A Multi-Objective, Multi-Criteria Approach for Evaluating IT Investments: Results from Two Case Studies

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ABSTRACT

While information technology investments have the potential for providing competitive advantage, actual returns on such investments have varied widely and a majority of CEOs rank IT investments as disappointing. Numerous methods exist for investment evaluation, but traditional methods do not adequately account for the intangible benefits that characterize strategic investments and lack other features of portfolio selection. This paper describes a model based upon the analytic hierarchy process, combined with integer programming, to overcome the deficiencies associated with traditional approaches to economic evaluation of IT investments. It also presents results of two case studies in which the model was used successfully and important contextual factors were observed. The multi-objective, multi-criteria approach was found to reflect both tangible and intangible benefits, link the investment to business strategies, increase management participation in the evaluation process, and provide important features of portfolio selection.

Keywords: information technology investments; analytic hierarchy process; strategic information systems planning

INTRODUCTION

American Airlines' apocryphal success with the Sabre System heralded the potential of IT as a source of strategic benefits (Hammer, 1991). While the competitive advantages from superior IT investments are widely recognized, actual returns received on IT investments vary widely and the IT productivity paradox has international recognition (Brynjolfsson & Hitt, 1998; Dewan & Kraemer, 1998; Santos & Sussman, 2000). A majority of CEOs admit to having funded IT investments that were economically infeasible but express confidence about the future ability of IT to provide strategic advantages (COMPASS, 1998, 1999). While most companies submit IT-based applications to some form of economic feasibility analysis, the numerous objective measures used in practice provide little relationship to the strategic direction of the firm (Liberatore, Monahan, & Stout, 1992). Moreover, despite recognition of the importance of qualitative benefits, economic analysis of IT returns relies primarily on quantitative measures (Powell, 1992). At least one author concludes that the productivity paradox may result from a bias towards quantitative measures in MIS research (Chan, 2000).

Traditional approaches to capital budgeting have not proven useful in the economic evaluation of IT-based investments. Single criteria techniques, such as discounted cash flow (DCF) and cost/benefit analysis, are biased towards the tangible benefits that can be more easily identified and quantified. Calculations of IRR or net present value may ignore the "soft", qualitative benefits of IT applications or build them into the model so creatively as to devalue the results. Traditional approaches can penalize investments with valuable soft benefits, so often present in strategic applications. Hence, proper evaluation of IT-based investments requires a method that reliably measures all benefits in a consistent manner that is understood and supported by management.

Maximizing returns from IT investments also requires a total portfolio planning approach that cannot be accomplished by valuing each investment individually. In reality, some investments are mutually exclusive, other investments have mutual dependencies, and some investments should not be combined due to the total risk.

Applying both objective and subjective judgments to numerous projects, across multiple criteria, in a consistent manner is an imposing challenge for IT management. At the same time, it is becoming increasingly important that just such an approach be adopted to maximize the return on IT investments.

Combined with integer programming, the Analytic Hierarchy Process (AHP) supports a multi-objective, multi-criteria (MOMC) approach that addresses several issues hindering the success of IT investments. An MOMC approach, for example, can improve the alignment of the information systems plan with organizational goals. AHP has a wide variety of applications in industry and government (Zahedi, 1986; Vargas, 1990). IBM has called it "an extraordinarily powerful decision-making tool," (Saaty, 1994). AHP has multiple indicators of success, allows for broad evaluative participation, and specification of criteria that are strongly related to organizational strategies. More importantly, AHP has been used to counter political issues, engage management in the process of ISP planning, and provide a highly visible evaluation process that supports commitment. While research has reported on the use of AHP and integer programming as a ranking mechanism, the approach has not actually been tested on ranking IT investments in practice.

The purpose of this paper is to demonstrate the MOMC approach to IT investment analysis using a methodology that, heretofore, has not been demonstrated in practice. This paper first demonstrates the applicability of the proposed model using an illustrative example of five information systems projects. Next, it reports on the results of two case studies in which the model was successfully applied. Finally, facilitators and inhibitors and generalizable findings derived from the cases are presented.

THE IT INVESTMENT DECISION

Despite intensive research, there is little persuasive evidence that investment in IT positively impacts the financial position of the firm or increases productivity (Brynjolfsson & Hitt, 1995). For example, Sircar et al. (2000) could not find a relationship between IT investments and net income.

Measurement problems are numerous. One problem is the time period between investment and realized benefits. Another problem is that the direction of causality is difficult to prove. For example, Hu (2001) found no relationship between investment in IT and subsequent financial performance but found a positive relationship between improved financial performance and subsequent investment in IT. Thus, establishment of a relationship does not necessarily support investment-performance causality. This study examines a more direct method of influencing business performance: improving the quality of the IT investment portfolio.

Although most researchers and practitioners would agree that the mechanism for selecting and prioritizing IT investments would heavily influence the actual return realized on the overall investment portfolio, there has been a paucity of research directed towards improving the efficacy of the measurement mechanism. Regardless of whether research can establish a direct relationship between IT investment and financial performance, those companies that are able to select the best IT investments will have a greater chance of positively influencing the financial performance of the company (Kayworth, Chatterjee, & Sambamurthy, 2001).

Past evaluation of major IT investments has relied heavily on traditional financial accounting measures. These methods suffer from: (1) isolation—they do not consider alternative investments simultaneously; (2) difficulty in valuation of benefits, particularly intangibles; and (3) low explanatory power. For this reason, many companies subject investments to multiple measures in the hope that those that survive will have a higher likelihood of success. This approach ignores basic investment tenets (Clemons & Weber, 1990). First, it ignores the fact that the results will only be as good as the data used. Managers wishing to promote their projects may assign high values to the intangible benefits. In time this practice can reduce the credibility and usefulness of the process, calling the results into question. Conversely, some companies choose to ignore intangible investments and value them at zero, critically denying the chance for many strategic investments to survive the analysis. Second, all financial measures are sensitive to the valuation of benefits. Thus, higher benefits generally lead to acceptance under all measures and vice-versa. So, investments that have overvalued benefits will likely be favored by all of the financial accounting measures. Third, the approach assumes that each investment stands on its own merits without regard to other investments. This disregards mutually exclusive investments and the risk diversity of the overall portfolio. Finally, some investments, such as ERP systems, generally have failing marks under ROI and passing marks under net present value (Mullen, 2001). Management of many companies have elected to fund expensive ERP investments despite the failure to score well over a number of measures. In so doing, they have asserted their belief that the financial accounting measures fail to account for the true value of IT systems.

IT-related investments represent in excess of half the annual capital expenditures for many firms. Despite this resource intensity, an agreed-upon approach to measuring IT investments does not exist (Weill & Olson, 1989) and returns on IT investments have been unsatisfactory (Compass 1998, 1999). Researchers and practitioners have called for a more comprehensive approach to the selection and prioritization of IT investments (Brynjolfsson & Hitt, 1995; Kauffman & Kriebel, 1988).

