INFORMATION TECHNOLOGY PLANNING FRAMEWORK FOR LARGE-SCALE PROJECTS

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ABSTRACT: New information technology developments continue to have a significant impact on large-scale architectural/engineering/construction (A/E/C) projects. However, the issue of whether A/E/C organizations are receiving adequate returns from their information technology (IT) investments remains an important managerial concern. Earlier work on financial models has concentrated on firm-wide strategies for maximizing the return of investments. Traditional financial models for measuring the value of information technology investments typically work well for static business strategies and single business scenarios. These models are inappropriate for large-scale A/E/C projects, which typically have multiple firms participating over a fixed project life cycle and proportionately splitting the cumulative benefits accrued over the project life cycle after their involvement on the project. To resolve these issues, the paper proposes a strategic planning framework based on IT diffusion for maximizing the value of investments in strategic capabilities. The essential steps in the strategic planning framework include environmental scan, internal scrutiny, IT diffusion analysis, and IT investment modeling. To demonstrate the framework and an integrated approach to IT investment planning, the paper presents a case study based on a large-scale A/E/C project.

INTRODUCTION

The importance of information technology (IT) in the architectural/engineering/construction (A/E/C) industry has grown exponentially over the past years. Computer-aided design packages, scheduling and contract management software, document management systems, and Internet applications have demonstrated their ability to improve operations, increasing both service quality and productivity. Hence, investments in IT have become a dominant part of capital budgets of many large-scale A/E/C projects. In addition, the increasing number of applications of IT, and their direct and indirect impacts to the core business, have made management of the IT investment process an increasingly critical problem for the senior management of large-scale A/E/C projects. As IT programs in projects grow in complexity, functionality, and magnitude, it has become increasingly important and increasingly difficult to evaluate the benefit that such an investment will return. To summarize, the senior management of large-scale A/E/C projects is faced with a number of difficult questions:

- How should IT investments be designed to ensure alignment with overall project objectives and strategy?
- How should these investments be prospectively justified?
- How can the value of these IT investments be measured over the project life span?
- How can the value of IT investments be quantified when the benefits accrue to more than one participating party (i.e., owners, contractors, and architects)?

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Answering these questions for the senior management of large-scale A/E/C projects requires a paradigm shift from the current project management approach to an investment management approach requiring periodic valuation, monitoring, and evaluation of investment programs over the project life span. To create such an investment management approach, there is a need to develop a sound methodology for planning and evaluating IT programs that will (1) allow greater accuracy in planning; (2) provide data on the return of IT investment; (3) reduce the risk associated with such a strategic investment; and (4) monitor the benefits of the IT investment over the entire project life cycle. In addition, such an investment management approach would need to handle the continuous infusion of IT investments over the project life span. It would also need to give sound quantifiable results of such an infusion in the project. IT investments in A/E/C projects also have to address important characteristics of large-scale infrastructure projects such as a fixed project life as opposed to an infinite life span for most firms and split cumulative benefits accrued by a number of different project participants over a number of years. To address these issues, this paper proposes an IT strategic planning framework based on the environmental scan for identifying the factors to be considered in developing and evaluating an IT planning, deployment, and evaluation program for large-scale A/E/C projects. This involves understanding the internal businesses of the A/E/C project as well as the external dynamics of the overall economic environment. An IT investment modeling technique for calculating the return of IT investments in large-scale A/E/C projects. To highlight the basic components of the IT strategic planning framework, the paper presents a case study based on data from a large-scale A/E/C project.

STRATEGIC PLANNING FRAMEWORK

The strategic planning approach formulated here (Fig. 1) is based on prior research (Weber and Peña-Mora 1997) on a generic IT diffusion model for the economic sector in a region. Motivated in part by work done by Hax and Majluf (1996) and Tozer (1996), the framework provides a unifying architecture for dynamically analyzing field data and the associated IT investment modeling. Before formulating such a dynamic IT strategic plan in a large-scale A/E/C plan, it is necessary to identify the needs for IT and the potential competitive advantages (as well as their sustainability) that could be achieved through its use in a project. The competitive advantages could be provided in the form of operational advantages (e.g., faster

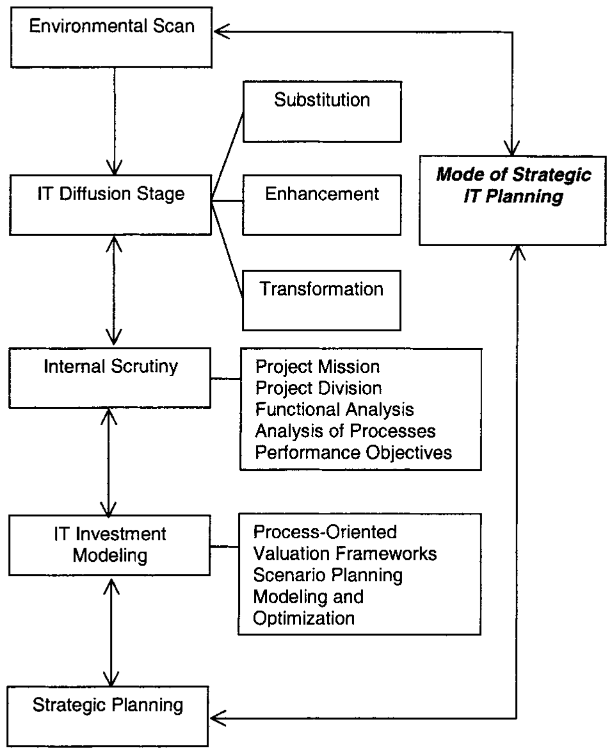

FIG. 1. IT Strategic Planning Framework [adapted from Weber (1997)]

turnaround in change orders because of reduced transmission time) or strategic advantages (e.g., design can be performed by a distant contractor with teleconferencing tools). To estimate the specific value of IT for a firm, several valuation frameworks have been proposed in the literature (Brynjolfsson and Hitt 1996; Mooney et al. 1996). These prior research efforts have suggested that for a correct assessment of IT value, second-order effects such as the efficiency variability of owner-contractor relationships, typical in A/E/C projects, have to be taken into account, which complicates the necessary analysis. Furthermore, market dynamics can generally be expected to have a more pronounced impact on individual projects than on consolidated firms. Hence, strategic IT planning for large-scale A/E/C projects has to consider the particular growth dynamics and changes in the relationship with the project participants. In this context, it has to be clarified what role IT can play and where it can add value, compared with other more traditional production factors, such as a new crane for the A/E/C project.

The first step in the framework is to understand the businesses of the A/E/C project as well as the dynamics of the overall economic environment in which the project operates. This environmental scan yields the boundary conditions for the strategy of the project and has to be followed up by a thorough internal scrutiny at the intraproject level and the different functional units of the project. Given these two elements, one can identify the strategic thrusts and possible performance measures for the project.

The second step in the development of an IT strategy is an analysis of the relevant processes and functions within the A/E/C project. The strategic thrusts and performance measures developed in the first step are used to create ''guiding benchmarks'' for continuous monitoring. More specifically, it is important to identify the intraproject flows of control and information within or across functions and processes. Subsequently, interproject networks as established in strategic alliances or in contractor-owner relationships need to be considered.

