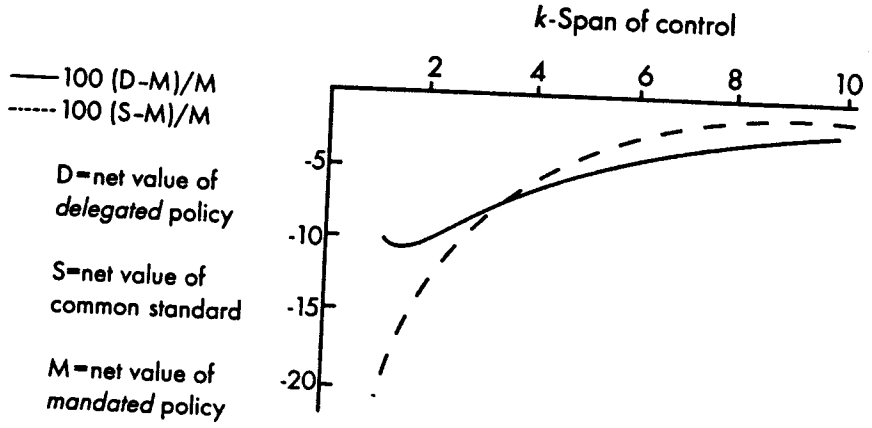

Figure 7. Percentage Difference in Organizational Net Benefit from a Common Standard and the Delegated Policies

sues, and work with more external competitive data. These striking differences in decision modes and information need result in different preferences for systems. The middle-level preferences are assumed to lie between these two. As the number of levels increases, in our analysis, we assume that the top and bottom levels retain their original job descriptions and information system preferences. Adding a few more levels in between these two extremes reduces the difference in decision modes and information needs between any two adjacent levels. As a new level is added, the immediate superior is interacting with a person whose preferences are closer than that of the subordinate before the level increased. The effect is similar for the immediate subordinates as well.

Figure 8 plots the difference in value of mandating and delegating the system choice as a function of the number of levels in a linear organization—a hierarchy with a span of control of one. Initially, the relative advantage of mandating a standard increases with the number of levels. Beyond a certain point, however, this relative value decreases with the increase in the number of levels. This unimodal behavior arises from two competing effects: First, the amount of communication increases as the number of levels increases, which increases the value of mandating a standard. Yet, a reduction in disparity in information processing between adjacent levels in the hierarchy reduces the relative advantage of mandating a standard.

This is not surprising, because more heterogeneous users are introduced with each new level, and the externality effects dominate. As the level increases further, the value of standards drops off, because when there are many heterogeneous users with limited communication, even the mandated solution favors the use of different systems. Hence, the difference between the delegated and mandated choices is not great. The range in system choices tends to remain fairly large, indicating that the use of disparate systems is

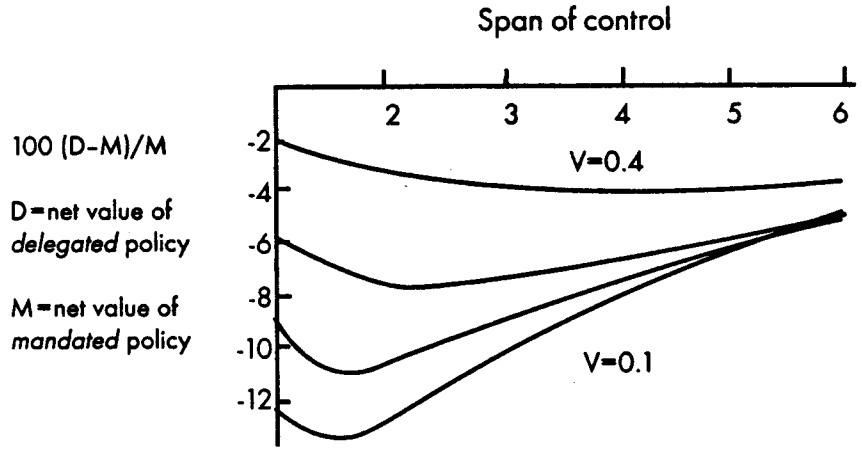

Figure 6. Percentage Change in Organizational Net Benefits due to the Impact of Changes in Communication Volume ($v = v_m$ from 0.1 to 0.4)

for smaller spans of control a delegated system is superior to a standardized single information system choice. However, as the span of control increases, a common standard becomes the most desirable policy. The organization's policy choice is described in theorem 4.