The shortcomings of traditional approaches to reflect intangible, or qualitative, benefits has been well documented (Driscoll, Lin, & Watkins, 1984; Kaplan, 1991). Herein may lie the problem: the essence of a measure's effectiveness is its ability to consistently produce the desired results. In the case of IT, the desired result is the selection of IT-based investments that produce the highest value for the firm and that value must reflect a combination of both quantitative and qualitative criteria (Chan & Lynn, 1993).

Various methodologies for economic evaluation have been reviewed (Sylla & Wen, 2002). In practice, more than 50 approaches to evaluation of IT investments have been identified (Irani, 1988) indicating the overwhelming lack of consensus for a preferred approach. The cost and time associated with performing a cost-benefit analysis and the detailed compilation of data associated with the analysis may be factors in management's failure to adequately control these investments, particularly when faith in the mechanism is low. The multitude of appraisal methods used in practice suggests a lack of control over the process. Traditional economic evaluation is not sufficient for the selection of major IT investments. Hence, a decision support process is needed that will incorporate all relevant decision criteria (Stout et al., 1991).

THE ANALYTIC HIERARCHY PROCESS

Examples of real-world AHP applications are numerous and include strategic planning, microcomputer selection, software productivity measures, oil pipeline route selection, budget allocations under constrained resources, flexible manufacturing systems, manpower selection, energy policy planning, healthcare resource planning, model selection, plus numerous applications in accounting, auditing and marketing (Hamalainen & Seppalainen, 1986; Finnie, Wittig, & Petkov, 1993; Lee, 1993; Saaty, 1994; Ramanathan & Ganesh, 1995). AHP models have been proposed for the evaluation of enterprise information technologies and project management (Kamal, 2001; Sarkis & Sundarraj, 2001).

The capabilities of AHP have been extended through combinations with other techniques such as multi-dimensional scaling, and integer and linear programming in the areas of business, government, medicine, social science, and mathematics (Arbel, 1993). For example, Imber (1990) used a combination of AHP and linear programming to improve the management of fisheries. Thurston and Tian (1993) combined integer programming with AHP for long-range product planning. Using AHP and integer programming, Sylla and Wen (2002) proposed a conceptual framework using goal targets against which proposed IT investments would be evaluated. There have been no prior illustrations, however, of this use in practice.

The successful prioritization and selection of IT investments is made problematic by the number of issues that must be addressed. The multi-objective, multi-criteria process presented in this paper is an effective measurement process that:

1. ranks alternative investments according to criteria that support corporate strategies;
2. is amenable to the strict time constraints of the planning process;
3. supports consensus among a diverse group of individuals;
4. can reflect investment precedence or

exclusivity constraints;
5. can incorporate both quantitative and qualitative criteria; and
6. can be understood by management.

THE IT INVESTMENT MODEL

Corporate Strategies Used as Project Ranking Criteria

The importance of linking IT strategies to corporate strategies has been well documented. Strategic linkage and competitive response are highly important evaluative criteria in allocating resources to competing projects (Bacon, 1992).

The selection of IT investments can be highly political, requiring a considerable amount of negotiation. Two factors that appear to influence the selection mechanism's credibility and acceptability are the degree of management involvement and alignment with corporate strategy (McKeen & Guimaraes, 1985). IT often does not support management involvement, embracing a technical focus and being "unaware of the human and organizational factors" that account for IT investment failures (McDonagh & Coghlan, 1999, p. 43). Alignment is critical. Companies which support alignment between their IT plan and corporate strategies outperform those that do not (Das et al., 1991).

Traditional discounted cash flow (DCF) techniques often lack linkage to corporate strategy (Liberatore et al., 1992). AHP facilitates specification of criteria based upon corporate strategies. In fact, the criteria can be the specific strategies that the investment alternatives support. At the same time, AHP can incorporate DCF measures for the projects.

Level of Difficulty

The issue of process implementation depends upon the level of difficulty. This includes technical expertise required to perform the prioritization, requisite understanding of the related theory, the effort and time required to collect and enter data, and the time required to perform the analysis and analyze results. Closely associated is the flexibility of the measurement process in reflecting changes, performing sensitivity analysis, producing viable alternative solutions, and providing an explanatory trail.

IT planning may involve the examination of a considerable number of investments. A large number of investment alternatives can create a cumbersome amount of data. AHP methodology uses a paired-comparisons approach with semantic anchors. These criteria indicators represent typical investment alternatives. Each investment can then be assigned an indicator value for each criterion. The sum of these values becomes the investment's global score that is used for final ranking. The ranking of a large number of investments can thus be accomplished with a limited number of semantic anchors (Wedley, 1990).

Explanatory Power

For IT professionals to create an effective dialogue with senior management, it must be clear how potential projects fit into the overall corporate context. Perhaps the most valuable feature of AHP is its explanatory power. The hierarchy is simple to communicate and the weighting process is highly intuitive. Moreover, it offers a convenient framework for concise representation of the most critical elements that affect the funding decision (Lauro & Vepsalainen, 1986). When combined with an integer optimizing model, AHP offers a formal, systematic, consistent approach that can be presented in a clear and understandable concise manner. Managers from other functional areas can quickly relate to the hierarchy that can be easily visualized and componentized. The relative weight of each decision alternative and criterion can readily be compared to the weights of other elements and discussion centered upon a single element or a level of elements. Managers are able to see into the process as opposed to accepting results from a "black box". Such a process is more likely to support participation and future commitment to the investment decisions.

Creating Consensus

Using the method of paired (also known as pairwise) comparisons, AHP is highly effective in distilling information from groups and fostering consensus—an important foundation for acceptance when IT projects are later transferred back to users. In the absence of an absolute scale, all people have the ability to perform relative comparisons between alternatives. As the number of such comparisons increases, however, the consistency tends to decrease simply due to the limits of human cognition. Using this notion, AHP organizes this thought process and creates quantitative rankings using a systematic approach to capture priorities and measures the consistency of the overall process.

Justification of the investment is improved in several ways. AHP allows for the simultaneous consideration and evaluation of both quantitative and qualitative criteria, the inclusion of managerial judgments in a direct manner, and managerial focus on those parts of the decision that pose the most uncertainty. As a consensus builder, the process benefits from the ability to encourage a mixed dialogue among all functional areas as opposed to having each area sign off on each IT investment independently (Stout et al., 1991).

Cost, Precedence, and Exclusivity Constraints

Portfolio selection for stocks using AHP has been described by Saaty et al. (1980). A difficulty arises, however, in ranking investments with significantly different costs. Resource constraints limit the number of investments that can be selected. Rankings may be deceptive as in the case where a top-ranked investment costs as much as two other projects that were precluded due to limited resources, but the sum of the benefits of the two precluded investments exceed the benefits of the more highly ranked investment.

