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ABSTRACT: Information technology (IT) infrastructure has been identified in recent years in some businesses as having a critical impact on the firm's ability to use IT competitively. Although a flexible infrastructure is considered highly valuable under certain circumstances, it is difficult to plan and to measure because there is no common, operational definition. This paper addresses the problem at two levels. First, it presents and explores various efforts to define or describe infrastructure flexibility in the literature. It identifies basic components of IT infrastructure and previously proposed characteristics of flexibility. The discussion considers concepts of IT resource management, including technological architecture, alignment of planning, and human resource skills, all of which have also been linked to definitions of infrastructure flexibility. Second, the paper explores how the concept of infrastructure flexibility is viewed among IT executives. The characteristics of infrastructure may vary with firm resources and industry characteristics such as information intensity; consequently, we may expect flexibility to be either developed or thwarted in a great number of ways. An informal study of IT executives' experience with and opinions of infrastructure flexibility results in a view of the practical issues of infrastructure flexibility. Based on the outcome of this study, a framework is presented for developing tools for future efforts to evaluate infrastructure flexibility. Methods by which the framework may be used to develop individualized infrastructure benchmarking tools are proposed.

KEY WORDS AND PHRASES: flexibility of information systems, information systems planning, information technology infrastructure.

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IN INFORMATION-INTENSIVE INDUSTRIES, WHERE STATE-OF-THE-ART use of information technology (IT) is a strategic necessity, infrastructure has become a central issue in information systems (IS) management. While individual systems are generally identified as a direct source of IT's business value, IS executives are gradually recognizing that IT infrastructure is key to the development time, the cost—essentially the feasibility—of implementing an innovative system.

Historically, the study of the strategic impact of IT has focused on specific firms used as mechanisms of unique change or innovation. Such systems have been implemented to alter or reduce costs, reduce suppliers' bargaining power, redefine and improve services, or enable a firm to offer new products (e.g., McKesson Drug Co. [6], American Airlines' Sabre [8], and Wal-Mart [14]). In the 1980s, such innovations were sometimes celebrated and explored as unique sources of sustainable competitive advantage.

An examination of strategic theory, however, prompts revision of this perception. In his seminal work on the characteristics of strategic resources, Barney [2] points out that a resource can offer sustainable competitive advantage only if it is inimitable. Alone, information systems are commonly perceived to be eminently imitable. In practice, we see innovative systems successfully reverse-engineered and imitated rapidly. Being first-mover on an IT innovation is generally unlikely to afford the developer prolonged strategic benefits unless either (1) the developer establishes standards that make emulators dependent on some of the developer's products [21], or (2) the required time or cost of imitation prohibits competitors from matching the innovation [7].

In practice we find that the cost of imitation, in both time and money, may vary from firm to firm, depending on each firm's resource base. Thus, recent work has suggested that the strategic resource for American Airlines, McKesson Drug, or Wal-Mart may not have been their unique applications as such. Rather, the set of resources that made feasible both innovation and continuous improvement of IT systems was the true source of sustainable competitive advantage. That set of resources is IT infrastructure [3, 26]. That is, unique characteristics of the IT platform make the cost and value of technological innovation different for different firms. One firm's infrastructure may make strategic innovations in business processes feasible, while the characteristics of competitors' infrastructures may likewise cause their *in*ability to imitate the innovations rapidly enough to mitigate the first mover's advantage. This set of characteristics has been loosely described as infrastructure "flexibility." If it does alter competing firms' options for implementing business innovations, then it could arguably be a very powerful strategic resource.

It is thus not surprising that over the past three years, surveys of IS professionals have repeatedly listed IT infrastructure as a top concern in IS management [17, 18, 22, 29]. However, to date, our understanding of infrastructure and its flexibility is too general to be useful either in research or in management of IS resources. Research has formulated an "open systems" vision to describe infrastructure flexibility [16]. This vision suggests a technological capacity for "anything to anyone at anytime" in the firm. If data or applications are not shared, it is a consequence of a business decision rather than of technological capability. While surely there are few business examples where such capacity has been required and used, the capacity can nevertheless be defended as the epitome of flexibility. On the other hand, practitioners deal with the concept of infrastructure flexibility from the perspective of omission. That is, to the extent that new development or maintenance tasks are made difficult by the technology already in place, infrastructure is inflexible.

Today our knowledge of the resource value of IT infrastructure remains largely in the realms of conjecture and anecdote. This is a problem both in practice and in research. IS executives often find it difficult to justify expenditures on infrastructure. Because infrastructure expenses are difficult to tie to specific business benefits, general management is more likely to perceive those expenses as unaffordable overhead, or even as dispensable IT "toys."

Likewise, with a single exception [28], infrastructure has been omitted from most studies on the business value of IT resources because it is widely perceived as unmeasurable [19]. Before infrastructure value research can be undertaken, we must establish a clear understanding of it both conceptually and in application. We must identify characteristics of infrastructure flexibility that are practical, common across firms, and in some way measurable. This paper is the result of a study designed to explore and expand our information on the meaning and operationalization of the construct "infrastructure flexibility."

