CIFE CENTER FOR INTEGRATED FACILITY ENGINEERING

DECISION ANALYSIS TECHNIQUES FOR INTEGRATION TECHNOLOGY DECISIONS

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CIFE Technical Report
Number 95
July, 1994

STANFORD UNIVERSITY

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Summary: CIFE Technical Report Number 95

Title: **Decision Analysis Techniques for Integration Technology Decisions**

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Date: July 1994

Funding: CIFE Seed Project

Abstract: This report discusses the use and benefits of implementing decision analysis to model integration technology decisions. A general description of decision analysis is followed by discussion of a generic decision diagram to illustrate the variables and the relationships involved in integration technology decisions. The report then describes use of decision analysis for a strategic decision and an operational decision related to integration technology: selection of a computer estimating system by a general contractor and selection of hardware and software for computer-aided design by a shipping company. Key conclusions from these applications include potential benefits for both types of decisions, value in structuring analysis of the situation and framing the decision, and need for application at appropriate level of detail.

Subject: The research described in this report focused on evaluating the potential use of decision analysis techniques to select integration technologies and methods for implementation.

Objectives/Benefits: The objectives of this research were to assess the feasibility and benefits of using decision analysis techniques for decisions regarding integration technology and to develop recommendations to increase the effectiveness of decision making for developing and implementing integration technology. The results assist managers considering alternate techniques to support the complex decisions characteristic of integration technology.

Methodology: The major activities for this research included reviewing background to identify the variables in adoption decisions related to integration technology, analyzing a general contractor's decision regarding a computer estimating system, analyzing a shipping Company's decision regarding a CAD system, and highlighting conclusions and recommendations.

Results: This research indicates that decision analysis techniques can assist in evaluating and selecting integration technologies for application on design and construction projects. Although the technique is normally applied for strategic decisions, it also assisted in framing operational decisions. This included focusing on key alternatives and determining the value of collecting specific additional information. Selecting the appropriate level of detail for application of decision analysis and the source of the expertise is critical.

Research Status: This report completes the CIFE seed project that sponsored the work. No additional CIFE research concerning this topic is currently planned.

Contents

Chapter 1

Introduction and Objectives

The architecture, engineering and construction industry presents many opportunities for the adoption of new technologies which could improve performance and productivity. Recent developments in the computer industry provide the opportunity to achieve substantial gains in process technology innovations. A particular process technology that promises high rewards is computer-based integration. The goal of integration technologies is to improve the quality and efficiency of the design, construction, and facility management process through improved ability to share data and knowledge. Increasing accurate information transfer between the various project phases and among the project participants has the potential to realize considerable efficiency gains for construction firms and overall reduction of project lifecycle costs. Observation of the AEC industry clearly indicates that *"the architecture, engineering and construction (AEC) industry, now highly fragmented, offers enormous potential for improvement through integration."* (Tatum 1990, pg. 47) Furthermore, current trends of increasing complexity of the construction industry indicate that *"as complexity increases, ... it may be extremely difficult to adequately coordinate these [AEC] specialists without new computer technology for integration."* (Tatum 1990, pg. 51) Pressure from clients, who are increasingly requiring computerized scheduling and design models and documents, as well as pressure from competing firms that are realizing productivity gains and a resulting competitive advantage from integration technologies are encouraging companies to adopt new computer-based technologies.

Because the cost of implementing integration technologies is substantial and the benefits are often difficult to measure, many firms are reluctant to make a large investment in technologies where the costs are obvious but the potential benefits are not. Construction firms are increasingly leaner and more business oriented, but even so, *"as business administration practices grow more prevalent, ... time and cost [of new technologies] are more accurately forecast, ... but the benefits [are] not adequately quantified."* (Gerwick 1990, pg. 557) The decision to adopt an integration technology is difficult, and frequently it is highly influenced by the management's enthusiasm toward utilizing new technologies. In other words, subjective tendencies for or against integration technologies may play a larger role than the objective indications of the benefits. The adoption of integration technologies may not be the correct choice for every firm. However, the present method of determining the need for an integration technology is inadequate, being neither objective nor effective. It is clear that an efficient method of making rational decisions based on available information is vital to determine the need for integration technologies.