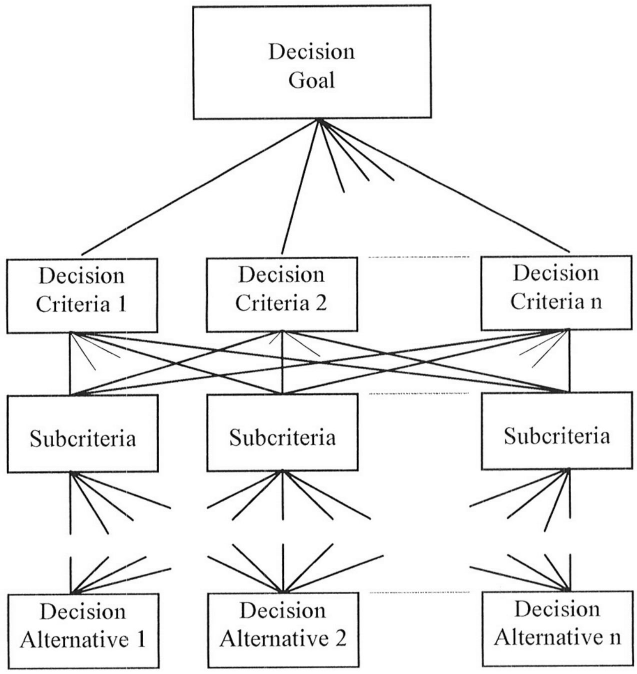
Other problems also arise which cannot readily be solved within a ranking schema. Selection of one investment, for example, may preclude selection of another due to overlap in functionality or competition for non-cash resources in the initial phase. Selection may also be predicated upon another investment's selection.

An effective approach to solving multi-criteria resource allocation problems is to convert them into integer programming maximization-type problems. The investment alternatives are used as variables and priorities are used as the variable coefficients in the model's objective function (Ramanathan & Ganesh, 1995).

Structuring the AHP Hierarchy

Because it is a hierarchical process, decisions in AHP are made at various levels descending from the overall goal at the

Figure 1: *AHP Decision Schema*



top level, to decision criteria at the second level, and proceeding on down to the decision alternatives at the lowest level. A general schematic of such a hierarchy is presented in Figure 1. Note that there are n alternatives and k levels possible. Each criteria may or may not affect each alternative. In practice the total number of levels rarely exceeds nine and often is limited to only three: *goal*, *criteria*, and *alternatives*. Saaty (1990) points out the importance of this descending arrangement from goals to alternatives.

AHP Theory

First, it provides "an overall view of the complex relationships inherent in the situation; and helps the decision-maker assess whether the issues in each level are of the same order of magnitude." Second, it supports meaningful comparisons between attributes at one level (*local*) before comparing them to attributes at another level (*global*). A potentially unmanageable problem is thus reduced to a set of manageable steps to achieve the desired result. The matrix algebra underlying paired comparison of elements is summarized in Appendix A. Four steps are commonly cited in solving a decision problem using AHP:

1. Establishing the *decision hierarchy* by formulating the problem as a stepwise progression of interrelated decision elements;
2. Creating input data and making *paired-comparisons* of the decision elements;
3. Estimating the *relative weights* of the decision elements using one of several methods; and
4. *Aggregating* the relative weights of decision elements to arrive at a final set of ratings for the decision alternatives.

Paired-comparisons, for the decision hierarchy presented in Figure 1, result in a set of priorities that represent the individual importance of each criteria with respect to the overall goal. Criteria can be compared in n(n -1)/2 different ways. Paired-comparisons are repeated at each level of the hierarchy with respect to the criteria in the immediately preceding level.

Incorporating Quantitative and Qualitative Investments

Identifying and selecting the right information systems and making wise information technology investments is an important factor in sustaining corporate viability for many firms. Rational choices that support corporate strategies is a goal expressed by many senior executives (Bacon, 1992). In practice and theory, there is no consensus on the appropriate mechanism for ranking IT investments, although application of some form of DCF analysis is frequently used. Objective evaluation methods cited include net present value, cost-benefit analysis, project risk, value analysis, benchmarking, multiple criteria approach, DSS evaluation, aggregate scoring technique, and anecdotal evidence (Powell, 1992). Subjective methods often depend on attitude surveys and the opinions of users and analysts.

AN INFORMATION SYSTEMS EXAMPLE

To illustrate the multi-objective, multi-criteria model, a simple hierarchy that includes both financial and non-financial criteria is considered. Five IT investment proposals and costs are assumed:

1. design and install a new *customer relationship management system* ($210,000),
2. purchase and install software for *material acquisitions system* ($107,000),
3. purchase and install software to perform *manufacturing control system* ($185,000),
4. expand and enhance an existing *logistics control system* ($75,000), and
5. purchase and install software for a *data warehouse* ($160,000).

In reality the number of investments to be ranked could be much larger. The approach and simplicity of the process, however, remain the same. These investments will be compared on the basis of five criteria representing the following corporate strategies:

1. investment risk: investments that have

Table 1: Final Rankings of IT Investments

Proposed Investments	Rank	Overall Rating
Customer Relationship Mgmt System	1	.394
Materials Acquisition System	2	.203
Manufacturing Control System	3	.149
Logistics System	4	.142
Data Warehouse System	5	.112
	total all ratings	1.000

lower risks are more attractive.

2. ***revenue enhancing***: investments that increase revenues are more attractive.
3. ***operating efficiency***: investments that increase operating efficiency are more attractive.
4. ***customer satisfaction***: investments that increase customer satisfaction are more attractive.
5. ***market growth***: investments that capture more market share are more attractive.

The first step in AHP is to define the decision hierarchy. The goal is to rank the decision alternatives (i.e., IT investments) in order of preference as determined by the priority weights of the criteria. The second step is to input the data. This step may take one of several forms depending upon how the decision maker has formulated the problem criterion. *Expert Choice™*, an AHP applications software package, provides simple step-by-step instructions for data entry. After entry, the input data are manipulated using matrix algebra to produce the relative weights or priorities for each level of the hierarchy. *Expert Choice™* provides a visual result of each step in the ranking process including presentation of both local and global priorities which indicates the relative importance of each alternative at various stages. A "consistency index" for each criterion measures the degree of consistency inherent in the decision-maker's ranking of alternatives. Values above .10 for criteria indicate inconsistency and the need to inspect paired-comparisons. The final step is aggregation of all weights to produce a vector of composite relative weights between the criteria and the alternatives (Saaty, 1980; Zahedi, 1986). These weights, which are displayed visually, represent the contribution of the alternative and criterion to the overall goal. Each column of weights sums to the criterion's priority.