> *Theorem 4: For $v_w > v_m$, the organization prefers to require a common standard for spans of control above $1/(v_w - v_m)$ and delegate the choice to the users below that limit.*

(The proof is obtained by comparing the organization's net benefits under the two policies and is omitted here.)

Levels in the Hierarchy

Another critical design parameter for hierarchical organizations is the number of levels in the hierarchy. Increasing the number of levels may support the processing and aggregation of business information as it travels from the lower levels of the organization to the top. On the other hand, it introduces delays and increases cost [21].

In this section we explore the impact of changes in number of levels in the hierarchy on the desirability of mandated policy versus the delegated policy. It is assumed that the top-most-level and bottom-most-level users perform vastly different tasks and consequently have the maximum difference in their preferences for information systems. The users at the lower level of the hierarchy tend to deal with structured operational decisions, address short-term issues, and work with internal transaction data. The users at the highest level of the hierarchy face unstructured strategic decisions, address long-term is-

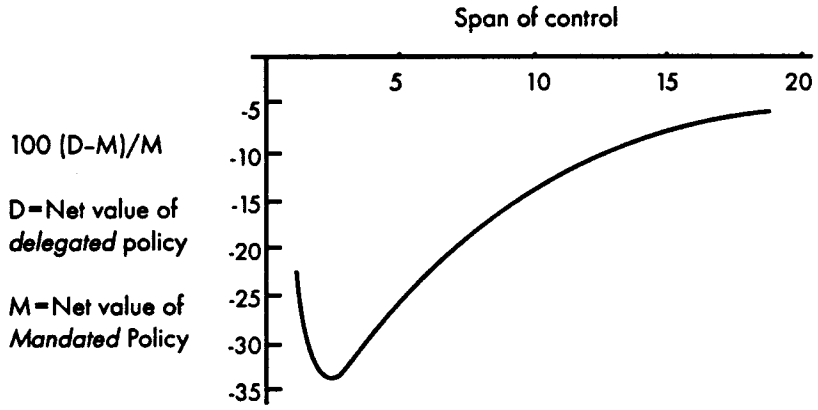

Figure 5. Percentage Difference in Net Organizational Benefits from Using Delegated or Mandated Policies (Homogeneous Users, 2-Level Hierarchy)

those made independently by the users. Voluntary standards emerge, and the relative advantage of mandating a solution decreases.

This result has significant managerial implications. Organizations with either narrow or relatively broad spans of control are likely to benefit less from mandated standards. Moreover, it indicates that changes in organizational structure, in particular span of control, have significant impact on the choice of information systems and on the policy adopted for coordinating infrastructure choices. Over the past few years, many organizations have moved toward flatter hierarchical structures with increased spans of control. At the same time, many of these organizations moved toward greater decentralization of information systems. These results explain why increased span of control is associated with more delegated or decentralized information systems.

The percentage difference between delegated and mandated policies is plotted for four different levels of communication, $v = v_m = v_w$, in figure 6. The curves corresponding to higher communications volume are higher, indicating that increasing the information flow reduces the relative difference between the policies. This occurs because the manager's incompatibility cost goes up and he shifts closer to subordinates' choice. As the intensity of information exchange increases, the relative value for mandating system choices decreases.

The delegated and common standard policies are compared in figure 7. We use the optimal net benefit in the mandated policy to normalize the graph.

The relative value of a common standard depends on the structure of the hierarchy. The relative value of both the delegated and common standard policies over the mandated policy for different spans of control is plotted in figure 7. The fact that the two curves intersect is significant; it implies that

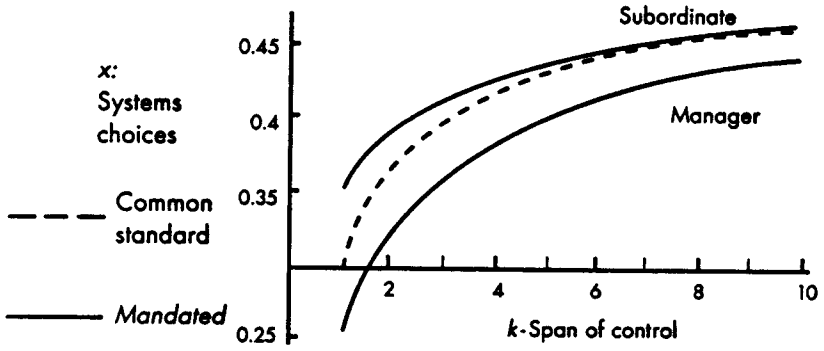

Figure 4. The Common Standard and Mandated Choices

(The proof is similar to that for Theorem 1 and is omitted here.)