The third step in the development of the strategic plan consists of developing an IT investment model that can then be integrated into the overall strategic planning framework to devise the generic dynamic strategic plan introduced above. In particular, the following questions have to be considered:

- What are the current plans in terms of internal network and external information sharing?
- What are the different levels of information sharing at present (facsimile paradigm, information repositories, or interactivity)?
- Which groups of information (financial, engineering/design, managerial, and documents) are likely to be shared, and which of those are the first to be made accessible.
- Definition of information to be shared on a step-by-step progression between various project participants.

ENVIRONMENTAL SCAN

The 1990s have been a time of great advances in the use of information technology in the A/E/C industry. It has also been an era with a marked change in the overall objectives of IT deployment within the A/E/C industry, with the focus shifting from that of managerial decision support to one that leads more to the overall competitive advantage. Even the primary target for IT applications has shifted from individual line managers to complete lines of business. IT is no longer a back-office support technology managed by data processing departments within individual A/E/C firms but an integral part of the senior management's responsibility. However, the A/E/C industry has shown a history of erratic IT spending (Betts 1992). The peculiarities of the A/E/C industry such as site driven production, long but finite project duration, and project costs, add to the already complex problem of calculating the IT investments. The organizational structure of the industry on the whole, in terms of the separation of design and construction, the growing degree of specialization in the industry, and multiparticipant design and implementation phase, has exacerbated the problem even further (Betts et al. 1991). It is not sufficient to concentrate the environmental scan at the macroscopic level of the A/E/C industry alone. This is because even at the microscopic level of large-scale A/E/C projects, IT spending has grown rapidly with operations and maintenance costs dominating the budget. In addition, an environmental scan can capture the dynamic nature of project participants in a large-scale A/E/C project. To better understand the relationship of all the components of an IT program for large-scale A/E/C projects, it is helpful to examine the program in a systematic way, looking at the various investments, and the direct as well as organizational returns from these investments.

Before A/E/C projects can attain stated benefits from IT deployment, they must traverse an IT abyss (Dempsey et al. 1997). The IT abyss has been traced back to the gradual diffusion of IT within a project. The gradual IT diffusion refers to the lag between IT investment and realization of the cumulative benefits arising from the investment during the project life cycle. Investments are high at the start of a phase, and as the technology is adopted, the investment decreases, until a new phase starts and new investments are required, creating a declining step function (Fig. 2). As the direct and indirect effects of IT are felt, a push for a project to enter a new diffusion phase is felt, both at micro- and macrolevels. Armed with an in-depth diagnosis of the IT diffusion process, the top management can determine the best strategy to improve their overall IT performance in projects.

IT DIFFUSION

When an investment in IT is made, there is a time lag before that technology is adopted throughout the project, and its full

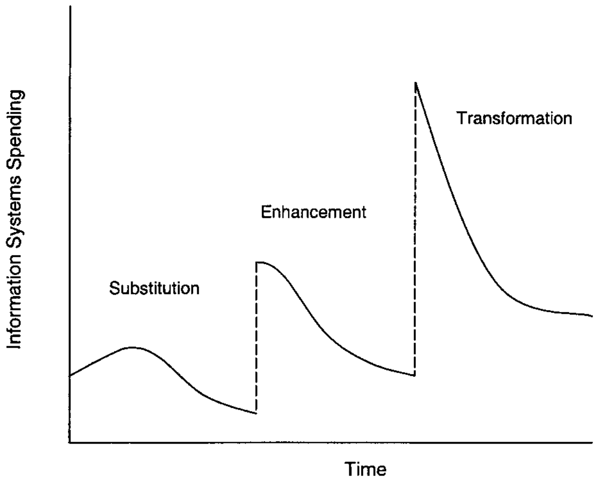

FIG. 2. IT Diffusion Modeling: IT Funding

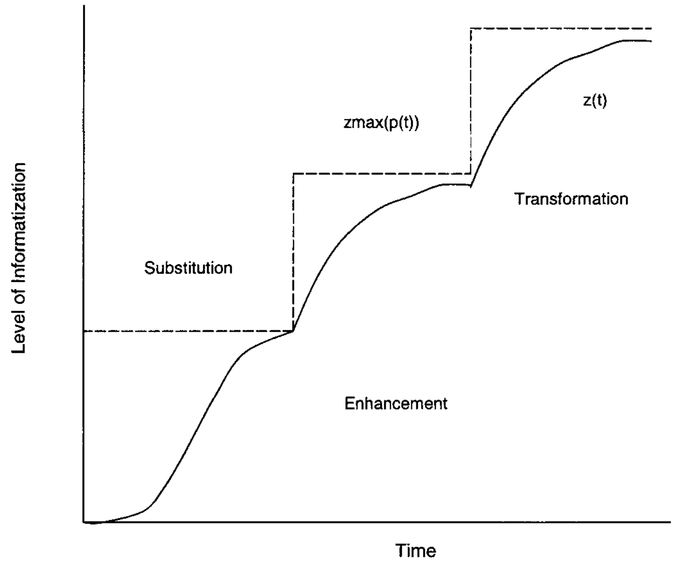

FIG. 3. IT Diffusion Modeling: Level of Informatizaton

potential is harnessed (Weber and Peña-Mora 1997). This process of adoption is termed diffusion. Three main phases of IT diffusion have been identified (Hannah et al.): (1) Substitution of existing technologies; (2) enhancement of processes; and (3) transformation of organization and strategy. Within each phase, the diffusion process is seen as a sequence of ''S-curves'' (Fig. 3) that describe a stepwise progression. During this progression, structural, technological, and organizational barriers such as the lack of technological maturity, lack of information about technological possibilities, lack of ability to analyze problems, lack of resources to realize optimal changes, and lack of ability to implement changes optimally are overcome.

As time progresses on the project, the level of informatization on the project rises as shown in Fig. 3. During the substitution phase, IT is used to replace existing processes. The returns seen during this phase are often related; automated tasks and electronic transmissions decrease wasted time and improve efficiency. One example might be the efficiency realized by the computerizing drawing transfer in the design phase of a project. Enhancement occurs as the organization realizes new, more effective, or efficient processes that increase quality or improve productivity on the project. An example of an enhancement strategy might be the automatic monitoring of material inventory, with global purchasing based on project and market conditions. Transformation involves the evolution of the strategy to a point where IT forms a major part of the deliverable product. The development of ''smart'' components of a highway might be an example of an evolution technology. The creation of a web-centric integrated field office where the contractor, designer, and owner representative work together can also be classified in the transformation phase. In that case, all of the project participants could work collaboratively with the same data that is collected once and reused for all the different tasks appropriate for each party, with the explicit understanding that the data are the group project data and not single party data. Another example is an operation and maintenance adaptable close-out information system where the facility management system automatically builds from the information developed during the design and construction phases.

Understanding the above-mentioned IT diffusion phases is a first step in determining what phase the project is in and where it should go. IT diffusion phases also define how separable information technology is from the core project agenda. By clearly demarking the core project agenda from the IT investment process, the project management can quantify some of the benefits of IT in the project. Another important attribute of IT diffusion is the underlying definition that a project undertakes an IT deployment program based on its existing infrastructure. Thus, knowing the particular diffusion phase of a project, an estimate of the existing IT infrastructure and IT adoption decisions can be made.