For the sample problem, the final solution, shown in Table 1, ranks the market evaluation model first with an overall weight of 0.394. Not presented in this paper, is the visual presentation of results at each stage of the process, which increases management's understanding of the process and how the final results were achieved. By doing so, it improves the overall explanatory power and credibility of the process.

Optimizing Using Integer Programming

The final rankings do not reflect several criteria that have been purposefully

Table 2: IT Investment Example Costs

IT Investment	variable	cost ($000)
Customer Rel Mgmt System	X_1	210
Materials Acquisition System	X_2	107
Manufacturing Control System	X_3	185
Logistics System	X_4	75
Data Warehouse System	X_5	160
total cost all investments		737

omitted: investment cost, precedence, and exclusivity. Formulating the problem to maximize the AHP priority weights with the resource constraint completes the measurement process by including these remaining evaluative factors. Generally, the mathematical statement for an integer programming problem is:

Maximize $\Sigma\, a_{ij} x_i$, subject to a given constraint set where a_{ij} are the performance coefficients in the integer programming model that, for our purpose, become p_i or the priority weights from the AHP rankings (Ramanathan & Ganesh, 1995). For our problem, assume the following costs for each of the five variables in Table 2.

To illustrate cases of exclusivity and dependence, assume that:

a) a budget constraint of $500,000 exists for all investments;
b) management has decided that it is not necessary to purchase both the CRM system and the data warehouse system immediately; thus the solution will include either the purchase of one or none of the two models, but not both;
c) the manufacturing control system cannot be installed without the materials acquisition system; thus the latter may be purchased without the former but not vice-versa;
d) using the priority coefficients of our AHP rankings in the objective function and the above three constraints, the model is:

$$\text{Maximize} \quad 0.394X1 + 0.203X2 + 0.149X3 + 0.112X4 + 0.142X5$$

$$\text{subject to} \quad 210\,X1 + 107\,X2 + 185\,X3 + 75\,X4 + 160\,X5 \le 500$$

$$X1 + X5 \le 1$$

$$X2 + X3 < 1$$

$$Xi = 0,1$$

The last constraint ensures that the result variables will be binary; i.e., we either fund an investment or do not fund a investment. The optimal solution is (1,1,0,1,0) with an objective function value equal to 0.709. Higher values for the objective function signify higher overall returns for the IT investments. Alternatives with explicit cost and associated benefit can quickly be derived.

Thus, the multi-objective, multi-criteria model has the capability to prioritize investments by a set of criteria and to select the optimum set of investments given cost, precedence, and exclusivity constraints.

EVIDENCE FROM TWO CASE STUDIES

Research Methodology

Two case studies were performed using the IT investment model. The case approach was selected because it was believed that contextual conditions could impact the outcomes. The author acted as investigator with the goals of: (1) ascertaining the efficacy of the proposed ranking mechanism; and (2) collecting and reporting the attitudes, behaviors, and perceptions of the CEO, CIO, and other managers towards the process. Results of the investigation were reviewed by the CIOs of the two companies with only minor corrections and revisions. The approach elected is in the interpretivist tradition in which the investigator enters the organizational setting without an *a priori* model but with a good understanding of the underlying literature and theory. The purpose is to further understanding of the phenomenon (Cavaye, 1996). Using multiple cases allows the investigator to replicate the results and improves generalizability.

The study will show that management involvement is necessary for the successful ranking and prioritization of IT investments. The study will also show that organizational structure affects the success of the ranking process. Because of the sensitive nature of the information gathered and discussed, both companies requested complete anonymity. For reasons that will become apparent, the companies are referred to herein as Hot and Lukewarm. The backgrounds of the companies are now presented in order to provide the reader with a contextual framework.

Case Study Background of Companies

The multi-criteria IT investment model was tested on two U.S. utility companies, one in the north-central region and the other in the southern region. The two companies, each with assets in excess of $2 billion, shared several operating similarities. They were both generators of electricity, had retail and wholesale markets, sold surplus power, and controlled their own transmission and distribution systems. Both had CIOs committed to IT planning. They also had differences. Hot was a smaller company under greater competitive pressure, had a higher cost of electricity, which caused customer complaints and pressure from regulators, and had wholesale markets that were currently threatened by competition. Hot had a highly participative management structure with younger management who had previous experience in non-regulated industries. From the beginning, Hot was highly committed to planning and the strategic use of IT.

Lukewarm, the larger company, was known as a low-cost provider of electricity, had relatively secure markets, but recognized the ensuing issues of deregulation that would shortly put wholesale markets under competitive pressures. Management was hierarchical with traces of political rivalry. The engineering and financial areas were highly insular. Marketing had played a lesser role in the past, but was slowly developing. With the exception of the CEO and CIO, top management was without experience outside their field and had limited experience outside of the utility industry. Both the CEO and CIO had previous experience in non-regulated industries and were committed to planning and increasing returns on IT investments.

IT Planning and Evaluation

Hot initially developed the set of decision criteria and subcriteria that was subsequently adapted by Lukewarm. Hot's management took an interest in IT planning, was interested in using IT strategically, and wanted a system that would satisfy all areas of management as to the final selection of projects. Several members of management had recently participated in an MBA program where they took classes together. It was during this period that they recognized the need for improved selection techniques for IT investments. In developing business strategies, Hot often asked IT management for assistance in identifying technologies that might allow revision of business processes to improve efficiencies and customer service.

Lukewarm's management delegated all IT planning to the CIO, and complained about the time and cost of implementing systems. An IT steering committee composed of several senior managers reviewed major projects prior to funding, but relied heavily on the opinion of the CIO. IT investments were identified after completion of the business plan. The IT plan contained a "wish list of applications that continually changes with the political climate."

Hot had used a combination of project evaluation tools including ROI, payback, and a corporate model. Management admitted that they did not understand how the project rankings were arrived at and considered the methods "useful but probably unreliable." Lukewarm used a cost/benefit and payback approach wherein total costs were simply divided by total benefits. Selection of projects were often based on how well managers could creatively assign dollars to benefits to get projects approved. A payback period of over three years required a meeting with the board for final approval. Lukewarm also used a financial planning model to evaluate certain investments, but the model did not lend itself to a broad range of IT-based investments.

Hot had approached the author about implementing a comprehensive methodology that would support management participation, have high explanatory power, and would be easy to manipulate. The proposed investment model used decision criteria initially developed by Hot and later refined during the study.

Lukewarm's management was convinced by Hot's management of the superiority of the multi-criteria IT investment model and asked to be included in the study. They agreed to use the same decision criteria if they could stipulate their own sub-criteria and assign their own weights. Both Hot and Lukewarm asked that the decision criteria, weights for the decision criteria, the sub-criteria, or their weights not be disclosed.