The following section reviews and discusses past definitions of IT infrastructure and flexibility. We next describe a field study conducted to gather practical, measurable indicators of infrastructure flexibility. Conceptual dilemmas in the emerging picture of infrastructure flexibility are then identified, followed by presentation of a framework for designing evaluation tools based on the study, along with a sample of indicators developed for the Life/Health Insurance industry. Finally, we discuss the usefulness of the method to IS planners and researchers and suggest a direction for future research on infrastructure.

Flexible Infrastructure: Definitions

WE BEGIN OUR EFFORT TO DEFINE INFRASTRUCTURE flexibility with infrastructure. Infrastructure is defined in the literature at two levels: first, it is explained in terms of the basic technology components of which it is comprised; second, some definitions have been extended to consider resource planning and management factors that may affect the design and capabilities of infrastructure. The definition is completed with a discussion of flexibility as it applies to IS resources.

Infrastructure Technology Components

Definitions of IT infrastructure generally describe a set of *shared* [9, 13, 20, 22, 27], tangible [13, 19], IT resources that provide a *foundation to enable present and future* *business applications* [13, 16, 22]. The primary, tangible resources include:

1. "Platform technology" (i.e., hardware and operating systems);
2. Network and telecommunication technologies;
3. Key data; and
4. Core data-processing applications [13, 22].

McKay and Brockway's thorough definition [20] also includes shared IT services such as universal file access, a video conference center, and e-mail. As interest in infrastructure has grown in recent years, additional factors of infrastructure design and implementation that affect its flexibility have been added to infrastructure definitions. Assessing exactly how these factors relate to infrastructure flexibility requires careful analysis.

Infrastructure Planning and Management Factors

As research struggles to understand how an infrastructure becomes flexible, some definitions have been broadened to include secondary, or related, IS resource planning issues—even to the point where flexibility has been described as "the firm's core competence or capability relative to IT" [9]. Three common factors include (1) the alignment of IS plans to business objectives, (2) information technology plans or architecture, and (3) the skills of all personnel involved in IT resource management. A clear concept of infrastructure requires that we consider carefully how these factors relate to it.

Alignment of technological plans to business plans has been argued to be critical to infrastructure flexibility and efficacy [15]. Key to our practical understanding of infrastructure flexibility is the issue of responsiveness: infrastructure is flexible as the IT organization is able to respond rapidly and effectively to emergent needs or opportunities. Since practitioners tend to regard flexibility as the underlying cause of an infrastructure's responsiveness to business requirements, and since the purpose of planning is to improve readiness, it seems logical to conclude that planning alignment is critical to infrastructure flexibility.

However, one reason why infrastructure flexibility is perceived as critical to information-intensive firms is the quantity of *unplanned* systems requirements faced by IT organizations. A key symptom of inflexibility is the difficulty developers have with users' demands that require systems to do things they were not designed to do. The historic solution has been either to update the systems to do those things, or to build a new system to reflect new processes and processing efficiencies. An alternate approach is to develop an infrastructure that allows flexible manufacturing of systems. The perceived importance of infrastructure flexibility is that it does improve systems developers' ability to design and build systems to do things they were not designed or built to do. In this case, planning alignment is less a measure of flexibility and ability to meet unanticipated needs; rather, it is a measure of foresight that reduces the need for flexibility.

This point is illustrated by a problem faced by Provident National Bank of Philadelphia. Shortly before Christmas, a major competitor announced the availability of free checking services. Provident was committed to the philosophy that it would keep up with any products and services offered in the industry, but the task of implementing the systems needed to offer free checking seemed so large, especially in the face of the traditional work inefficiencies of the holidays, that Provident was concerned about losing market share to the competitor. Upon review of the requirements, Provident's IS management advised general management to announce the service immediately. They believed, correctly, that they would be able to implement the unanticipated, unplanned systems changes needed within one billing cycle. That is, Provident could sell the product before IS had the relevant system because IS would have it before the bank actually needed it. In this case, IS responsiveness had to be independent of planning alignment because the requirement was unplanned.[1]

The argument that aligning IS planning with business planning is prerequisite to infrastructure flexibility may be countered with the suggestion that planning alignment is a *substitute* for flexibility. While aligning business and technology planning may help IS management to prepare to support the implementation of firm tactics, it will arguably have little impact on the true value of infrastructure flexibility—its support of unanticipated requirements. This leads us to the question: What kind of planning, if any, *does* affect infrastructure flexibility?

Architecture has been described as the essence of the corporate IT strategy. As the technological blueprint for the firm, it includes "a high-level map of the information requirements of an organization" [22] and a "detailed plan that combines business directions, technology, process and human resources into a cohesive whole" [18]. It provides a "framework for analysis, design and construction of the IT infrastructure" [13]. Architecture is the model of the firm's technological requirements and the general plan for the organization of resources in order to best meet long-range technological needs. Focused policies, plans, and standards for IT management emerge through architecture development, and document the body of knowledge of those who plan this organization of resources. They may be the foundation for infrastructure, controlling and guiding the growth and change of an evolving infrastructure as well as the applications it supports. The architecture is thus perceived to directly affect infrastructure flexibility.

In practice, this set of plans may not be documented in formal standards. In fact, previous research in the insurance industry found that only 23 percent of a sample of eighty-two firms indicated that they operated with formal IS architecture plans. Fifty-seven percent claimed an "informal, but widely understood" architecture with greatly varying coverage of standards and requirements for the various components of infrastructure [12].