Extending guidelines from Iacovou and Benbasat (1995) and adapting them for the A/E/C project context, the IT adoption decision for large-scale A/E/C projects can be defined in terms of (1) project readiness—the level of financial and technological resources within the project; (2) external pressures to adopt—when pressure is exerted from a third party on the project (e.g., public owner financing is a new way of doing business in large-scale A/E/C projects); and (3) perceived benefits—in terms of the relative advantage of IT usage on a project according to the concerned project participants.

In terms of informatization, Chow (1967) used statistical tests to show that both Gompertz and logistic curves can adequately describe increasing demand for computers. For a long time, the infrastructure investment in computers was used as a measure for informatization and IT investments. The logistic growth curve $Y(t)$ has been expressed as the solution of the equation

$$Y(t) = \gamma Y(Y\max - Y) \qquad (1)$$

where γ and $Y\max$ = positive constants. However, it has become important to take into account other investments made in software, training, and methodologies in addition to computers to better estimate informatization and IT investments. Paich and Sterman (1993) used a more general logistic growth model to simulate complex boom/bust dynamics of ''experimental'' markets. Typical IT investment patterns closely follow such boom/bust dynamics (Fig. 2). The essential difference between such a generalized logistic growth model and Chow's simplified version is that additional variables are included to capture different ways in which growth might be influenced. These variables will be chosen to describe IT adoption or deployment qualitatively in Iacovou and Benbasat's terminology (1995), as introduced above. Based upon this analysis of IT growth within single projects or across several different projects, a (generalized) logistic diffusion model has been formulated. Weber (1997) described the level of informatization $Z(t)$ (i.e., the ''accumulated IT adoption and deployment'' in a project) as a function of time t. Then $Z(t)$ is described in terms of the following first-order ordinary differential equation:

$$Z(t) = (Z\max(p) - Z)\,(\boldsymbol{\alpha}\mathbf{1} + \boldsymbol{\alpha}\mathbf{2}Z) - \boldsymbol{\beta}Z \qquad (2)$$

where $\boldsymbol{\alpha}\mathbf{1}$, $\boldsymbol{\alpha}\mathbf{2}$, and $\boldsymbol{\beta}$ = nonnegative scalars, with $\boldsymbol{\alpha}\mathbf{1}$ = external adoption pressures, $\boldsymbol{\alpha}\mathbf{2}$ = perceived benefits, and $\boldsymbol{\beta}$ = system upgrading/discard rate. The (generally varying) saturation level $Z\max(p)$ describes the maximum level of informatization that may be supported at any given instant in a project, depending on a parameter vector that may incorporate, for example, the price of the new technology. Note that this saturation level is not reached for $\boldsymbol{\beta} > 0$ and that the S-shape of the logistic curve segments is most noticeable in the early stages of diffusion. A more detailed example is included in Weber (1997) and not repeated in this publication. However, the conclusion of that work is that to correctly plan any IT investment on a project, there is a need at various stages in the project life cycle to identify the IT diffusion stage of the project. Based on the IT diffusion phase a project is in, the project can be evaluated in terms of the informatization level it can support to limit under-/overspending on the project.

INTERNAL SCRUTINY

In planning an IT program, it is important to be able to assess the costs and benefits that will be realized. Quantifying the direct and indirect benefits from an IT program requires internal scrutiny at the project level. This would require a functional analysis of processes directly and indirectly benefited by the IT project. Cost predictions can be made based on a number of scenarios once the requirements in terms of hardware, software, staff, and training have been developed. Benefit predictions, however, must be made based on approximate models of varying accuracy. The reliability of the predictions is controlled directly by the accuracy of the benefit model. In the dynamic realm of information technology, there is no magic formula, which will provide an accurate benefit analysis. Thus, the lack of accurate information during planning phases necessitates a continuous, parallel, planning, and deployment strategy. By iteratively updating the plan based on progress feedback, it is possible to refine the program to deliver the best information on return on investment. The key to the success of this process is accurate measurement and evaluation throughout the project development.

The most straightforward approach to measuring benefit from an IT program is through an internal scrutiny by trying to measure performance of specific, predetermined goals. Taking the needs and goals identified in the early phases of the definition, along with the project positioning in the IT diffusion stage, a way of tracking performance in those areas is developed. For example, a predicted gain of IT investment on a project might be a reduction in processing time due to electronic transmission. The average time required to complete a common action or class of actions affected by transmission time could be tracked, and data obtained could show time saved. In this way, estimated gains are measured against actual outcomes. It should be noted that this also includes the identification, and tracking of estimated pitfalls as well as gains. Using this method, returns are identified as goal achievements. This allows analyses to shed light on the validity of the goal set, and the applicability of the solution to those goals. The data are also directly related to project processes, hence time-responsive, and give a faithful time-lapse representation; changes in the performance are immediately seen in the results. By tracking performance in several distinct areas independently, it becomes possible to evaluate the success of the program on a very fine scale. If the data are gathered over enough time, and at close enough intervals, the results can also capture the effects of the training/learning phases, allowing better prediction of further learning.

The possibility of tracking an IT implementation from the planning phase through its entire life cycle allows the necessary monitoring to follow concurrently with the implementation. It is also important to periodically update the evaluation process to accommodate unanticipated aspects of the investment. Actual users need to be surveyed to identify these unanticipated aspects, and new data taken to capture them. In this way an internal scrutiny could track both predicted and unpredicted losses and benefits from IT projects.

INFORMATION TECHNOLOGY INVESTMENT MODELING

The IT investment process can be broken down into three main processes: (1) Systematic identification of potential IT applications; (2) economic justification of each application by forecasting the return of investments; and (3) recommendations of IT projects involving the combination of economic justifications with business logic. The identification of potential IT applications is typically carried out by the IT division of a project with final recommendations being made in conjunction with the core project managers. A number of theories has been put forward for the intermediate step of economic justification of IT investments. For example, several authors (Weill and Olson 1989; Clemons and Weber 1990; Brynjolfsson and Hitt 1996) have attempted the measurement of the return on investment for information technology in large firms. Brynjolfsson and Hitt (1996) collected data for investment and earned value over a long period of time and identified the production coefficients of those components. However, the project life span of typical large A/E/C projects may not be long enough to look at investment in such a continuous manner. It is therefore important for the evaluation to start with classifying the IT investments and then to extend the scope beyond the returns realized during the project development phase.

Investments

Before calculating the return of IT investments in projects it is important to classify the investments. Such a classification is also useful in the evaluation phase when the benefits resulting from the IT program can be systematically categorized. Through interviews, this research effort has identified that the investments in an IT program can be divided into hardware, software, training, support, and personnel. It is important to note that the nature of these investments will vary over the life of the project, as it proceeds through the different phases of IT development. Depending on the complexity and uniqueness of an implementation, these categories will carry differing weight, both in terms of impact and in terms of investment. For example, a unique IT implementation may require a great deal of development, whereas a complex but standard implementation would require a comparatively higher investment in standardized hardware. Another key element in IT investments that often plays a key role is the investment made in personnel as part of the IT investment strategy. In the case study used for this research effort, personnel costs were more than 60% of the total IT investment. The personnel may include untrained employees who will become the users of the technology, semitrained professionals who will be part of the administration and support staff, pretrained experts to take the lead in the implementation, and expert consultants to assist and/or architect the implementation. The makeup of this team depends largely on the uniqueness of the implementation. As such, the composition of the personnel will have a large influence on the training investment and the success of the IT strategy.