The Hot Results

The decision criteria and sub-criteria were originally developed by a team of IT managers and later modified by other members of management. (The decision criteria included two business and two technical dimensions supported by greater detail in the sub-criteria.) The concept was introduced in a two-day joint application development (JAD) session held off-premises. An outside consultant, familiar with AHP, facilitated the process. Many members of management, particularly the engineers and financiers, had attended a four-hour workshop and developed familiarity with AHP prior to the JAD session. Most managers were enthusiastic and several later stated that they could apply the AHP methodology to other decision-making problems.

The first day was spent discussing the importance of IT investments and attendant problems, introducing the AHP multi-criteria investment concept, and reviewing the major IT investments currently under investigation. Much of the day was spent answering questions about the IT investments, and it was decided to separate the investments by category and apply the new process to only ten investments that were strategic in nature, cost in excess of $300,000 each, and had higher-than-average risk. The second day was spent in explaining the weights for the decision criteria. Discussion centered on understanding how the weights were derived, which was clarified by a handout (from IT management). Using a modified Delphi technique in which groups made adjustments to the weights, compared results, and made further modifications, a final set of weights was derived. Finally, preliminary paired-comparisons were made. During the process, IT management played an impartial advisory role. Strong leadership was provided by managers that were either project leaders or closely associated with the projects.

Over a period of two weeks, the paired-comparisons and other parameters –primarily costs, benefits, and risks– were refined. It was agreed up front that the initial analysis would not be binding and that, with support, changes could be made to the parameters after reviewing the initial model results.

Working with managers from finance, engineering, and marketing it took approximately a week for IT to complete the initial analysis that used both the AHP and integer programming models. Results were provided to the management steering committee for review. Within two weeks, comments were gathered, adjustments made, and a final analysis completed.

Post interviews with managers revealed a general consensus on perceived benefits derived from the process. All agreed that the process was effective, fair, understandable, and could easily be replicated and modified. Several managers had collected articles on AHP and had become intricately acquainted with the theory. This was expected to positively influence future use of the model.

One disadvantage was the total time involved in making the paired-comparisons and estimating other parameters. However, most agreed that their understanding of the process would help to make future estimates easier and cut the time requirement. The results were used to select five IT investments with a capital requirement in excess of $18.5 million.

The Lukewarm Results

The Lukewarm study was expected to benefit from the results of the Hot experience. The JAD approach, which had proved highly successful in the previous case, was only partly implemented and with less success. One day, on-site, was devoted to the session. The session was facilitated by the CIO. Managers were previously briefed about the purpose of the meeting in a memo from the CEO. The meeting agenda paralleled the first day of the Hot session. However, other members of management generated little discussion and the focus kept returning to who would create and who would approve the paired-comparisons. Managers initially objected to the process, stating that they could not compare their projects to projects for which they were not responsible. They also questioned the amount of time the process would require, where administrative responsibility would reside, and approval of parameters.

During the session, several managers were called away to phone calls, which disrupted the continuity of the meeting. At the end of the meeting, it was agreed that all managers would attempt to provide an initial set of paired-comparisons for those projects for which they had some responsibility. A cross-functional management team would review and refine the comparisons after individual discussions with managers. It was further decided that the management team would have final authority and that appeals would be made to the team first and the CEO second. After three weeks, the management team circulated the final results. Several appeals were made to the team that resulted in minor adjustments, but no appeals were made to the CEO. The CEO later admitted that complaints had been voiced, but no manager had requested altering the final decision of the management team. The CEO supported the process but did not participate directly other than proclaim, "Information technology is our strategic weapon of the future."

After two more weeks, the management team circulated the initial results of the analysis. On the advice of the team, a categorization of IT projects was made and only those investments identified as strategic, high cost, and high risk were evaluated. In total, 26 investments were analyzed (many were overlapping and mutually exclusive). A total of eight investments were selected with a capital cost in excess of $34 million.

Post interviews with management revealed several positive findings. IT management was pleased that the process shielded them from complaints that they controlled the process and allocated much of the decision making to a cross-functional team. In fact, IT had made it clear at the beginning that they did not want responsibility for the final selection of investments. Several managers made positive comments. One stated, "I think we trust the process more than in the past." Another said, "IT is going to be more important to us in the future and the process will be appreciated then."

There were also problems. It was clear that most of the work was pushed upon the management team. Many managers continually requested revisions of the management team. The revisions were quickly made using a spreadsheet program and the team viewed this as minor harassment that would disappear in the future. A few managers continued to complain about the outcomes and questioned the parameters. However, the management team quickly countered by issuing a memo reminding management that they could make any adjustments to the parameters that could be supported. They also performed a modified ROI analysis on the selected projects to mollify any outstanding complaints. The analysis showed returns in excess of the company's cost of capital for all of the selected investments.

At the request of the management team, the CEO issued a memorandum of support, reminding management that they owned the process and that results reflected their own decisions. Although the process did not initially run smoothly and all managers did not participate fully, IT managers felt that the direction was an improvement over past experiences and would improve over time. They also decided that a two-day, off-site JAD session should be held annually to start the process of reviewing IT investments.

RESULTS OF INVESTMENT DECISIONS

A review of progress was undertaken 11 months after the initial analysis. Information was collected from the CIO, the CEO, and other members of management at both companies with the objective of determining: (1) how the project selection method had been accepted by all managers, (2) the status of the IT investments selected, (3) the status of the selection process, and (4) if there were findings that could be generalized.

Acceptance

Managers of both companies voiced enthusiasm for the methodology with some qualifications. Several managers from both companies commented that the documentation for the methodology improved their understanding and made it easier for new managers to grasp. An engineering manager at Hot voiced this opinion:

> *We have strict limits on spending. As a result, there has been some frustration about which projects would be funded. I'm sure every manager has had projects delayed or cancelled. This can be a morale breaker. Particularly if you think some other guy is getting funded for the wrong reasons. This approach gives me more faith in the system. Now, if I can defend my assumptions, I have*

a fair chance of getting the project funded. I think the playing field is more level now than in the past.

The CIO at Hot believed that the new methodology had "proven itself" as evidenced by the status of the IT investments selected. An executive from marketing provided one of the reasons for the acceptance of the approach:

I've been here for nearly ten years and came from a company where there were plenty of turf issues. Managers here have so much turf that they don't feel threatened. The CIO has more business sense than most techies and our managers seem to be technically aware. They were early adopters of PDAs, in fact there were arguments over which one was best. And you see everyone carrying around notebooks. They opt for those so they can take them on trips and home for the weekend. They trade them in every two years and go cutting edge. I don't know if we became this way consciously or not, but it seems that all of the hires over the past five years or so have certainly had technical orientations.