Skills, the experience and expertise of personnel as they relate to infrastructure flexibility, are the least tangible and most difficult resources to analyze or prescribe, yet they may constrain the quality of the other resources, at both the primary, or component, and secondary, or resource management, levels. IS professionals require expert knowledge both of the firm's set of IT resources and of other technologies—extant or expected—in the environment. Knowledge of the firm's technology is essential for effectively integrating new systems with old ones and for optimizing the firm's technology investments. Other, new technologies may be necessary for developing architectural plans to guide the firm in future technology acquisitions.

Knowledge of the business has been suggested to contribute to infrastructure flexibility because it affects the IT organization's ability to plan effectively [15]. Understanding business needs and business processes may enable systems developers to anticipate specific implementation needs better. The relevance of this issue to infrastructure flexibility has already been questioned in the discussion of alignment. Again, the importance of responsiveness to unplanned requirements suggests that flexibility may be better served when understanding the firm's practices, tactics, and goals enables IS planners to anticipate *types* of needs. For instance, they may visualize opportunities for flexible data structures, new concepts of resource integration, or emerging platform uses. The strategic nature of the IS plans, their alignment with organizational goals, and the vision with which standards and policies are developed all depend on the unique skills of the people involved in planning and managing IT resources. While the specific requirement may be unknown, knowing the probability of various types of requirements and understanding their business meaning may be useful skills for those who plan and manage IT infrastructure.

Flexibility

Flexibility is defined in management literature as the ability of a resource to be *used for more than one end product*. The greater the flexibility of the resource, the more options the firm has for diversifying into less related end products [4]. Thus, we must begin with an understanding of infrastructure flexibility as the degree to which its resources are *sharable* and *reusable*.

The importance of the sharable aspect is explored by Keen [16, p. 179], who defines the "business functionality of the corporate IT platform" in terms of "reach" and "range." Reach refers to the *connectivity* of IT platforms, or the number and variety of platforms internal and external, local and remote, to which a firm can connect. Platform configuration, and the availability and implementation of network and telecommunications technology, are critical concerns to this dimension. Range pertains to the capacity to share types of IT services, from conventional messages to data transmission to cooperative transactions. Configuration of platform, network, and telecommunications are likewise key to infrastructure range. The resources must be both available to the firm, and *compatible* with each other to optimize both reach and range.

Reusability has been less explored but is no less important as a factor of infrastructure flexibility. Its applicability to platform is obvious to the many firms where IT history begins with mainframe computing. More important, reusability is key to our understanding of applications and data as elements of infrastructure. McKay and Brockway [20, p. 4] include among infrastructure resources, "the backbone of networks, databases, applications and 'groupware' that enables effective long-term use of IT by individuals, work groups and entire companies." Niederman et al. [22] list "core databases" and "mission-critical applications." The application of the flexibility construct to these components has not been explored to date.

In a private interview, an IS architecture executive at a firm viewed by its competitors as a leader in both IT achievement and vision offered a third explanation of the role of data and applications in IT infrastructure. Data and software components are subsumed into infrastructure as they become technically independent—standardized, sharable, and reusable in a variety of business implementations, present, future planned, and future unknown.

> Over time we should get good enough at system design such that 90% of systems and support would be infrastructure. That is, we simply "clip" systems together. OOT[2] will help, but it will take a complete shift in thinking away from our engineering mind set.

This vision takes the decades-old concept of modular programming to an extreme. The executive explained that repeated IS functions such as data or software module call routines, as well as data, can and will be converted into reusable objects. As data and applications components become independent and reusable, they become part of infrastructure, and the processes of development, maintenance, or reengineering of "direct-purpose" systems are simplified, and the costs are reduced.

The qualities of sharability and reusability, as they apply to IS infrastructure, have powerful value implications for the firm. Flexibility seems to affect business capabilities in two ways, both of which suggest strategic implications.

First, infrastructure affects the feasibility and cost of technology-based business innovations. The decision to support an IT-based innovation is difficult for firms because of the high cost of substantial IS capital requirements, uncertainty of development time, and uncertainty of final outcomes. The literature suggests two ways in which infrastructure mediates these difficulties. First, a flexible infrastructure may reduce the time to market for new products [27]. Platform readiness for new software, easy access to the relevant data, and the presence of necessary networking systems all affect cost and development time. Thus, they may be critical to the "go/no go" decision on innovation development.

In addition, by lowering the costs of present innovation efforts, we may expect to be lowering the costs of future innovations as well. The basic benefit of platform applies to each layer of innovation, but research indicates that innovation likewise reduces the risk and cost of future innovation [10]. Thus, we may project that, with a flexible infrastructure, IS-related innovation may in fact become a core competency of the firm.

Second, infrastructure affects a firm's ability to refine or reengineer business systems. As business practices evolve, information systems are updated, and frequently, the resulting system grows increasingly complex, as does the maintenance process itself. As maintenance and updating grow less efficient, the IS group becomes less responsive to changing business requirements. Eventually, project teams find they can no longer update a system incrementally: it must be completely redesigned. Where enhancement requires platform changes, infrastructure integrity may gradually be confounded. When a system is redesigned, it is again designed in such a way that the efficiencies reflect current business practices. The cycle of systems efficiency deterioration begins again as business processes continue to evolve.