Returns

One approach to measuring IT returns is to focus on areas within the organization where value is created (Tallon et al.

1997). Increased productivity, increased quality, and risk reduction can be cited as the primary returns from an IT investment (Venkatraman 1997). It is important to note that their effect is also felt throughout the development and deployment phases of the project. It is important to mention here that IT investments can result in negative returns especially during the deployment phase. For example, negative returns are felt throughout the development phase in terms of employee turnover. The loss of trained employees represents a loss in the overall expertise of the workforce. In the area of information technology, this expertise is a particularly important asset.

In addition, at the end of the project deployment phase, the accumulated IT value of the organization—the staff of trained employees and the software and methodologies developed during the project—is shared among the organization participants. As this value represents a considerable benefit, it is important to consider which participants will benefit from the IT program and to what degree, during the planning stage. By identifying the primary beneficiaries of the IT investment, it may be possible to leverage those benefits into a benefit for the project at large as well as to assign investment contributions.

Organizational Breakdown of Returns

The immediate returns mentioned above, in productivity, quality, and risk reduction are of primary benefit to the owner and operator of the project. In addition, IT investments that fall under the diffusion category of substitution are intimately involved with the deliverable product. Their return value is value added to the project itself, after the deployment phase is complete. In the example of smart highway systems, the return is in the efficiency and operability of the highway itself, taken throughout its lifetime. In this way, the primary benefit is again to the owner and operator of the project. This is, however, not the case for all the returns that an IT program can generate. Expertise, software, and IT related methodologies, all important products of an IT program, are shared among the project participants including designers and contractors. In addition, it is possible, in many cases, to identify tangible benefits of IT development that are passed on to the public at large.

Throughout the project lifetime, and at completion, as mentioned above, the project loses trained staff. Ignoring the components of the staff that came already trained (e.g., outside expert consultants), this represents a loss to the project of resources devoted to training. In the realm of information technology, this loss can be quite significant as technological expertise represents an important commodity. This is especially true of cutting edge or unique technologies. A large portion of this trained staff—those lost at completion—reverts to their parent organizations, either owner or contractor, thus giving some benefits to their parent organizations in the form of indirect benefits in addition to the more direct benefits arising from capital IT investments. This ''spillover'' effect is often neglected in calculating return on investments in traditional models. In addition, this may be considered a second-order benefit as knowledge and experience become an important commodity during IT deployment. Discounting the significant numbers of trained staff that are lost to third parties (the public at large), the training of those that do remain represents a gain to their parent organization. Thus, it may be important to note that a major portion of the returns generated by an IT investment would then be shared by the parties involved in that project, roughly in proportion to their staff.

Another important product of the IT program is the software and methodologies that were developed over its duration. The value of these products will vary with their applicability beyond the project. In an innovative technology, however, they will almost always have some value, as the stock in a knowledge base, to be used by the owner, management consultant, or contractor organizations in future projects. The ownership of actual software may be clear-cut, but the ownership of the methodology is given to those parties that have some mechanism for retaining and using that knowledge, either through retention of trained staff, or through electronic knowledge retention.

A final category of return, applicable to many large-scale projects is the public benefit; the owner in a large-scale civil engineering project is often a public authority. It is possible that the products of an IT program on such a project might benefit the public at large. Innovations made during the project, which affect the public directly, or advance industry as a whole, may be considered public returns and may be attributed to the public at large.

Fig. 4 provides a graphical summary of the ideas presented in this section. Investments are typically made in the form of hardware, software, and training for personnel. IT generates direct and indirect benefits for all project participants. The benefits are in the form of trained personnel and software methodologies developed. IT generates tangible benefits, as it changes the basis of competition as well as changes the ways of doing business in owner-contractor relationship. Hence, the realization of benefits from IT investments has a direct relationship to the project organization's ability to reuse the technology, methods, and processes after the completion of the project. Although all the project participants reap the major benefits of IT in large-scale A/E/C projects, most times, the owner picks up the costs alone. Based on primary and secondary benefits that a typical IT program can generate, this research effort proposes that the IT investment costs should be borne by all the project participants proportionately to the benefits that they receive.

Value and Depreciation

As discussed above, the products of an IT program may be of significant value to the project participants and may therefore be an important consideration in evaluating or planning an IT investment. It is, however, also important to consider the depreciation of that value, in evaluating the long-term benefit to the various parties involved. Training and knowledge are only a commodity as long as they are up to date. If their value is to be considered among the returns of an IT investment, it will be necessary to look not only at ways to quantify that value but also at the speed with which it depreciates, particularly in IT, where new technologies are introduced at a fast pace and the value of the technology may be limited. The same applies for software and hardware developed in the IT program.

Assessing IT Business Value in A/E/C Projects

To quantify the costs and benefits of information technology from the perspective of an A/E/C project, a statistical approach such as the one by Brynjolfsson and Hitt (1996) to study firms may not be applicable. Statistical approaches in the present context will be tedious as the IT benefits are accrued over the project life cycle and by a number of different project participants collaborating only at the project level, instead of a firm for undefined periods of time. Mooney et al. (1996) suggested a process-oriented approach for assessing the business value of IT that takes place both at the managerial and the operational level. According to Mooney et al. (1996), IT encompasses ''automational,'' ''informational,'' and ''transformational'' dimensions, which stand in contrast to firm level output measures.

According to the above process-oriented framework, Table

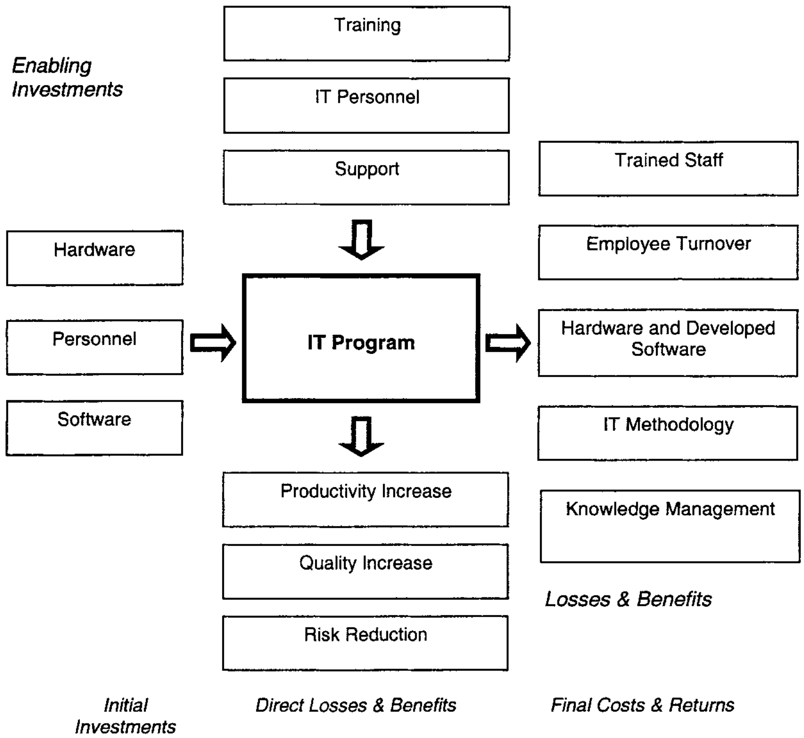

FIG. 4. IT Program Inputs and Outputs

TABLE 1. Process-Oriented IT Business Value Metrics [Adapted from Mooney et al. (1996)]