The common standard is compared to the mandated choices in figure 4.

The optimal single standard mandated is a convex combination of the optimal system choices mandated centrally for the manager and the subordinate. (This is *not* the case when choices are delegated to the users.) As the span of control increases, the optimal single standard rapidly asymptotes toward the choices made by the subordinates. The balance tilts in favor of subordinates because the incompatibility costs are a linear function of the number of users.

In the following paragraphs, we further explore the difference between these two policies by examining the net value to the organization under the mandated and delegated policies. Figure 5 is a plot of the percentage difference in organizational net benefit obtained from the delegated and mandated policies as a function of the hierarchical span. For each span value, the optimal systems choices are computed and the organizational net value for these choices is determined.

As expected, the range is negative, since a centrally mandated policy provides the maximum net benefits. We see from figure 5 that the relative value of delegated standards initially decreases with the span of control because of increased incompatibility. As the span of control increases, each superior must communicate with an increased number of subordinates, and this results in a higher volume of information exchanges across the adjacent levels. It peaks for a span of four in figure 5. At that point we find that there is a mandated policy that provides a net benefit that is 32 percent greater than that obtained from the delegated policy. Beyond that point, increasing incompatibility forces all users to converge independently toward similar systems. Consequently, for larger spans of control, the relative advantage of mandating goes because a central choice of the information system tends to yield the same system as

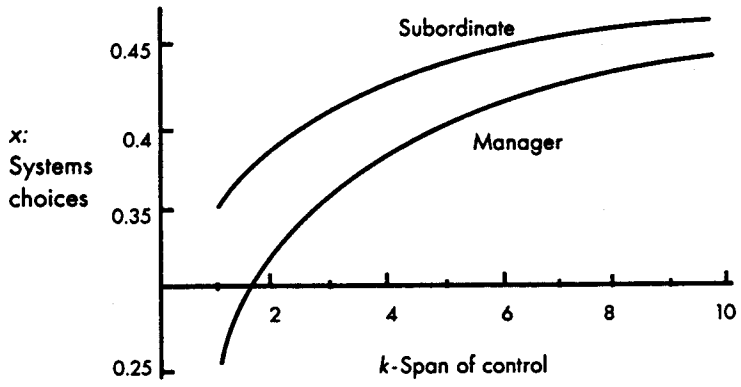

Figure 3. Systems Choices under the Mandated Policy

ume. This captures the essential difference in the two policies: choices in the delegated policy reflect each user's individual preference, whereas the choices in the mandated policy reflect that of the organization as a whole. As theorem 2 indicates, the choices tend to converge towards the subordinate's preference, for both the manager and the subordinates, as the span of control increases. This is further illustrated by figure 3.

Here we find that the initial choice made by the manager for $k = 1$ is for a system indexed at 0.25. The initial choice made by the subordinate is for a system indexed at 0.35, similar to the delegated case above. Again, we notice that, under a mandated policy, the manager and the subordinates are not necessarily required to adopt the same system. However, as the span of control increases, both constituencies are forced to converge toward more similar information systems. The overall pattern is very similar to the one discussed above for the delegated policy. Decentralized decisions and a centrally mandated policy may result in a similar pattern if the information is shared by all decision makers.

We now compare the use of a common standard with delegation of system choice in organizations with different spans of control. As was the case with the mandated standard, a senior manager or CIO picks the common standard. The key difference is that a single system is chosen for all users. Theorem 3 describes the choice.

Theorem 3: In a two-level hierarchy, using the notation and assumptions above, the common system choice is

$$\frac{p_m + k\,p_w}{1+k},$$

that is, the population-weighted average of preferences.