Hot is rather unique in the limited political rivalries and the congruence of a CIO with business acumen and managers with technical acumen. The internal environment and organizational structure are more conducive to acceptance of new processes, even those with technical orientations. This supports prior research that found hierarchical decentralization and lateral communications important to strategic investment decision processes (Papadakis, 1995).

The CIO at Lukewarm stated that acceptance of the methodology had removed a major burden from IT planning and that he no longer incurred the wrath of managers who had not been funded. Lukewarm's CEO commented:

This hasn't solved all our problems but I believe we're on the right track. This used to be a political football and you knew that there would be resistance against these systems every time we put them in place. I could count on one hand the successful ones [i.e., IT investments] over the past ten years. Now, I believe every project underway is going to be successful. I call that progress.

This supports recent findings of Sylla and Wen (2000) that one of the benefits of the MOMC approach is the balancing of conflicting objectives of different users and stakeholders. It also supports the previous findings of Koksalan and Sagala (1995) that MOMC methods, while still evolving, have generally been successful, where preferences and personal judgments can be reflected in the selection process.

Status of the IT Investments Selected

Despite the economic downturn, only two of the projects initially funded had been delayed. Utility earnings are partly protected and both companies had continued to earn a satisfactory accounting return. Thus, there was no immediate pressure to cut capital investments. Of the two companies, however, Hot had lower earnings-per-share, and management had delayed one project to conserve cash and deploy resources to the other projects in order to realize the benefits more quickly. Also, Hot wanted to see a return on two projects, targeted at cutting costs, before further IT investments were undertaken. These two projects were scheduled to be completed within the next three months. The projects were on schedule and both were running slightly under budget. In fact, all of the projects at Hot were on or under schedule and, in total, under budget.

Lukewarm's CEO stated that the process may have benefited from reduced political tensions, but admitted that remnants of politics remained. Although implementation of the selection methodology was highly centralized, project management and implementation for many systems took place at the operating companies. Most of the projects were on schedule and within budget. One project, involving an intranet that would ultimately be installed at all of the operating companies, had experienced a major delay. The CIO who had technical responsibility for the project stated that the delayed project had suffered from a political tug-of-war about infrastructure issues. Rather than risk later opposition, the CIO had asked the steering committee to shelve the project until the underlying problems were resolved.

Overall, stated the CIO of Lukewarm, the IT projects were an outstanding success. Management seemed to be "more in synch" and ready to work with project members. One particular area of improvement, identified by the CIO, was in the creation of service-level agreements (SLA). The SLA process, which had evolved over a period of several years, had been the basis for several battles that had created ill-will among some of the company managers towards IT and the CIO. In discussing several SLAs for the new systems, the CIO found managers more literate and understanding about the functionality and limitations of the new system. The CIO stated:

They [the managers] appear to have more rational expectations about what to expect from these systems. In the past, I don't really think they had been involved or knew what to expect. Now they're forced to be involved. As a result, they have an appreciation for the complexities and the tradeoffs.

Status of Selection Process

Managers of Hot were continuing to modify and enhance the model. They wanted to be able to analyze individual investments on a stand-alone basis. The approach would include four "surrogate" investments, with favorable parameters, to establish a threshold against which proposed investments could be ranked. A continuing effort was the use of a program to quickly generate an initial set of paired-comparisons based upon a set of questions that the manager could answer by checking boxes on a one-page questionnaire. This initial solution made deriving a final solution much faster.

In addition, Hot had decided to categorize IT investments into five categories: strategic over $1 million; strategic under $1 million; non-strategic over $1 million; non-strategic under $1 million; and mandatory. The mandatory class usually consisted of smaller projects that were demanded by regulatory bodies. By their nature, these were not subjected to the analysis. Four separate sets of criteria and sub-criteria were developed for the four remaining classes. The two strategic categories had greater emphasis on valuation of intangible benefits. The two over $1 million categories had greater emphasis on risk analysis, an area that had been largely ignored in past analysis.

The major area of difficulty was in establishing the paired-comparisons. With the revised criteria, the CIO of Hot realized that managers would lose some of the familiarity gained earlier. Also, it was not feasible to create the paired-comparisons by comparing to all other projects within the category, and it was impractical to prescribe a single point in time for all managers to make the comparisons. To address these two problems, the CIO asked a team composed of financial, marketing, and engineering managers to develop a surrogate investment for each category. The surrogate would possess benefits that would make it attractive investment for each of the criteria. Criteria for proposed investments could then be pairwise compared with the surrogate. These comparisons would then serve to develop the paired comparison matrices between the actual IT investments. Thus, given actual investments A and B and surrogate C, knowledge of matrices AC and BC provides the matrix for AB. This eliminated the temporal dependency of the paired-comparisons and allowed for a less complex analysis. Furthermore, changes in the criteria for a single investment could quickly and easily be reflected.

Hot had also begun assimilating IT investment proposals for the next round of evaluations. Although a temporary freeze had been placed on funding of new projects, it was expected to be lifted with the successful completion of two IT projects within three months. More standardization was being added to the investment proposals. IT investments were submitted using a set of forms for outlining costs, benefits, human resource requirements, risks, and alternatives. The steering committee would screen out any unsound proposals or ones that lacked proper support. For those investments that were tentatively accepted paired-comparisons would be made. The objective of the screening process is to force sponsors to provide sufficient and precise information to support the investment proposal.

In about the same period of time, Lukewarm had accomplished much less. Although the CEO supported the process, he did not participate with the exception of attending quarterly steering committee meetings. At these meetings he did champion several IT issues and tended to support the CIO, as when he decided to shelve one project until questions had been resolved between managers whose disputes were hindering the project. The CEO had to contend with several presidents of the operating companies and had less time to focus on IT. Some of the company presidents had greater knowledge of IT and were supportive of the new process. The CEO had increased the operating budget of the centralized IT function but the time-period was not sufficient to show productivity gains by the hiring and training of new IT personnel. For that reason, little had been accomplished towards improving the process, primarily documentation of the process and the training of new managers. The CIO, however, was confident that the next round of investment proposals would be handled more expeditiously than in the past. Queried as to why this would be, he replied:

> *There is a new attitude. I see more managers today. They ask more questions. I have managers asking me if their new systems can be used with our intranet or if the intranet server will be centralized, things like that. They seem to be taking charge. Some are actually enjoying it. Even the ones who still grumble are not grumbling about how we approach ranking the investments, it's just*

about things like doing these [paired] comparisons.

Generalizable Findings

Research has shown CEO involvement to be a predictor of SISP success (Basu, Hartono, Lederer, & Sethi, 2002). In this study, the new process was supported by the CEOs of both firms. In one firm the CEO had greater knowledge of information systems opportunities and how they had been used strategically by other firms. This CEO worked closely with the CIO and other managers followed the lead. In the other firm, the CEO had superficial knowledge but was convinced that IT investments were an important strategic tool, particularly for the future. This conviction appeared to be based on discussions with CEOs at other companies and articles from journals, periodicals, and industry reports. The CEO's support was encouraging for the CIO, particularly in creating an improved environment in which to implement systems. However, while voicing strong support, this CEO did not work closely with the CIO, concluding that the IT area was capable of managing the process.