Business processes (1)	Dimensions of IT Business Value		
	Automational (2)	Informational (3)	Transformational (4)
Operational	Labor costs	Utilization	Product and service
	Reliability	Wastage	Innovation
	Inventory costs	Operational flexibility	Cycle times
	Efficiency	Quality	Customer relationships
Managerial	Administrative	Effectiveness	Competitive flexibility
	Expense	Decision quality	Competitive capability
	Control	Resource use	Organizational form
	Reporting	Empowerment	
	Routinization	Creativity	
Inter-Project	Transaction cost	Search cost	Collaborative design
			Outsourcing efficiency

1 [adapted from Mooney et al. (1996)] was supplemented here with interproject processes, to provide a starting point for a systematic IT value assessment. Note that the above IT value dimensions are related to the different diffusion phases explained in earlier sections. For example, the automational value will play a role mostly in the early stages of diffusion (i.e., substitution and enhancement), whereas in the later stages, the transformational value of IT is likely to become dominant. Issues related to the above business value metrics for IT are project size, economies of scale and scope, and linkages (i.e., interproject networks).

To determine an appropriate allocation of resources in IT, its business value for the project has to be estimated and compared to that of competing assets, such as direct production inputs. Hence, it is essential to identify the levels of information infrastructure to be considered by the A/E/C project management teams. The role of IT in the creation of value along the project's value chain and across the boundary of the organizations involved in a project has been controversial in the literature and is still being debated. Brynjolfsson and Hitt (1996) proposed three measures of information technology's value at a firm level: (1) Productivity; (2) Business profitability; and (3) Consumer surplus. Productivity is captured by a production function that relates inputs and outputs of the firm, whereas business profitability measures the competitive advantage in terms of return on investment. Consumer value reflects the benefits that have been passed on to consumers.

Despite many of the known and well-accepted benefits of IT such as reduction in transaction and search cost, as well as increase in efficiency of operations, actual productivity increases are hard to detect; one has to resort to large-scale, long-term analyses (Brynjolfsson and Hitt 1996). In fact, although benefits in second-order effects, such as customer satisfaction, improved contractor relations, and the controlling and enhancing of growth are often apparent, the direct impact on productivity is less obvious in most cases. Hence, it is important to ask the right questions when trying to assess the value of IT. Here, we are particularly concerned with the impact of IT on managing growth and managing owner-contractor relationships, as these are central issues for most large-scale A/E/C projects. IT can aid in managing growth on the project by providing real-time information for monitoring and controlling the project. The first is related to the internal information infrastructure of the project, whereas the second has mostly to do with communication and data sharing across the project's boundary.

The analysis presented in this paper will therefore be split into intra- and interproject information systems. An investment in intraproject communications has to precede any investment in interproject communications; that is, the development of efficient external communication links has to be based on a sound information infrastructure inside the project. For a good understanding of what processes of the project can benefit the most from the use of IT, it is useful to know what links exist between different processes and functions inside the project.

Another important input is knowledge of information streams that are in place to control the normal production workflow (e.g., from input to output), as well as to control special events, such as a change order. After having analyzed the internal information needs of the project, it is then important to identify points of communication and data sharing between different projects/organizations that are related in strategic alliances or owner-contractor relationships as mentioned before. Moreover, the management may have a personal stake in developing external communication links to improve contacts with other clients as well as to satisfy particular information needs, such as obtaining procurement information over the Internet.

Assessing the business value of IT concludes the discussion on the strategic planning framework based on IT diffusion, shown in Fig. 1. To illustrate the application of the framework outlined in the earlier sections, the remainder of the paper concentrates on a case study, but first, the essential theories and steps underlying the strategic planning framework presented in Fig. 1 are reiterated as follows:

- Perform an environmental scan to understand the overall business strategy of the A/E/C project and the economic environment in which the project operates.
- Identify where in the IT diffusion stage the project and the participant organizations are.
- In the internal scrutiny step, determine the need for an IT investment depending on internal processes as well as the level of informatization that can be sustained on the project. In this step, define the scope and analyze the design alternatives and the system definition for IT deployment.
- Lastly, divide the sources of costs and benefits, particularly for large-scale projects in terms of training, personnel, models, methods, and processes developed among the beneficiaries from the different organizations (i.e., owners, contractors, and designers).

CASE STUDY

First, as part of the environmental scan in this case study, a brief background on the Boston Central Artery/Third Harbor Tunnel (CA/T) project, including its scope and organization, is provided. Second, the scope definition of the case study, the various businesses and technical alternatives considered during the case study, and the system definition constitute the internal scrutiny step from the framework. The central issue is the optimal allocation of resources for the internal diffusion of IT within the CA/T project. This will highlight the IT diffusion stage in the framework. Then, the IT functional strategy at the level of the project with respect to the project strategic planning framework is presented next. Finally, the IT investment-modeling phase is highlighted by performing a cost/benefit analysis based on data from a sample IT deployment project from the CA/T project.

Environmental Scan

The Boston CA/T project is a multibillion dollar undertaking and currently the largest public works project in the United States. The core of the CA/T project is the transformation of Interstate I-93 through Boston and an extension of I-90 beneath the Boston harbor and onto Boston's Logan Airport. The part of the latter extension, including the new Ted Williams Tunnel, was opened in December 1995 to commercial vehicles. At present, major construction works are being conducted on an eight-lane underground section of I-93 to replace the old elevated section with a state-of-the-art expressway. The CA/T project is being managed by the Massachusetts Transportation Authority (MTA) in cooperation with a joint venture between two of the largest U.S. engineering and construction companies, namely Bechtel and Parsons Brinckerhoff (B/PB). The overall organization of the project is illustrated in Fig. 5. The project forecasts that the final cost by the expected project completion year of 2004 will be about $10.8 billion, with 70% to be paid by the U.S. federal government and 30% by the commonwealth of Massachusetts.

As a part of the case study, this paper presents the internal information technology strategy of the CA/T project. The project possesses a dedicated IT department that is subordinated to the engineering department of the B/PB joint venture but also reports to the client, MTA (Fig. 5). Global priorities for the IT section are set by the MTA project director and the program manager of the B/PB joint venture. On an operational level, the IT section is subordinated to the B/PB engineering department and reports in regular intervals to the MTA administration. The annual budget for IT in the CA/T project is fixed and in the order of magnitude of U.S. $5,000,000 used for direct expenses and personnel. This budget is at times augmented to cover extraordinary expenses. It should be noted here that information technology has always been a priority in the CA/T. Substantial IT investments have been made in the areas of 3D modeling and graphical fly-through and walk-through for clients and the public, as well as complex transportation analysis. The CA/T management views IT as an essential tool in achieving its objectives on time and on schedule.

Internal Scrutiny

The IT department represents a major ''function'' at the level of the CA/T project. It centrally allocates all information technology resources for the project, including hardware, software, telecommunications, and training, as well as maintenance. These resources can be seen as critical, as the overall management of the different construction processes is largely information-based and therefore the overall performance of the project depends on the quality of the information systems providing the backbone to the project infrastructure. The project strategic planning framework developed earlier is used to briefly outline functional internal scrutiny as well as the functional environmental scan to explain the ''strategic programming'' that has been developed with regard to IT diffusion within the CA/T project.