Infrastructure flexibility determines the ability of the IS department to respond quickly and cost-effectively to systems demands, which evolve with changes in business practices or strategies [7]. The ideally flexible infrastructure would be one that was designed to evolve, itself, with emerging technologies and would support the continuous redesign of business and related IS processes.

From these two premises, we may conclude that infrastructure may be the critical variable in competition between innovating firms and their competitors. The theoretical basis for this conclusion is found in the resource-based view of competitive advantage, which assumes that resources may offer competitive value to a firm when either their value or their accessibility is not homogeneous among firms [1, 25]. When resources offer a firm value that competitors cannot readily gain through the market or imitate internally, use of those resources may be a source of sustainable competitive advantage. Infrastructure is a complex set of technological resources developed over time whose precise description and value are quite difficult for even its developers to define.[3] As such, an IT infrastructure that offers a great deal of flexibility to its firm is unlikely to be homogeneously valuable or accessible across firms.

As the infrastructure affects the innovator's costs and development time, it likewise affects the time required by competitors to imitate the innovation. A flexible infrastructure enhances firms' strategic options, while competitors' infrastructure limitations restrict their ability to match efforts. Specifically, we may infer that it can determine the firm's ability to pursue a certain strategy. To the extent that one firm can implement an IT-based strategy to gain competitive advantage that its competitors cannot imitate because of technological limitations, a flexible infrastructure may be viewed as a strategic resource and potential source of sustainable competitive advantage [16, 22, 27].

Of course, the potential strategic value of a flexible infrastructure remains a matter of conjecture. Before research to test infrastructure value can begin, we must identify ways to operationalize the construct. So far, our understanding of infrastructure includes a set of related IT resources and some definitions of what it might mean, in the abstract, to a firm. More practical insight into the nature of infrastructure resources and their flexibility requires an examination of the experience of practitioners who work with those resources. Since the characteristics of infrastructure flexibility may vary with such industry characteristics as information intensity [23] and with such firm characteristics as size and strategy [12, 16], we obviously cannot construct a complete manual on the specifications of infrastructure flexibility. (If we could, it would hardly be the strategic resource that we have suggested that it may, in some cases, be.) To begin to operationalize the flexible infrastructure construct, we first gather the impressions of IT professionals about the characteristics of infrastructure flexibility. These impressions are used to develop a greater understanding of the characteristics of the flexible IT infrastructure in practice, and also help us to identify the problems and contradictions associated with its development and quality. The following section describes a study designed to gather the ideas of IS professionals identifying practical and measurable features and indicators of a flexible IT infrastructure.

The Study

THE EFFORT TO IDENTIFY AN OPERATIONAL VIEW of infrastructure flexibility involved two stages of field work. First, a simple Delphi procedure designed to ferret out the issues perceived as critical from the practitioner's point of view was conducted. The CIOs and high-level IS executives from twenty-one *Fortune* 500 firms who serve on the advisory board of the Texas A&M Center for MIS (CMIS) participated. CMIS member firms represent the petroleum, communications, consulting, retail, and insurance industries. A list of member firms is available from the author or the CMIS director. The Delphi study consisted of an open-ended survey followed by a large group discussion at the next regular board meeting. A second stage of research consisted of extensive, semistructured interviews with IS planning executives from three major insurance firms in Texas and a major investment bank in New York. These interviews were conducted to pursue the issues suggested by responses, and to expand and explore potential indicators of infrastructure flexibility within a single industry.

The Delphi study was intended to foster and to focus discussion on those characteristics of IS resources most relevant to infrastructure flexibility. Accordingly, a brief, open-ended survey instrument containing a short list of infrastructure features was devised to seek participants' views of the importance of various approaches to sharability and reusability for the various infrastructure components.

Because rules are a manifestation of formalized plans representing what the planners perceive to be important enough to control, the flexibility issues were listed in terms of rules. The survey included sections on the following for infrastructure components:

- Configuration rules,
- Compatibility rules,
- Integration rules,
- Access standards,
- Connectivity of systems, and
- Excess capacity.

Configuration and compatibility rules for various infrastructure resources are fundamental approaches to managing the firm's capacity for sharing in terms of Keen's "range" dimension. Because they apply to network technology, configuration and compatibility rules, like connectivity, relate to the concept of "reach." Integration rules and access standards for infrastructure components may have implications for both sharability and reusability. Resources can be used for new functions when systems are integrated such that data or processes can be shared and used in new ways. The use of standardized gateways to data and applications was expected to affect the reusability of those resources by simplifying systems developers' access to them.

Consistent with the work of Keen [16], Venkatraman [26], and Henderson and Venkatraman [15], the instrument also included a section on business orientation of

Table 1 Issues Listed in Open-Ended Survey

Type of rules or standards	Technology components
Configuration rules for	Hardware Operating systems
Compatibility rules for	Applications EDI Communications Data Multitechnology
Integration rules for	Applications Multitechnology integration
Access standards for IT resources: Centralized location	Data Applications
Access standards for IT resources: Location transparency	Data Applications
Access standards for	Interface standardization
Access standards for	Unlimited vendor choice
Business management leadership in long-term IT planning for:	Applications Data Communications Platform

Other issues
Autonomy of business unit managers in systems development decision making
Connectivity of systems across physical locations, local to international
Unused capacity

components. Under each quality, specific infrastructure or IS resources were listed. Table 1 presents the sections along with the technologies included in each.