In a relatively short period of time, Hot had capitalized on the new process by extending the model and adding administrative controls to further insure success and reduce the time requirement on management. In an almost equal time period, Lukewarm had accomplished much less.

Managers in both firms had an improved attitude. This was perhaps even more noticeable at Lukewarm, where the relationship had evolved from one that could be described as approaching adversarial. The new process improved the quality of information available to measure investment proposals, increased the involvement of managers who were most knowledgeable about the proposed investments, and added credibility to the final results.

A key problem is that an investment's potential return may be reduced because of implementation problems. For example, a software application project may fail because of the inability to control quality during system development. Westland (2002) showed that unresolved software errors became exponentially more costly with each new phase in the project. While it is uncertain what influence the selection and

Table 3: Generalizable Findings

1	CEO support of the IT investment process is essential
2	Managers outside of IT must be trained and made aware of how the process works.
3	Managers must realize that participation is as important to success as the measurement tool. Managers closest to the IT initiatives must participate fully in the process.
4	The multi-objective, multi-criteria approach is flexible, scalable, and able to accommodate various sets of criteria.
5	Administrative steps can improve upon the IT investment ranking process and reduce the burden for managers.
6	Implemented correctly, the process may provide serendipitous results. For example, the process may lower political tensions.

prioritization mechanism has upon this problem, it is possible that, when the process lacks credibility, management will be less motivated to actively participate and help insure the success of the projects. The current cases could not adequately address this possibility but, in both cases, an increase in management participation was matched with overall success of implementation.

Summary

These findings represent only two case studies from an industry that is not truly competitive. One company, however, was under increasing competitive pressures and both companies were interested in strategic level systems that would improve the quality of their customer relationships and prepare them for deregulation. Despite these limitations, researchers and practitioners alike would probably agree that several findings are noteworthy and could be generalized to other firms.

First, the role of the CEO in supporting the new prioritization and measurement process is essential. Other managers are unlikely to participate, and may resist, unless they are convinced that the CEO is fully behind the process. Second, the AHP and integer programming model has several attributes, as discussed earlier, that make it superior to other measurement tools. The process will only succeed if managers are made aware of these attributes and understand how they work. Third, the measurement tool is not the process, it is a part of the process. Other parts include management participation, especially in creating paired-comparisons and reviewing results. Without participation by managers who are closest to the initiatives for the IT investments, there will not be an improvement in the information made available to the process. Less hierarchical organizational structures may be more conducive to acceptance and participation. Fourth, the process is flexible and scalable. It can be extended to use various sets of criteria and sub-criteria and it can accommodate a reasonably large number of proposals. Fifth, the process can be improved administratively. The use of a steering committee for screening can filter out unsound proposals. The use of questionnaires can assist in deriving paired-comparisons. Sixth, if successful, the process may provide serendipitous results. The attitude of managers towards IT planning and service-level agreements may improve. These findings are summarized in Table 3.

DISCUSSION

Two case studies supported the overall effectiveness of the AHP process in prioritizing and selecting IT investments. The multi-criteria model was not directed at measuring the profitability of individual investments; a separate economic evaluation model is required to calculate the financial returns. Occasionally, investments must be approved on a stand-alone basis and cannot await the next IT planning cycle. These investments can be evaluated independently using an economic evaluation model or be ranked against a surrogate project that possesses criteria that would make it a desirable investment.

Neither company used the model for risk balancing, preferring to add this functionality at a future date. Although both had mutually exclusive investments, neither identified dependencies. Both companies made adjustments to sub-criteria weights during the studies. After the analysis, both companies experimented with small revisions to weights to test their sensitivity. At the conclusion, the majority of managers appeared to be reasonably satisfied with the prioritization and selection of investments.

Benefits and Limitations

Both Hot and Lukewarm identified the following benefits:

- the ability of the model to handle a large number of criteria,
- the ability to represent both tangible and intangible items,
- the ability to model exclusivity and dependency of investments,
- the ability to quickly reflect revisions,
- the explanatory power of the model, and
- the support for group decision-making.

The following limitations were also noted:

- the lack of a financial measure of profitability,
- the overall time requirements for management, and
- the problem of valuing intangibles, although ameliorated, remained.

Both companies agreed that the model, while not simple, was understood and accepted by the majority of managers. Hot also identified the process as one of continuous improvement. Over time, as managers gained experience with using the model and results of investments were evaluated, adjustments could be made to reflect the new knowledge. Both companies stated that the model would be useful for supporting expenditures with regulators who frequently asked for such justification.

Facilitators and Inhibitors

Process facilitators and inhibitors are summarized in Table 4 for Hot (Case 1) and Lukewarm (Case 2). While both companies used JAD, only Hot used an outside facilitator and maintained focus by allowing sufficient time and holding it at a remote location. Both companies benefited from the support of the CEO, although the CEO of Hot led a more participative role. Without the support of Lukewarm's CEO, however, success would have been in doubt. Both companies stated that the process was time consuming requiring the attention of many managers over a span of several weeks. Hot had the advantage of a smaller and younger management team that had previous experience in a non-regulated, more competitive environment. Lukewarm's management, less familiar with SISP and IT opportunities, were less enthusiastic but participated at a higher rate

Table 4: Process Facilitators and Inhibitors

Facilitators	**Case 1**	**Case 2**
Focused JAD Session	X	
CEO Support	X	X
Other Management Support & Participation	X	?
Cross-Functional Management Team	X	X
Strategic Use of IT	X	?
Desire for Improved Rankings of Investments	X	X
Process Understanding	X	X
Inhibitors		
Bureaucratic Management Structure		X
Low Level of Competition		X
Time Requirement of Management	X	X

than in the past. Both companies benefited from a cross-functional management team that provided the requisite expertise for making the paired-comparisons. The team may also have been responsible for reducing political tensions. Displeasure with past approaches and CEO support had motivated both sets of management to adopt a new approach, but Hot appeared to better understand the use of strategic criteria for aligning the investments with business strategies. Use of JAD, the process facilitator, the CIOs, and the written documentation, fostered an overall understanding of the new approach. This understanding made the step-by-step procedures and numerous adjustments that were necessary in the initial implementation much easier to communicate.

Several process inhibitors were apparent. Lukewarm's top-down style of management was more rigid and created a less harmonious environment that had undermined the JAD session and resulted in more adjustments to the paired-comparisons. The absence of competition may also have made Lukewarm's management more complacent and less concerned about the strategic value of IT investments and the alignment with business objectives. Both companies identified the time requirement for producing acceptable paired-comparisons as being the most imposing challenge. Hot was taking steps to address this problem.