Information technology enables the aggregation and desegregation of information-based work. A major part of the activities of the CA/T field offices is information-based, and this can be substantially enhanced through the use of IT. Investments in IT resources are required to achieve measurable benefits in the medium term. Such measurable benefits include a reduction in the job-hours at the level of the field offices, as well as increased quality and efficiency of the work output. A good indicator for benchmarking the CA/T project's workflow efficiency at an industry level is Bechtel's own experience with the use of a state-of-the-art proprietary project management system (Infoworks) in some of its other construction projects. In light of the substantial investments in information technology in the past as well as the levels of office automation and workflow integration, the CA/T project is working to develop information technology for the construction phase of the project through their paperless or IT enabled office study. The key questions in this endeavor are how to capitalize on the ''returns'' of past IT investments, and how to determine ''optimal'' spending levels for further IT diffusion within the project, to maximize the overall benefit of the project.

This paragraph highlights the scope definition of the paperless office study to highlight the internal scrutiny step in the strategic framework. Looking at IT implementations on the CA/T project, it became clear that what the project needed was an integration of its various tools. By integrating the tasks performed in the field office, data handling time and error in transfer would be decreased. This notion of integration led to

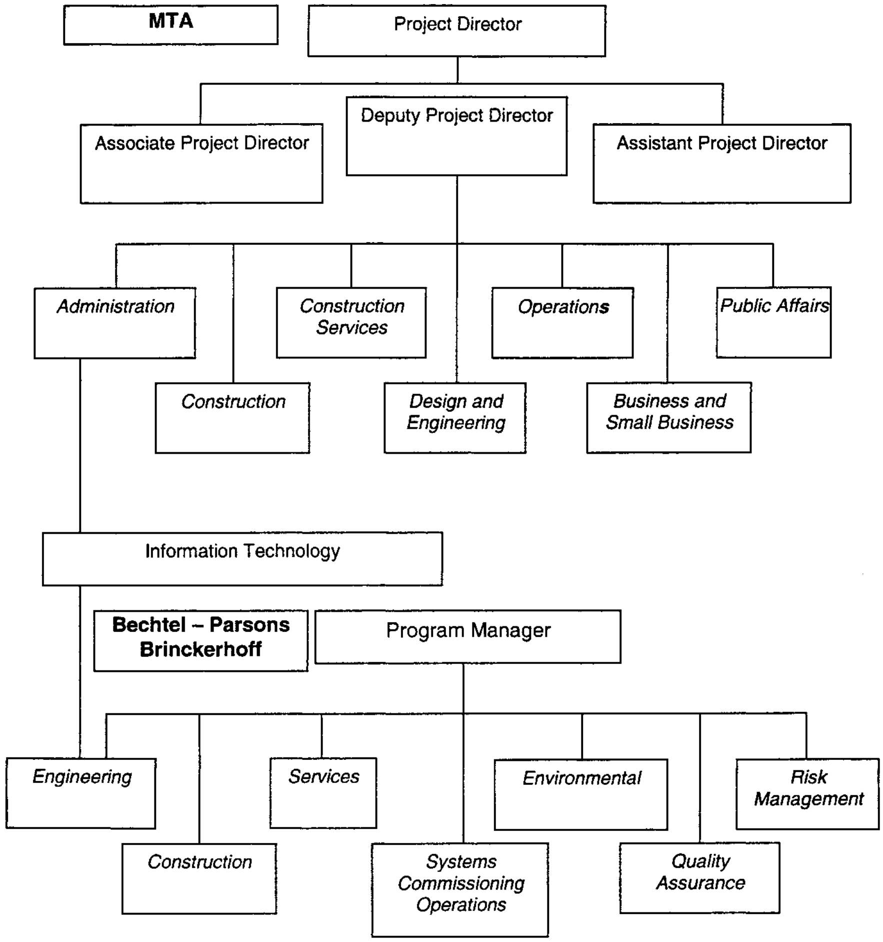

FIG. 5. CA/T Project Management System [Source: CA/T (1998)]

two extreme alternatives: (1) Slowly upgrade the project toward paper-less functionality; or (2) revamp the process immediately. The former has the advantage of low risk but had the disadvantage of slow changeover. In addition, because the real gain would be in the total integration of the office, measurable gains might not be seen for a long time. The latter had the advantage in speed but had the great disadvantages of high risk and heavy investment.

A compromise alternative was to develop the paper-less office for one test office. This would decrease the risk and investment during the test by decreasing the impact. In addition, overall risk would be reduced, because the test office would provide the project with the expertise to know how best to apply the concept on a larger scale. To pursue the test office, a paper-less office study group was formed with representatives of the following different groups involved in the test office: information systems, management, construction, document control, and laboratory testing. They were assigned the task of developing a paper-less office system plan and the evaluation of the potential cost and benefit of the new system.

As discussed earlier in the paper, a part of the internal scrutiny step is to identify and analyze design alternatives for IT development and deployment. In the current case study, this was achieved by looking at the software products available in the market or participating organizations; the study group determined several alternatives for a paper-less office system. The base products for these systems can be divided between enhancement of software already in use on the project and the adoption of entirely new packages available to the project. The alternatives are presented in Fig. 6.

Of these initial options, the Oracle (for database needs) and Keyfile (for workflow automation) options have the obvious advantage, in terms of investment, training, and general culture shock, of being already in use. Although the Oracle database was already automating many processes for the project, that level of customization already involved a good deal of programming time. It was not deemed feasible to expand the Oracle system to the full extent required for a paper-less office, when compared with commercially available ''best-of-breed'' products. It was, however, decided that the Oracle system was too central to the operations of the project at large to be excluded from the proposed paper-less office. This meant that any system would have to complement, and interact with, the existing Oracle system.

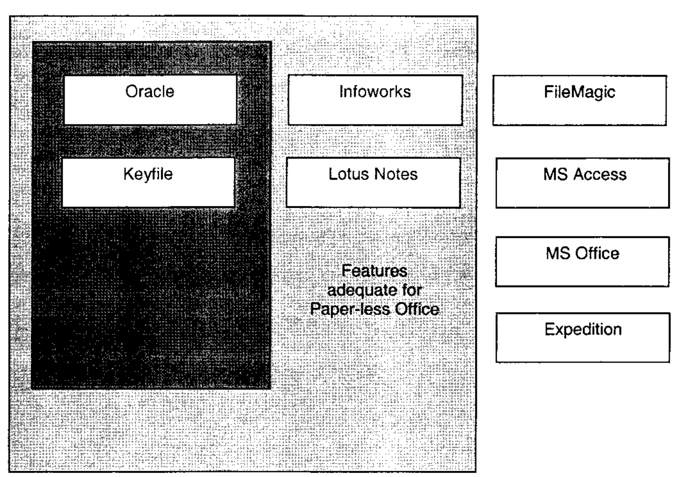

FIG. 6. Paper-Less Office Alternatives

Another part of the internal scrutiny step is analyzing existing IT infrastructure and comparing hardware and software products. In the present case study, of the new products to be examined, it was determined, through an initial feature comparison, that only Bechtel Infoworks with Xerox Documentum and Lotus Notes might offer more than, or even as much as, Keyfile for workflow, which was already in use. Members of the study group were sent to other sites where the products were in use to better research the products in question. Before the visits, a questionnaire was developed to guide the demonstration process. The questionnaire enumerated some of the possible features and difficulties of the system, as well as subjective questions about the experience with the product. On return from the visits, the issues brought up at the various sites were discussed among the group. Building on information gained during the demonstrational visits, the study group defined a set of criteria on which to base the comparison of the systems. These criteria were designed to encompass all of the possible features and possible pitfalls of a paper-less office system. The categories covered areas from storage to workflow to report writing. The various products were scored in each category, and the totals were used to determine the comparative overall capabilities of the systems. The scores for Infoworks and Keyfile rated approximately equal and much higher than that for Lotus Notes. The decision between Keyfile and Infoworks was heavily influenced by the fact that Keyfile was already on the project. By staying with Keyfile, start-up costs and risks would be reduced.