Board members to whom the survey was mailed were given the following scenario:

> *Imagine yourself an independent IT consultant reviewing the case of some client firm. What characteristics might you look for to get a sense of your client's infrastructure flexibility?*

Participants were asked to rate the listed characteristics only as "Important," "Somewhat important," or "Not important." Because the purpose of the study was largely exploratory, participants were further prompted to list additional issues or factors they felt were important to infrastructure flexibility. At the end, an open-ended section asked participants, "What other characteristics of infrastructure flexibility might be considered?" Since one goal of the study was to begin to develop a set of measures for the construct, participants were also asked to identify specific indicators or measures for each infrastructure feature that they felt was important to flexibility.

Recipients of the survey were encouraged to share the instrument with other IS professionals in the firm whose opinion on the subject they respected. Because the purpose of the study was to gain preliminary insight into a very unstructured problem rather than to test a hypothesis, increasing input was deemed more important than a rigorous sampling method. Nineteen responses were received from eleven firms. The following section describes the responses (both directed and open-ended), of the participants. It discusses their implications for a more operational definition of infrastructure flexibility in terms of the concepts developed in the previous sections.

Survey Findings and Issues

THE INFORMATION RECEIVED FROM THE INSTRUMENT AND FROM THE SUBSEQUENT discussions provided several levels of information about how practitioners view infrastructure flexibility, its characteristics, and the dilemmas in developing it. First, we identify the infrastructure characteristics listed on the instrument that were most consistently rated as important. Their relationship to the basic qualities of flexibility are reviewed. Then we explore the more complex, and sometimes conflicting, information received about the resource management issues related to infrastructure flexibility.

Survey Item Ratings

Survey responses were tabulated and the identified characteristics were ranked according to the overall judgment of their importance. The ratings helped focus attention on certain infrastructure features. The survey items deemed important by the most respondents included:

- *Compatibility* rules for: Communications/Networks; Data; and Applications;
- *Business management leadership* in long-term planning for applications;
- *Connectivity of systems* across physical locations, local to international; and
- *Interface standardization.*

Open-ended comments, suggested indicators, and subsequent discussion provided most insight into practical infrastructure flexibility values by highlighting both areas of general agreement and points of controversy. The following section attempts to illuminate both areas using examples from these comments and discussion.

Flexibility Issues for Infrastructure Components

Responses and discussion concerning both compatibilities and connectivity validate the previously discussed flexibility qualities of sharability and reusability. The ability to transport systems or their components is an important flexibility concern among IS professionals. Successfully using and reusing IS components in different environments depends on the compatibility and connectivity of infrastructure components. This ability is central to information-based innovation, reengineering, and also for managing the rapid change of technological generations.

Consensus on the importance of connectivity of systems underscores that sharability of IT resources at the platform level is fundamental to infrastructure flexibility. The ability to transport information depends heavily on the flexibility qualities in each group of IT infrastructure resources. Specifically, participants' open-ended comments stressed that standards for middleware and network protocols should be included among the important relevant technologies. The emphasis on network and telecommunication technology probably reflects its widespread status as an architectural hurdle in IS organizations' recent efforts to develop client-server technologies. Apparently, firms are keenly aware of their own implementation difficulties and their consequences.

The values of sharability and reusability both arise in the issue of compatibility for applications and data as well as for platform and network technologies. Problems with sharability and reusability of data and applications are dramatized through conflicting uses of respondents' language. The words "system integration" and "coupling" were used both positively and negatively by participants in the study. For instance, one participant observed that "connectivity will lose importance as we decouple systems and standardize interfaces." Yet, others emphasized coupling as a critical concept related to the sharability and reusability of technology. Similarly, while in general a capacity for increased system integration was treated as a very important infrastructure concern, executives in a major Texas insurance and investments firm spoke of integration as a source of maintenance misery. They described a case in which business management asked the IS organization to identify the implemented details of a specific business rule. It took IS two weeks to respond.

One explanation for these different views may be found in the implementation of the concept of IT modularity. Integration and systems coupling in the 1970s and even the 1980s often involved elaborate and uniquely contrived and implemented systems components. One IS executive in an insurance firm indicated that in a key legacy system, sixteen or seventeen business processes could be imbedded in the centralized system. Processes are so tightly integrated that a change to one process might affect sixteen others. These unique integration characteristics are now haunting current efforts to implement modern, modular integration concepts.

The concept of modular systems was introduced decades ago with structured programming. The idea is that applications are more manageable when routines are coded in separate modules. Today, IS executives seek a more sophisticated form of modularity which expands the concepts of sharability and reusability to both applications and data. The concept of modularity for applications has to do with isolating and standardizing as many business and systems processes as possible. At the most elementary level, IS organizations realize they can modularize routine systems processes such as data calls. At a more elaborate level, an IS organization may routinely store as many rules and functions as possible separately from the main application. Encapsulated in separate modules, business rules, implementation code, and individual processes may become far more accessible.

Modularity applies to data in a fashion similar to that of applications. Each firm's IS technology history, its unique perspectives on data ownership and usage across business units, and its approach to infrastructure all affect the sharability and reusability of data. Data, its rules, and its access options, when distinct from specific applications, may be redeployed easily as requirements change and technological barriers fall. The extent to which data and data management technology do *not* need to be changed when radical changes in processes or technology or systems occur may reflect the true flexibility of this part of infrastructure.