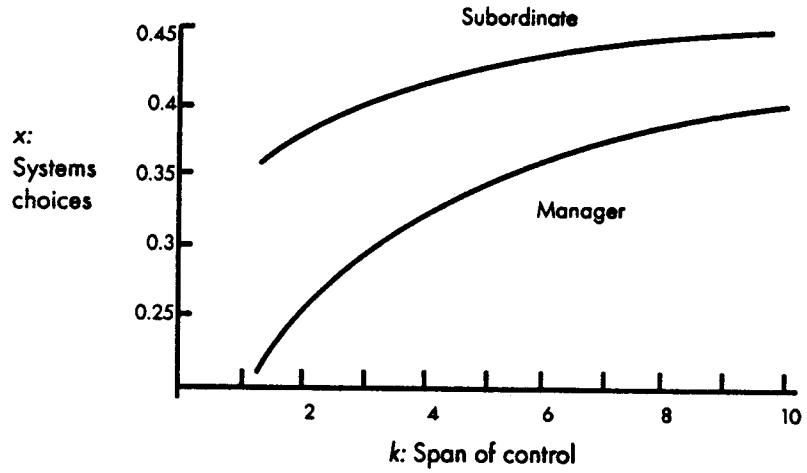

Figure 2. Systems Choices under the Delegated Policy

system preferences as a function of span of control is much more pronounced for the manager. As the number of subordinates increases, the intensity of communication received by the manager increases. Hence, the manager chooses a system closer to that of the subordinates to minimize incompatibility costs. The subordinates thus move away from their preferred system very little.

The choices made by the organization when it mandates a specific system for each user reflect the organization's net benefit rather than that of any particular individual. A manager whose interests lie in maximizing the net benefit to the shareholder could set this. Theorem 2 describes these choices.

> *Theorem 2: In a two-level hierarchy of a manager and k subordinates, the mandated choices for the manager and the subordinate, using the same notation as above, are:*
>
> *Manager's choice:*
>
> $$\frac{1+v_m+v_w}{1+v_m+v_w+kv_m+kv_w}p_m+\frac{k(v_m+v_w)}{1+v_m+v_w+kv_m+kv_w}p_w$$
>
> *Subordinate's choice:*
>
> $$\frac{v_m+v_w}{1+v_m+v_w+kv_m+kv_w}p_m+\frac{1+k(v_m+v_w)}{1+v_m+v_w+kv_m+kv_w}p_w$$

(The proof is contained in the appendix.)

It is interesting to compare the system choices in the mandated case with those in the delegated case. Once again, they are a linear combination of preferences; in this case, however, the coefficients for large enough volumes are the ratio of volumes *sent and received* and the total send-and-receive vol-

two-level hierarchy when the span of control is varied from one to ten.

We begin by examining the choices made by the users under different policies. One of the options available to the central management is to delegate the choice of the system to the user. Each user picks a system to maximize his net benefit while taking others' choices into account. The result is reflected in the following theorem.

> *Theorem 1: In a two-level hierarchy with a delegated system choice policy, the manager with a preference for system p_m and k subordinates with preference for system p_w, pick the following systems:*
>
> *Manager's choice:* $$\frac{1+v_w}{1+v_w+kv_m}p_m+\frac{kv_m}{1+v_w+kv_m}p_w$$
>
> *Subordinate's choice:* $$\frac{v_w}{1+v_w+kv_m}p_m+\frac{1+kv_m}{1+v_w+kv_m}p_w$$
>
> *where v_m and v_w are the volume of communication received by the manager from each subordinate and the volume received by each of the subordinates from the manager, respectively.*

(The proof is in the appendix.)

There are several points worth noting. The manager's choice is a linear combination of his and his subordinates' preferred systems. For large enough volumes of communication (when the extra term of 1 in the formula above can be ignored), the coefficient for the manager's preferred system is the ratio of a *subordinate's* received volume over the total received volume. This paradoxical effect arises from the reaction by a worker who picks a system closer to that of the manager if he gets much traffic from him. This makes the manager's own preference that much more desirable. These "cross" terms reflect the interconnectedness in choices made by the individuals. In the limit, as v_m, the volume of traffic received by the manager, increases, the manager shifts to the subordinates' preferred system to reduce his rising incompatibility cost. Increasing v_w, the volume received by the subordinates, has the opposite effect. The effect of increasing the span of control, k, is similar to that of increasing v_m: the manager shifts his choice closer to the subordinates' preferred system to reduce his incompatibility costs, and the subordinates' choices get closer to their own preference. This behavior is shown in figure 2 for our test data ($p_m = 0.1$, $p_w = 0.5$).