System Definition

Having decided on the base software for the paper-less office, the study group still had to fully specify the rest of the paper-less system. The final requirement that would need to be met was the integration of the different components. The paper-less concept demanded that all of the components work as closely together as possible, and so investigations were made into the possibilities of linking Oracle and Keyfile. These investigations led to two possibilities: (1) Programming consultants could be used to develop a set of conversion routines to enhance compatibility; and (2) purchasing additional software that provides a generalized interface between applications. The second option was chosen as it provided greater compatibility and better extensibility for future developments, or upgrades in the various products. Oberton software provided the best interface of this sort and was therefore added to the list. Standard office software such as Microsoft Office was also added to the system specification to take into account the normal office administrative tasks in addition to the managerial tasks undertaken by the field office. Based on the demonstration visits, to ensure the success of the office, it was determined, apart from the normal staff for managing the contract, one additional staff member would need to be added to assist in the automation. This individual would be responsible for monitoring hardware performance, assisting with application use, and making minor adjustments in the system. All of these recommendations covered the internal scrutiny step in the proposed strategic planning framework.

Modeling IT Diffusion at Project Level

In terms of IT modeling, we have adopted a highly simplified, though plausible model of IT diffusion based on logistic growth. Causal loop diagrams are basic system dynamics tools, which provide a method of capturing the multiple cause-effect relationships that the experts use to understand the complexity of their part of the system and its relationship with the rest of the system. In mapping out expert mental models, causal loop diagrams also provide a method for integrating multiple expert mental models into a single, all-encompassing model of the system (Morecroft and Sterman 1994).

Consider the causal loop diagram in Fig. 7, which shows a simplified model of IT diffusion at the level of the project. The model is driven by expenditure in IT, which results in the IT infrastructure. In the presence of a more sophisticated IT infrastructure, the demand for IT can be expected to rise, which then increases the ''level of informatization'' [i.e., the percentage of workflow (or, more specifically, job-hours) that are ''informatized'']. If left alone, without the inflow generated by IT expenditure, the level of informatization z, is assumed to slowly drop, as the hardware and software become obsolete. On the other hand, a high level of informatization in one part of the project produces a technology spillover effect, which increases the overall demand for IT, as others will want to be

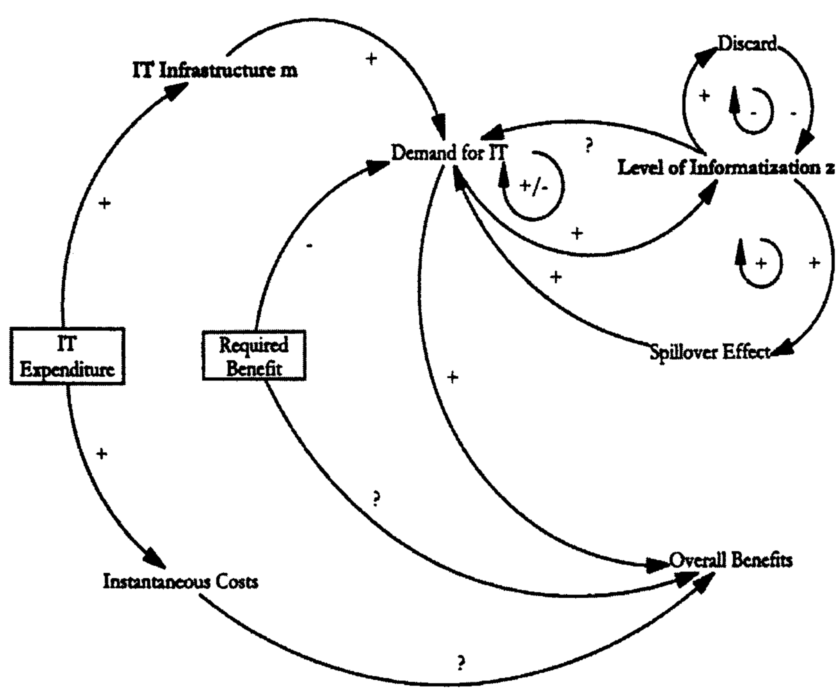

FIG. 7. Simplified Model for IT Diffusion in Project

part of the IT involvement. The demand for IT is dampened by the lack of realization or perceived realization of required benefit from its usage (for instance, the required reduction in job-hours achieved through its adoption). The overall benefits are then the cumulative difference of the achieved job-hour savings and the expenditure made in IT.

The diffusion of IT is modeled here in terms of ''penetration-percentage'' (i.e., the percentage of activities that can be regarded as fully enhanced through the use of IT). More specifically, it can be understood as the fraction of job-hours spent while working on integrated information systems. The modeling of IT diffusion is particularly important during the start-up phase of new information systems. The remaining sections describe the startup phases of one such information system proposed within the CA/T project.

IT Investment Modeling

As highlighted earlier, one of the most important steps in the IT investment modeling step is the cost/benefit analysis both during the IT development and deployment. In the present case, the final task of the study group was to evaluate the potential benefits of the paper-less office against the predicted costs. This task also included the development of an evaluation methodology for measuring the success of the project. The key immediate benefits expected from this test office were broken down into four categories:

- Increased management efficiency
- Increased productivity
- Increased field presence
- Improved quality

Examining the potential benefits in each category, goals and evaluation methods were developed for each.

Productivity

A paper-less office environment can be expected to result in increased productivity at a basic level, and automation leads to greater timeliness of information flow. Thus, less time is wasted doing nonproductive work. In the case of the CA/T field office team, further productivity gains can be realized through integration. The primary function of the field office is to assure that work is performed to specification, to verify work completion, to manage change, and to support mitigation efforts. A great deal of work in gathering data duplicates work done in the contractor office. By integrating the two, and sharing the data, the field office team can spend less time collecting data and more time managing and assuring the accuracy of the data that are collected. Earlier studies of automation benefits done on the project have identified various activities and average completion times. Measurements made in the identified activities will be compared with these numbers, and time and cost savings will be identified.

Field Presence

By integrating the contractor and project field offices, the scope of observation and management of the team is extended deeper into field activities. Timesaving, as mentioned above, may allow for a greater amount of time to be spent in the field. Because the integration is done through a paper-less environment, this scope is also extended back to the CA/T centralized offices. This increased presence in the field leads to better management of the field activities. To measure field presence, the number of hours spent in the field will be tracked against estimates. Effectiveness of the time spent in the field will be measured by measuring the performance of the management. For example, requests for information, changes, delays, and rework might be tracked to give an idea of the effectiveness of the time spent in the field.