One additional concern in modularity identified for both data and applications is access. Participants in the study repeatedly emphasized that both the location and actual configurations of data or application segments need not affect infrastructure flexibility if access can be managed modularly. That is, if gateways are constructed that automate the work of finding and accessing data or applications, then they may provide the flexibility needed. This perspective raises the issue of whether gateways are actually an important part of infrastructure flexibility or are another instance of a temporary solution to the consequences of inflexibility. Either is possible. If gateways are standardized or modular, then conceivably they become part of the infrastructure and substitute for data and application flexibility. If they are not, they may add the sort of complexity to the infrastructure that obstructs flexibility.

Resource Management Issues

Other flexibility issues raised by participants illuminate our previous discussion on those IT resource management issues related to flexibility. Comments and suggested indicators provide insight into an applied view of flexibility management; they also suggest ideas for flexibility evaluation and management, which are explored in the next section.

Alignment

The alternate views of the relevance of planning alignment to infrastructure flexibility discussed previously are raised by participants through two perspectives on business leadership of IT: the degree to which high-level planning was integrated between IS and business management, and the business management's tendency to value information technology in general. Comments that suggest the former focus on IS management participation in business planning, and the involvement of business unit managers in IT planning. As discussed earlier, these values may reflect the practitioner's effort to substitute excellent planning for preparedness for the unknown.

Yet other comments and suggested indicators seem to represent a different perception of the relevance of business management involvement to infrastructure flexibility. These indicators center on a general supportiveness from business management toward the value of IS services in general and the importance of infrastructure in specific:

- What is the business unit manager's attitude about IT?
- Do business and IT management understand the relation of corporate standards to costs and flexibility at a high level?
- Does business management understand the need for infrastructure rules?
- If business executives view IT as a strategic weapon for the business, then that IT group has high flexibility.

These concerns seem to suggest that infrastructure flexibility may be affected by a kind of support from business in which the need for infrastructure is recognized and IT leadership in planning for and managing those resources is supported.

Skills

Skills were identified by numerous respondents as important to infrastructure flexibility; yet, again, perceptions varied on what *kind* of skills mattered. The division by technology and business acumen is useful here. Respondents recommended that a flexible infrastructure would be dependent on skilled IT professionals. Recruiting policies for new skills acquisition, training practices, and an awareness of emerging technologies were cited as useful indicators of technological expertise available in the firm. Further, knowledge of both "old paradigm" skills such as COBOL and mainframe maintenance, and of integration concepts such as reuse, coupling, and cohesion were suggested.

In addition to skills in the use of new technologies, respondents listed skills with older technologies, complex resource management techniques, and knowledge of the business among their more important concerns in IS professional skills. Balanced business and IT skills among IT professionals, and experience in multiple business units of the firm were both listed on the survey and discussed in the meeting. Two interpretations of this issue may be pursued.

Many of the IT professionals describe their chief job responsibility and the key role of IS services within the firm as centering on the need to be responsive to the specific business demands of business users as they occur. The immediate pressures of continual new requirements and burdensome work backlogs place these IS organizations in a constant position of playing catch-up. Where this is the guiding philosophy of the IS organization, infrastructure development is heavily constrained. In such cases, knowledge of business practices increases IS's ability to prepare to be responsive in the relative short term, and thus knowledge of the business and its plans are very important.

An understanding of the business may also be seen as necessary to the IS professional's understanding of IT resources. A clear understanding of business practices and the firm's tactical philosophy may alter the IT professional's perception of data or applications as resources. Thus, those skills may be quite valuable in true, long-range infrastructure planning.

Architecture

A third concentration of issues has to do with systems architecture. This construct is arguably the most problematic in practice. Rules and standards are a cornerstone of IS architecture; they represent the firm's organized effort to balance conflicting needs and costs. Yet they also represent a difficult flexibility trade-off. While strict standards about technologies increase the ease with which IS can ensure sharability and reusability of infrastructure components, they reduce business options for IT implementation.

Yet, an important infrastructure management concern of participants is the growing attractiveness of the option to outsource "point solution" applications. One participant explains:

> A major determinant of flexibility is the ability to purchase off-the-shelf business solutions. This means that you must position your technology (hardware, operating systems, networks) in the mainstream where commercial products are being targeted.

In follow-up interviews, one IS executive explained that his firm's preference for meeting new systems requirements was to look at in-house resources to determine whether already owned systems or subsystems could be adapted to meet the need. Second choice, if the first is ruled out, is to seek shrink-wrapped solutions. In-house development was seen as a third, and least desirable, option.

If flexibility of infrastructure includes the ability to support a variety of unplanned outsourcing solutions to IT problems, the problem of restrictive standards is heightened. Such solutions are increasingly important to the maintenance of compatibility and connectivity, yet at the same time they may reduce the variety of choices available to systems implementers.

To attain flexibility for outsourcing, emphasis on standards for the critical resources themselves may have to give way to standardizing interfaces between new applications, related applications, data, and platforms. Clearly there is a difficult trade-off that must be managed insightfully by IT management in any firm.