Figure 2 shows the system choices (indexed on a cardinal scale between 0 and 1) made by the manager and the subordinates under the *delegated* policy. It is interesting to note that for $k = 1$ the manager initially chooses a system indexed at 0.2. The subordinate's initial choice is for a system indexed at 0.35. The ideal choices are at 0.1 and 0.5 for the manager and subordinate, respectively, but we see a deviation from this ideal point to reduce the potential incompatibility. As the span of control increases, both constituencies start converging toward more similar information systems. Clearly, the change in

individual user to effect these choices may be impracticable in most organizations. We include this policy option in our analysis to provide a "first best" benchmark for evaluating the other policy options. The formulation for picking system choices to mandate is:

$$\max_{x} \left\{ \sum_{i} b_i(x_i) - \sum_{i,j} (e + tv_{ji})(x_i - x_j)^2 \right\} \tag{4}$$

subject to:

$$x_i \in [0,1] \qquad \forall i\,. \tag{5}$$

The above formulation differs from (2)-(3) above for the *delegated* policy. Here the system choices, x_i, are not set to maximize each user's net benefits.

Corporate IS Standards and Networks in Hierarchical Organizations

Hierarchies are modeled using their information flow structures as discussed above. For simplicity, we assume in the following analysis that users at each level in the hierarchy are homogeneous, although they may differ across levels. Each level in the hierarchy performs a distinct task, and the users would prefer to choose systems to suit their needs best. The communication intensity from any superior-to-subordinate or subordinate-to-superior pair is the same across the same two levels of the organization. We simplify the model by assuming that $b_i(x_i) = b - c\,(x_i - p_i)^2$ for each user i, where b is the gross benefit in dollars, c is the cost in dollars per unit square difference in system indices, and p_i is user i's preferred system, the system that user i would pick if he were not to consider other users. This reflects the *ideal point* in the attribute space of system choices that the user faces. Parameters p_i, c (taken to be 1 in the subsequent analysis), and b are exogenous. To further simplify the model we assume that $e = 0$ and $t = 1$. We analyze the impact of several organizational parameters, such as span of control, communication intensity, asymmetry of flows and the number of levels in the hierarchy, on the optimal choice of corporate standards.

Span of Control

One of the key parameters in organizational design is the span of control, defined by the number of subordinates reporting to a manager. Numerous studies have looked at the effect of changes in the span of control on organizational performance, decision making, monitoring, and communications [17, 18, 20, 21, 22]. We examine their impact on the value and desirability of information systems standards. We study the form of the Nash equilibrium results for a

given others' choices. The users know that each choice is still very much affected by what the other users pick, as this will greatly influence the incompatibility costs. If the user chooses a system that is compatible with others, then incompatibility costs will be minimized; picking a system that is highly incompatible results in substantial translation costs for the user and those who communicate with him. The user makes a tradeoff between his preferred system and these incompatibility costs. Since system choices are *delegated* to users, in equilibrium, we will only see users with systems from which they do not have any unilateral incentive to change, for, if they could increase their net benefit by changing their choice, they would do so. Such an equilibrium is called a Nash equilibrium. [19]. Let user i pick x_i^* to maximize his individual net benefit:

$$x_i^* \in \text{Argmax}_{x_i \in [0,1]} \left\{ b_i(x_i) - \sum_j (e + tv_{ji})(x_i - x_j^*)^2 \right\} \tag{2}$$

Among such stable sets of choices, we seek systems choices, x_i^*, that will provide maximum organizational be enefits, which is the sum of the user net benefits:

$$\sum_{i \in N} b_i(x_i^*) - \sum_{i,j \in N} (e + tv_{ji})(x_i^* - x_j^*)^2 . \tag{3}$$

The Common Standard Policy

In this case, the organization picks a common standard for all users and departments. Such standards are commonly seen in organizations for some categories of systems. For instance, the Simon School requires all users' personal computers and workstations to be connected to a Novell network. Some organizations require all users to have ISA-compatible personal computers with a standardized suite of applications. Others may impose a common choice by making it free for all users and charging users for any other choice. We consider the problem of how the organization picks such a common standard. The choice is made so as to maximize the organizational net benefit. This amounts to maximizing (3) subject to the constraints $x_1 = x_2 = \cdots = x_n$ where $x_i \in [0,1]$ for each i.