Quality

One of the tasks of the field office team is to manage and analyze information. By managing the information in an integrated fashion, the paper-less office allows this mass of interrelated information to be processed in a more meaningful and efficient manner. This means that critical decisions are made based on the best available data, and they are made more effectively and efficiently. This is of clear benefit in the roles of change management and mitigation. By basing decisions on the best available data, the end product quality will be improved. To measure the quality benefits, the number of deficiency reports, laboratory reports, and inspection reports, as well as the quantity of rework, will be monitored.

Monitoring Group

A key part of the measurement and evaluation of the office will be a monitoring group. This group will follow the progress of the office and guide the process. The input from this group will make sure that the potential of the concept is being fully utilized and will guide new developments as the need arises. By directly interfacing with the field office, where much of the data will be collected, the group will have immediate access to the data needed to evaluate the test performance in the above areas. It was determined that the composition of the monitoring group should be cross functional, and interorganizational, to provide input on all of the activities of the office. It was recommended that the group be reconstructed using the existing study group, with the addition of a representative of the contractor and the field office. In this way, all of the knowledge gained during the study can be easily transferred to the field office. The involvement of the group in the test will last throughout the lifetime of the contract, with frequent meetings and heavy involvement during start-up and close-out, and quarterly meetings in between to check on progress. The group will be charged with reporting progress to project management on a regular basis.

Spillover

An important interim objective of the test is to identify possible areas for spillover to the project at large. The benefits from these processes, once proven in the test, are applied to other teams in the greater project. The management of this process will be another charge of the monitoring group. They will provide the guidance necessary to identify areas of possible benefit and to determine the best ways to extend those benefits to the project at large.

These paragraphs highlight the cost/benefits analysis forecasted for the case study that is the heart of the IT investment modeling step in the proposed strategic planning framework. Taking the specifications for the system developed during the study, the total cost of the paper-less office was determined. This was then compared with an estimation of possible benefit. Using these costs, and extrapolating from an earlier study that had attempted to quantify the possible benefits of automation on another contract, an estimate was made of the possible productivity return on the paper-less investment. The calculated possible return for the investment in this test office is from 23% loss to 61% gain. This return represents a maximum equivalent gain of about one person over the life of the contract that would be divided among three categories (productivity, quality, and field presence). In other words, some fraction of the total gain might be felt in staff reduction, whereas some of the gain would be felt in the increased quality and field presence. It should be noted that the construction, for which the test office is responsible, will not be completed until the end of 2002. The research efforts presented here will continue to monitor the test office and will report actual benefits, as data become available.

The data collected and evaluated during the test will provide a sound basis on which to determine the costs and benefits of extending the paper-less concept to a large and complex contract. Through this evaluation, and through improvements developed during the test implementation, the risk of introducing the concept in a large contract will be reduced. Because it influences possibilities projectwide, thorough planning and evaluation in this test have the potential for large-scale returns, while maintaining a smaller scale investment level.

The value of the test experience extends well beyond the realm of construction. The paper-less methodology, combined with accurate benefit models at the end of the test, will provide the state of Massachusetts with a base on which to build a way of doing business that will take its public construction projects into the next century. By developing knowledge not only about how to implement automation, but also about how best to plan and evaluate an automation program, the CA/T project will give the state of Massachusetts the ability to successfully deploy IT enabled A/E/C projects at minimum risk.

CONCLUSIONS

New IT developments continue to have a significant impact on large-scale A/E/C projects. To maximize returns on their IT investments, the senior management of A/E/C projects are faced with a number of difficult questions:

- How should IT investments be designed to ensure alignment with overall project objectives and strategy?
- How should these investments be prospectively justified?
- How can the value of these IT investments be measured over the project life span?
- How can the value of IT investments be quantified when the benefits accrue to more than one participating party (i.e., owners, contractors, and architects)?

For an A/E/C executive, the paper highlights the IT strategic planning framework to answer the above-mentioned questions. The framework has four distinct phases: (1) Environmental scan; (2) IT diffusion; (3) internal scrutiny; and (4) IT investment modeling. The framework takes account of the fact that the A/E/C industry has come to the point where it must embrace information technology on a fundamental level. In order to do so, within the bounds of a project organization, the framework highlights that planning, evaluation, and deployment be tightly integrated and carried out concurrently.

The organizations, both public and private, similar to the participant organizations of the CA/T project, must take the lead in developing planning and evaluation methodologies for sound IT implementations. A/E/C firms must tackle the main IT management processes: setting strategic and technical direction for IT applications, making decisions about funding, executing IT business strategies, and reviewing performances of IT investments over the entire project duration.

To resolve the above-mentioned issues, this paper presented a strategic planning framework based on IT diffusion for maximizing the value of investments in strategic capabilities. To summarize the framework steps, the top management of A/E/C projects undertaking a new IT investment plan would need to take the following steps:

- During the environmental scan of the project, analyze the overall business goals of the A/E/C project and identify the economic environment in which the project operates.
- For the IT diffusion step, identify where in the IT diffusion phase the project and the participant organizations are.
- From the internal scrutiny perspective, determine the need for such IT investment depending on internal processes as well as the level of informatization that can be sustained on the project. Account for how the return on IT investment will be measured, right from the planning stage.
- Lastly, in the IT investment modeling phase divide the sources of costs and benefits, particularly for large-scale projects, in terms of training, personnel, models, methods, and processes developed among the beneficiaries from the different organizations (i.e., owners, contractors, and designers). Account for value and depreciation in such benefit estimations. With this information, relate the benefits to the dimension of value according to the business processes in Table 1. Compare the IT investment with the competing interests such as production investment and relate it to intraproject infrastructure (i.e., number of contracting organizations).

The above-mentioned four steps—environmental scan, IT diffusion analysis, internal scrutiny, and IT investment modeling—are typically followed in succession with some degree of iterations between the successive steps.

Assessing the value of IT is still a controversial subject in the literature. The production function approach adopted by early researchers is not very helpful at a project level, since the production function approach treats a project as a ‘‘black box’’ with no regard for the different workflow involved. This work has concentrated on IT diffusion in large-scale A/E/C projects. The IT diffusion approach used in the paper is modeled on logistic growth that is still widely used to explain technological diffusion. When IT diffusion within a project approaches the transformation stage, where IT becomes an integral part of the final product-service offering, its value becomes hard to separate from the one generated by other production factors such as human capital. As a part of future research, the IT diffusion model developed for the CA/T project will be mathematically modeled and the resulting objective function will be solved using parameters from actual IT investments made in the CA/T project. Another part of the research will also try to analyze and isolate IT investment patterns from historical data of large-scale A/E/C projects. IT investment pattern refers to a common theme of instructive information that captures the essential architecture and insight of a successful family of proven IT investments. IT investment patterns have a specific structure describing, among other things, the project's internal details, the IT diffusion phase of the project, and the IT benefits. Such investment patterns will be a natural fit in the strategic planning framework proposed in this paper. Searching for similar IT investment patterns would be a first step during the internal scrutiny step of the framework. The case study on the CA/T will be extended for the life of the project, and actual benefits will be measured and compared to the forecasted benefits.

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