These more complex perspectives on flexibility offer further evidence that the nature of skills relevant to infrastructure flexibility depends on the IS role in the organization. Participants agreed that where the mission of the IS organization within a firm focuses more on service provision and system implementation than on systems building, knowledge of vendors and the ability to build relationships with them become valued skills. In these cases, expertise in the processes of system adaptation and gateway management may precede development skills in value in the IS organization. These skills support the firm's ability to "leverage" its resources by improving the feasibility of hybrid business processes. The relative importance of such skills to infrastructure flexibility may vary with the IS organization's leadership or service orientation.

Measurement

THE RESULTS OF THIS STUDY REVEAL THAT THE "FLEXIBLE INFRASTRUCTURE" construct does have commonality across firms at a certain level. Detailed information about the conditions, characteristics, symptoms, and barriers to flexibility uncovered in this study may be used to begin to develop structure for further exploration of the construct, both for business and for research purposes.

To this end we propose a framework for infrastructure flexibility evaluation. This framework combines three component elements of infrastructure flexibility: the technological components of IT infrastructure, flexibility characteristics, and types of applied flexibility indicators. The basic values of infrastructure flexibility, sharing and reuse, are included in the form of the three applied values previously discussed:

Table 2 Infrastructure Flexibility Dimensions of Evaluation

Components	Flexibility qualities	Types of indicators
Platform	Compatibility	Component characteristics
Networks/telecomm	Connectivity	IS resource management practices
Data	Modularity	IT capabilities
Applications		

resource compatibility, connectivity, and modularity. The framework also includes three means of resource evaluation, or types of flexibility indicators. The components of the framework are depicted in Table 2.

The three types of indicators were classified from the set of comments and suggestions made by IS executives involved in the research. They enable us to gauge the presence of flexibility values in a firm. By applying flexibility qualities to the types of indicators, we may devise an instrument for evaluating a firm's IT infrastructure either for in-house self-study or for research. Technological components' characteristics may be evaluated individually. Naturally, individual firms or industries may need to identify for themselves which characteristics they deem most important. Then resource management practices can be evaluated, again, in the context of industry or firm needs and values. Finally, infrastructure flexibility may be tested through capabilities of IT services in a variety of firm- or industry-appropriate business requirements.

Table 3 presents a list of sample questions based on the flexibility ideas identified in this study and illustrating each of the three indicator types. The sample questions include both subjective (e.g., cell 8) and objective questions (e.g., cell 2). Since they are a first effort to evaluate infrastructure, and because infrastructure flexibility is such a complex construct, both types are needed. An accurate response to some of the questions would require extensive analysis. To accommodate the participant's need to approximate responses, the questions are designed to support Likert or percentage range response scales. In the following sections, we describe the application of the framework underlying the questions in Table 3. The discussion is organized around the three types of indicators.

Component Characteristics

Flexibility qualities of the technical components of infrastructure include such concerns as fundamental compatibility and connectivity. Flexibility features such as the presence of user interfaces that provide invisible access to platforms (Table 3, cell 1) may indicate some of the tools of flexibility. In isolation, such an indicator may seem strategically trivial at first blush, since individual examples may be easily acquired in a variety of ways. However, the great quantity of resources involved and the historic complexity behind their sharability and reusability may in fact make the composite difficult for competitors to imitate.

Table 3 Sample Indicators

	Infrastructure Component Characteristics	Resource Management	Capabilities
Platform	(1) Today user interfaces commonly provide invisible access to platforms. (L)	(5) Current corporate rules and standards for hardware and operating systems support: —future platform compatibility (L) —standardized platform gateways (L)	(9) What percentage of applications software can be transported across multiple platforms today?
Network/ telecomm	(2) What percentage of all PCs in the corporation are networked today?	(6) Current corporate NW standards adequately address: —Vendor choices for NW operating systems (L) —Protocol selection and use (L)	(10) To what percentage of branch offices can you transmit data electronically?
Data	(3) In our major systems, data rules and relations are not hardcoded into applications. (L)	(7) Our firm has formally and sufficiently identified data to be shared across business units. (L)	(11) What percentage of corporate data is currently sharable across organizational boundaries?
Applications	(4) Generally speaking, business rules such as tax regulations are hardcoded into the relevant application module. (L)	(8) Our firm has adequately identified those business process components which are sharable. (L)	(12) The complexity of current applications software seriously restricts our ability to develop systems of single-process, reusable modules. (L)

(L) = Likert response scale required.

For decades, producers of platform technology have upgraded their systems as well as innovated new ones. Each new generation of platform technology has had to manage compatibility with older systems. Firms that commit to only one platform type give up the flexibility of access to special capabilities of other products; firms that have acquired a variety of platform technologies with little compatibility may face integration problems. Firms that manage the issue with use of compatibility tools such as middleware may have greater flexibility than either of the other two.

Resource Management Practices

The practices of the IS organization are particularly useful for gaining insight into the qualities of the secondary characteristics of infrastructure flexibility. The presence of formal or informal rules and standards can be explored to understand the firm's use of architecture to increase (or decrease) flexibility. The presence of standards indicates the firm's commitment to planning its development of IT resources and hence may indirectly reflect its commitment to support IS requirements. The nature of the standards provides valuable insight into how the firm views this resource. Standards may be designed chiefly as cost controls, or they may be in place also to increase flexibility by ensuring such characteristics as technical compatibility and connectivity. Naturally, *how* they ensure compatibility will affect flexibility too.