The Mandated Policy

The mandated policy results in a set of choices given by the vector $x = x_1, \ldots x_i, x_n$ which maximizes the organizational net benefit. Such a policy does not necessarily lead to a common standard. A custom choice that reflects the particular use and benefits is made for each user. As mentioned above, this policy requires a huge amount of information available centrally and the ability to mandate a choice for each individual. Getting truthful revelation about preferences and writing complex individual contracts with each

requires data translation and reformatting. Let t be the incompatibility cost per message ($/message). Let e represent the fixed cost associated with establishing a communication link between two incompatible systems. It accounts for protocol translators, data converters, or other losses of scale economies in purchasing and support ($/link). There are additional incompatibility costs that depend on the difference between the systems. These costs increase as the difference between systems increases. Further, these costs may increase at an increasingly marginal rate. This reflects the fact that it is often easier to transfer data between two incompatible systems by using an intermediate system that is less incompatible with either one. For instance, it is easier to transfer a table from Word Perfect to Excel if Word is used as an intermediate system. We use the simplest function that offers the marginally increasing behavior we seek to model, the quadratic function, to represent these costs. Specifically, these incompatibility costs are assumed to be given by $(e + tv_{ji})\ (x_i - x_j)^2$. Without loss of generality, we assume that the receiver of a message from an incompatible source incurs a cost t per message. We treat the organizational design as exogenous.

We analyze three policies for specifying the information system: a *delegated* choice, a *common standard*, and the *mandated* policy. Under the delegated policy, the choice of the system is left to the individual users or departments. The users make individual choices and try to maximize their own net benefits given the choices made by other users. In contrast to the delegated policy, a firm adopting a common standard will dictate a common choice for all users. The mandated policy represents the other extreme, in which the firm centrally makes detailed individual choices for each user in a way that maximizes the welfare of the firm. This policy requires a significant amount of specific information and an extreme involvement in every user's choice. This is rarely observed in practice but provides a useful "first best" benchmark to assess the relative value of the other policies.

The value (or cost) of delegating the choice or picking a common standard is derived by comparing the net value obtained from these policies with that of the benchmark mandated policy. The delegated policy is modeled next.

The Delegated Policy

Let $x_i \in [0,1]$ represent the system chosen by user i. The benefit for user i is $b_i(x_i)$. The incompatibility costs incurred by user i (operating with system x_i) depend on the systems chosen by the other users ($j \in N, j \neq i$) as well. If these choices are different, $(x_i - x_j)^2$ is non-zero and $(e + t\ v_{ji})\ (x_i - x_j)^2$ is the cost incurred by user i from receiving v_{ji} messages per unit time from user j who operates an incompatible system x_j. Summing over all users gives the total incompatibility cost incurred by user i. The user's net benefit is

$$(1) \qquad b_i(x_i) - \sum_j (e + tv_{ji})(x_i - x_j)^2 .$$

Under the *delegated* policy, each user picks a system that is best for him

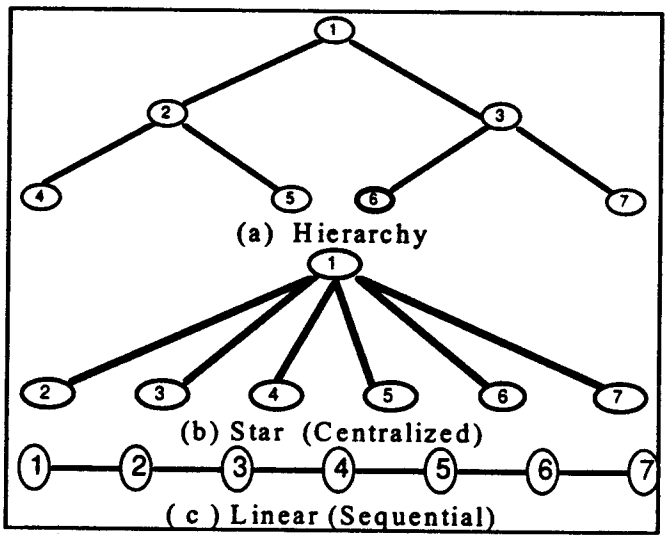

Figure 1. Forms of Hierarchies

explore the effect of communication intensity on IS standards for such organizational forms.