An important process facilitator was the adeptness of certain managers in both firms with the more quantitative aspects. Managers had little difficulty in using the application software and some had read several articles on AHP to gather a more complete understanding of the process and develop methods for handling the paired-comparisons. Both companies had existing computer models for integer programming, with which several of the engineering managers were highly skilled. The cross-functional team approach was very useful in adding a broader perspective to the identification of items to be included in the constraints for the integer programming model.

STUDY CONTRIBUTIONS

This study makes several useful contributions. First, it provides a tested process for prioritization and selection of IT-investments that can improve future returns. Researchers can further test the process in a manner that parallels this study and note its effectiveness. Practitioners can implement the process as part of their own IT planning practices.

Second, the study identifies benefits and limitations inherent within the process. While the benefits are several, there are also important limitations. Researchers and managers may be interested in how these limitations can be overcome. CIOs certainly want to be cognizant of the limitations in order not to oversell the process.

Third, the study identifies facilitators and inhibitors and generalizable findings to the approach. Researchers would be interested in how these are related to the contextual environments of other industries. Practitioners can benefit by knowing what management behaviors are supportive of the process and what outcomes may be expected from implementing the process. For example, practitioners would know that participation is essential and that the initial task of creating paired-comparisons is time consuming.

Finally, the study can assist the introduction of the process. Companies have difficulty adopting new processes because of resistance and cognitive limitations. CEOs and CIOs can make use of the example and case studies to introduce the process into their own firm and provide other managers some familiarity with the concepts.

Suggestions for Future Research

The measurement process for prioritization of information technology investments proposed herein has profound implications for practice. To test applicability of the methodology, further case studies are suggested wherein a portfolio of IT investments from different industries is evaluated. It would be interesting to see what criteria and sub-criteria are developed by different companies. Further case studies would provide more insights into the completeness of the approach, the time requirements, and the level of consensus and management support achieved.

Researchers could also examine the impact of contextual variables on the success of the IT investment model. How do organization structure, size, and IT maturity impact the usefulness of the process? Are bureaucratic organizations more or less likely to benefit from the process?

The balancing of investment risk was not tested in this study. The process lends itself to identifying the types of risk associated with each investment. Using an integer program constraint, each risk type could be limited so as to achieve a balance of risk for the overall investment portfolio. At minimum, each risk type could be measured for the portfolio.

Finally, the relationship between process credibility and subsequent development and implementation remains unresolved. Future research could help provide a clearer understanding of how the selection process impacts the implementation success.

CONCLUSIONS

The MOMC approach, utilizing AHP and integer programming, merits attention as a investment selection and ranking tool. The model's positive features, evidenced by two successful applications, include (1) incorporation of tangible and intangible benefits, (2) ease of use and flexibility, (3) intuitive appeal, (4) a forum for participatory decision-making which can help de-politicize the process, (5) a measure of consistency, and (6) availability of user-friendly software.

Although AHP has enjoyed extensive use in both the corporate and government sectors, there are apparently no examples of its actual use for ranking IT investments whereby investment costs are properly included. Combined with integer programming, AHP provides a MOMC approach that can improve the IT investment process. Strictly quantitative approaches have not yielded satisfactory results in the past but subjective approaches lack explanatory power and cannot be easily adjusted to reflect new knowledge. The model proposed and tested herein offers completeness and balance in its representation of relevant, and competing, factors in determining an overall prioritization and can be updated for changes in judgment reflecting new knowledge.

Basing selection criteria on business strategies ensures the alignment of IT investments with these strategies and increases the communicative power of the process to top management. While assessing the value of intangible benefits cannot be done with absolute accuracy, the process offers multiple advantages and overcomes the deficiencies of a strictly objective approach. The successes of two companies using the MOMC approach provides

APPENDIX A

Paired-Comparisons, Eigenvalues, and Consistency

Relative scales can be derived by using judgment or data taken from a standard scale. The underlying mathematical theory and operations have been covered in detail by Saaty (1977, 1987, 1994). Following is a brief summary of the eigenvalue method for making paired-comparisons and measuring consistency.

Generally, the matrix of paired-comparisons can be represented as:

criteria	1	2	3	...	n
1	w_1/w_1	w_1/w_2	w_1/w_3	...	w_1/w_n
2	w_2/w_1	w_2/w_2	w_2/w_3	...	w_2/w_n
A =3	w_3/w_1	w_3/w_2	w_3/w_3	...	w_3/w_n
...	...	...	...	...	...
n	w_n/w_1	w_n/w_2	w_n/w_3	...	w_n/w_n

Matrix A has rank 1, every row is a constant multiple of the first row, and all of its eigenvalues except one are zero. Also,

$$\mathbf{A} \cdot \mathbf{W} = \mathbf{n} \cdot \mathbf{W}$$

where $W = (w_1, w_2, \ldots, w_n)^T$ is the vector of actual relative weights, and n is the number of elements. Thus, n and W are the eigenvalue and the right eigenvector of matrix A. AHP theory posits that W is unknown to the decision-maker who is, therefore, unable to create a matrix of consistent paired-comparisons. An estimator of W (denoted as ***W'***) can be obtained using the relation

$$A' \cdot W' = \lambda_{max} \cdot W'$$

where ***A'*** is the observed matrix of paired-comparisons, λ_{max} is the principal eigenvalue of ***A'***, and ***W'*** is its right eigenvector and represents an estimation of W (Zahedi, 1986; Saaty, 1990). (In the example, n = 5 for five criteria and W is estimated by using the paired-comparisons for matrix ***A'***.) λ_{max} is an estimation of n and can be shown to be always greater than or equal to n (Saaty 1980).

AHP does not demand strict consistency. Not only does it allow for inconsistency, it measures it and supports interpretation of its source. The closer the value of λ_{max} to n, the more consistent are the observed values of ***A'***. It can be shown that inconsistency throughout the matrix is captured in the number λ_{max} - 1. Using this property, a consistency index, CI, can be constructed to measure the consistency of the decision-makers' comparisons as

$$\mathbf{CI} = (\lambda_{max} - n) / (n - 1)$$

Inconsistency may be introduced through error, as the result of a multitude of comparisons, or naturally. An example of the latter case is the relative judgment in which A is preferred twice as much as B, B is preferred three times as much as C, but A is *not* preferred six times as much as C.

Generally, a consistency index of 0.10 or less is considered acceptable. To improve consistency for the paired judgments, a reciprocal relationship is enforced. Let aij = wi/wj in the matrix A. Then we must have aji = 1/aij.

evidentiary support for its future usefulness in helping to solve the problem of failed IT investments.

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