Questions can be developed to determine whether a set of standards exists, first at the organizational level (an IS architecture) and then at the level of infrastructure components (e.g., is there a set of platform standards, or network standards?). Are these standards formal or informal? Do IS planners perceive them to be adequate to secure the needed level of infrastructure flexibility? Then participants can be asked to identify which of the listed characteristics for each group are governed by standards.

Similarly, business practices that affect the ability of IS to plan, study emerging technologies, or acquire training are indicators of practices that will affect the development or maintenance of IS professionals' skills.

IT Capabilities

A flexible infrastructure may be assumed to be causally linked to IT service capabilities. For instance, compatibility of hardware, operating systems, and networks determines the transportability of systems across platforms, and transportability affects the cost and feasibility of changing processes, distributing systems, or reusing parts of systems in new ways. Hence, the service capabilities themselves may provide indirect indicators of flexibility. Both business and IS development capabilities may reflect the flexibility of infrastructure components. From the IS development perspective, we may ask how long it takes IS to perform certain common development or maintenance tasks in order to begin to capture flexibility for the related components. "What percentage of applications software can be transported across multiple platforms?" (Table 3, cell 9) describes IS capabilities dependent on platform compatibility. How easily certain information-based business needs can be implemented may provide further information on infrastructure flexibility; for instance, can resources be shared across some specified boundaries? While any one issue may not capture the entire flexibility of infrastructure, a collection of issues together may provide a third window on a firm's instantiation of the construct.

The framework presented in Table 2 provides the technologies, the qualities, and the types of indicators that must be combined for analysis of infrastructure flexibility. While the qualities of flexibility outlined through the framework may seem simplistic at the outset, the implementation of those qualities, and the relative interpretation and importance of resource management issues may vary across industries and even from firm to firm. Hence, the development of questions for benchmark tools may best be undertaken, for now, on a case-by-case basis.

Uses and Research Directions

THIS WORK OFFERS A FIRST STEP TOWARD DEVELOPING an applied definition of infrastructure flexibility. The information and tools resulting from this research offer new information on the nature of a complex and strategically important set of IT resources. It identifies specific technology components and qualities key to the flexible infrastructure construct. It clarifies the dilemmas implicit in conflicting IS management functions and their implications for infrastructure. It suggests a simple model for developing infrastructure evaluation tools.

This first step points out a great deal of creative and analytical work that must be done to develop a usable set of infrastructure measures, to establish the contexts in which these measures are reliable, and to guide their use in both IS practice and research. The nature of the work to be done may be illuminated through descriptions of the future benefits.

Benchmark Development

This work provides a framework for developing a benchmarking instrument for the systematic analysis of infrastructure resources. Such an instrument can be used to support a firm's self-evaluation of infrastructure including periodic reviews of the relevant resources. It may also be used at the industry level so that firms can determine how their infrastructure compares with that of their competitors. An instrument for this purpose has been developed and implemented by the author for the life/health insurance industry.[4]

Instruments for other industries must be developed and implemented in order to gather data for several purposes. As we gather analysis tools and use them, we will become better able to judge the relative strengths and weaknesses of various indicators. Analysis of flexibility issues across industry groups should provide strong data for clarifying some of the construct uncertainties described in this work. First, data are needed to clarify the contexts in which flexibility indicators are meaningful and reliable. Specifically, we may need to consider industry, firm size, age of the IS organization, information intensity of the industry, and the firm's perceived information intensity. More data must be collected in the field on IS professionals' experiences, problems, and practices with infrastructure building. These data will enable us to develop weights for the various issues presented here. Systematic analysis of infrastructure flexibility in business is also needed to tie component features to the requirements established by resource planning and management. These data will help us establish the conditions under which various infrastructure choices are appropriate.

As benchmark tools are refined, the firm may find the instrument to be useful for justifying "IS-push" expenses. That is, firms frequently find that IS investments in specific business applications are much more easily funded than are infrastructure-related costs, because individual business applications are more obviously related to their business value, while infrastructure resources are perceived as expensive overhead, or frills. As overall factors of flexibility are uncovered and flexibility is linked to capabilities, the IS professional may find it easier to demonstrate to general management the value of these previously unquantifiable resources. Hence, justification for infrastructure investments may become less difficult.

Research in IT Resource Value

The development of a set of measures of infrastructure flexibility offers significant value and challenges to IS research. As benchmarking tools become available, they may be used in research intended to relate specific types of IS resource investment to firm value and performance. For example, a study of the impact of outsourcing on infrastructure flexibility in the insurance industry using the benchmark data mentioned above is in progress [11]. Although practitioner experience and some theoretical work [7, 27] lay out compelling arguments for the strategic value of infrastructure, the measurement tools needed for a generalizable study simply do not exist. Yet there is much promise in a resource-based approach to empirical research of strategic information technology. Weill's study of the value of IT by type [28] opened a new door in both method and theory. His findings offer evidence that IT type does affect strategic value, and conjectures that industry type is also a determinant. Weill's work was in the manufacturing industry. To carry this type of work forward into the service industries, measurement of infrastructure flexibility is essential.

NOTES

1. Thanks to Eric K. Clemons for sharing this example with me.
2. Object-oriented technology.
3. Causal ambiguity and historic complexity are two sources of resource inimitability defined by Barney [2].
4. A description of the results is forthcoming through the trade journal published by the Life Office Management Association (LOMA).

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