Let $b_i(x)$ represent the benefit to user i from using system x, $x \in [0,1]$, assuming all other users have also chosen this system. (Typically, this will include the net present value of the productivity gains less the purchase, installation, and support cost.) The function $b_i(x)$ is assumed to be a continuous, twice differentiable concave function. It is also assumed that it achieves its maximum at x in the interior of the interval [0,1] for each user. This last assumption simplifies the algebra and requires that systems with indices 0 and 1 are extreme in the range of systems and are not the independent choice of any user. In practice, this is rarely a problem as the scale can be extended to include systems that match the attribute range but would not be chosen by any user. Now we turn to incompatibility costs. If other users, who communicate or share jobs with user i, pick a different system, then some users may also incur an incompatibility cost, which is described below. Figure 1 depicts an example of the organizational form we will use: a binary hierarchy with three levels, seven users (n), and six communication links (n–1). We use a matrix **V** to represent the organizational communication structure. Element v_{ij} denotes the volume of information flowing from user i to user j (messages/unit time). The information exchange matrix, **V**, can be used to represent all organization forms. In the case of hierarchies, one deals with a triangular submatrix.

Systems choices give rise to both positive and negative externalities. For instance, a positive externality exists when the choice of a particular system by a user reduces the purchase and usage cost for other users. These may arise from site licenses, volume discounts, shared training and support, and other similar factors. On the other hand, a user making a nonstandard choice may impose costs on other users. These additional costs include data-translation and sharing costs. Sending messages between incompatible systems

Corporate Standards

Standards can have a big impact on an organization's IS. These costs are increasing over time and make up an ever greater portion of overhead. The Boeing Corporation provides a dramatic example of the negative impact associated with the lack of information technology standards. The process Boeing used for many years to coordinate engineering design and manufacturing required 800 different computer systems—and most of these computers did not communicate with each other. This cumbersome system stifled communication among the different units involved in producing the new Boeing 777, which led to reduced productivity and increased lead times and cost. By the end of 1997, Boeing hopes to standardize many of these systems; according to *Fortune Magazine* (Alex Taylor, August 1995), it expects that this will reduce costs by 25 percent and defects by 50 percent and shrink the order-to-delivery time from ten months to no more than six. Other users trying to integrate their information systems relate similar tales. One system user noted that "we just couldn't justify the move to a client-server computing after hearing the horror stories that other organizations have gone through trying to integrate different flavors of Unix" (Barbara DePompa, *Information Week*, May 27, 1996). When we add the integration of middle-ware, systems administration, and network access controls, it becomes clear why many organizations are continuously evaluating the cost and benefit implications of their standards polices.

Standards affect the quality of an organization's decisions and services. Corporate IS standards affect the communication cost among individuals and teams. Communication involves the transfer of information (data, documents, images, etc.) pertinent to carrying out tasks and decision making in a timely and accurate manner. The internal coordination costs of an organization can be significantly higher with incompatible information systems. Mandating a standard design approach, data structure, and architecture simplifies data sharing and system integration, and it can substantially decrease communication costs. Standards also provide economies of scale in purchasing. Training and support costs are reduced because of shared organizational learning and reduced variety in user systems. Yet, having to follow a *mandated* IS standard implies that users give up some decision rights; this may adversely affect morale, cost, and productivity. The impact and tradeoff between these factors on bilateral relationships have been examined in an earlier paper [11]. Here, in a more general context, the impact of organizational structure on the desirability of adopting IS standards for intraorganizational networking is explored.

Our study focuses on how different organizational forms may affect IS standards for intraorganizational networking and on how different standards policies may provide different values to organizations. It describes the effects of IS choices on communication, translation, incompatibility costs, and economies of scale. Specifically, we investigate the value of standards policies for hierarchical organizational forms. Hierarchies are characterized by the span of control and the number of levels. The effect of these two factors on the value of IS standards for intra-networking is studied. In addition, we

Issues	Paper	Methodology	Key Findings
Corporate	Dewan, Seidmann, and Sundaresan [11]	Two-players Single and multiperiod game	Multiperiod adoption process may result in shadow-rider phenomenon in which one internal user tries to exploit the earlier site licensing purchased by another department.
	Aach [1]	Discussion	Corporations benefit from structured processes for setting up and managing standards.
	Gordon [14]	Case study	Multinational companies face challenging problems in standardizing information systems and pursue different solutions.

Table 1. Corporate Standards: A Summary of Earlier Work

dards [4, 10, 12, 15]. In contrast, our research focuses on standards in a corporate setting. It explains how information system choices should be determined to facilitate intraorganizational networking. The special considerations addressed here for internal IS choices are driven by high incompatibility costs and the loss of scale economies in corporate purchasing and support. A summary of corporate standards research is provided in Table 1.

Some of the factors that affect the standardization policy have been examined by other IS researchers. These factors include software development [3], systems management, and organizational changes [7, 8, 16]. Recently, a few authors presented examples highlighting the benefits of corporate IT standards and discussed administrative procedures for developing them [1, 14]. It is clear that standardization decisions, which affect internal communication, are linked to the overall organizational design.

Optimal organizational design is determined by trading off the cost of delegating decision-making rights and the cost of providing the information needed to make those decisions [6]. Organizations may be characterized either by the set of decision-making rights, also called the "nexus of contracts," or by the information flow needed to support decision-making. Earlier studies have considered a firm's internal organization as a communication network. For example, Bolton and Dewatripoint [5] model a firm's organization as a network that is designed to minimize both the costs of processing new information and the costs of communicating this information among the agents; the tradeoff in the model is between specialization and communication. Radner [21] attempt to design efficient communication networks that minimize delay in processing a batch of items. Aoki [2], Cremer [9], and Geanakoplos and Milgrom [13] study the efficient allocation of information-processing tasks and costs. Many researchers have studied the symbiotic relationship between organizational structure and the type of IT adopted, and conclusions supporting different causal relationships have been drawn.

for decentralized organizations by coordinating the choices of information system components across various departments over time. Standardization provides economies of scale and maintains the integrity of the IS infrastructure by enabling transparent interoperability.

Most standards evolve in one of two ways. *De jure* standards are *mandated* by regulatory bodies or governments. In contrast, *de facto* standards arise when a number of entities cooperate or form joint associations to adopt standards voluntarily.

Most previous studies of technology standards have looked at voluntary choices made in the marketplace or by legislative bodies. In contrast, this paper provides a framework for setting *organizational* standards policies to facilitate communication within the organization. This has become a critical problem for many multinational corporations, which must integrate the flow of business processes and decision information across the globe. The paper analyzes standards policies for an organization where different users specialize in different functional areas, such as engineering, finance, marketing, process planning and manufacturing, and accounting. These users perform different functions, and they tend to choose information systems that suit their needs. Some of these systems may be compatible, but others may not.

We model the choice of information systems to capture the economic tradeoffs among individual preferences, communication costs, and shared benefits. For instance, a system that provides an excellent user interface may not provide good network-management tools. The cost of acquiring these various systems will also differ—a high-quality desktop publishing tool could cost a few thousand dollars per user, whereas some shareware, which provides only the basic functionality, is practically free. The costs of implementing, supporting, and using assorted systems varies significantly. Of many attributes of information systems, the ones that affect compatibility across systems are crucial in an analysis of IS standards. To this end, we simplify the model by characterizing a system purely on a single compatibility attribute. Specifically, we assume that each of the n users, $N = \{1, \ldots, n\}$, of an organization chooses systems that are indexed continuously in a single attribute, x, in the range of [0,1]. User i derives a value of $b_i(x_i)$ from using system x_i, which reflects the value that the user places on the compatibility and other attributes of the system that have been discussed above. In particular, for each user, the net benefit of using a system depends on the delivered functionality, resource consumption, hardware requirements, and the costs of cummunication with other users in the organization.

The following sections provide a background on corporate standards, noncooperative game models of systems choices under the three different policies, analysis of the impact of several organizational parameters, and a brief summary of our key conclusions. The proofs are in the appendix.

Background

In the free marketplace, vendors compete on capabilities and compatibility, and users may choose to follow any one of several potential stan-