The discipline of decision analysis provides such a tool. Decision analysis provides a framework for a consistent analysis of risk attitude and the variables that influence the decision process. By methodically proceeding through the decision process, the decision is modeled using the probabilities and relationships provided by the individual who makes the decision. A particularly useful decision analysis tool is the decision diagram, which simplifies communication between the analysts and individuals who lack a working knowledge of decision analysis.

The purpose of the research described in this report was to assess the feasibility and benefits of using decision analysis and influence diagrams for decisions regarding integration technology and to develop recommendations to increase the effectiveness of decision making for developing and implementing integration technology. The research activities included reviewing background to identify the variables in adoption decisions related to integration technology, analyzing a general contractor's decision regarding a computer estimating system, analyzing a shipping Company's decision regarding a CAD system, and highlighting conclusions and recommendations.

The major research activities structure this report. Chapters 2 and 3 give the results of the background review and the identification of variables in an adoption decision. Chapters 4 and 5 describe the analysis of technology adoption decisions by a general contractor and a shipping company. Chapter 6 gives the conclusions and recommendations from the research.

Chapter 2

Background Research

Evaluation Techniques for Integration Technologies

Several CIFE technical reports provided specific criteria to use in evaluating the need for a new technology. Hayakawa provided several methodologies *"to evaluate technology and to evaluate research and development, through which technology is created."* (Hayakawa 1989, pg. 2) All of the methodologies involve setting criteria, preparing data, integrating data, applying an overall rating, and making a decision with an algorithm. A variety of algorithms are proposed, including the economical index model (where I=R/C, I=index value, R=total return on project, C=total cost of project), the resource allocation model, and the scoring model. The scoring model weights each criteria according to level of importance in the decision, and then evaluates the criterion for each project. (Hayakawa 1989)

Mahoney identified specific barriers to the implementation of CADD including *behavioral, institutional, legal and organizational* barriers. *Behavioral* barriers are basic human behaviors and reactions to adoption of computer-based technologies, while *institutional* barriers are industry wide characteristics the inhibit the use of integration technologies. *Legal* barriers are the precedents and laws that inhibit the integration of new technologies, and *organizational* barriers are characteristics of individual companies that inhibit the integration of computer technologies into the AEC firm (Mahoney 1990).

Hansen discussed operational benefits *"which directly improve productivity, lower costs, compress the construction schedule, or increase quality during the engineering and construction process"* and strategic benefits that *"enhance the firms competitive advantage in the marketplace."* (Hansen 1990, pg. 9)

A monthly technology brief provided a concise summary of many of the variables used in the generic decision diagram (Jacobus 1991). This brief served to reinforce the variables and relationships previously defined from other information sources.

Decision Diagrams

In evaluating integration technologies, it is "necessary to break open and to examine the contents of the black box into which technological change has been consigned [by economists]."(Rosenberg 1982, pg. vii) Decision analysis provides an objective means of examining and relating the contents of the black box. Ronald A. Howard meticulously describes decision analysis in a series of articles. (Howard 1988) A particularly useful tool in decision analysis is the decision diagram. These diagrams are effective since they represent decision problems in a compact form, are simple to introduce to those not familiar with decision analysis, and are an excellent evaluation device.

The literature from several fields provides a wealth of information for both building a decision diagram and selecting the important parameters that should be represented as nodes. There were no case studies using decision diagrams for decisions similar to purchasing and implementing an integration technology. Therefore, this study combined the general concept of decision analysis with the information detailing the important factors for the decision to adopt or develop an integration technology. The result is the generic decision diagram for integration technology decisions presented later in this report.

Decision Analysis/Decision Diagram Process

Decision analysis is often defined as "quality conversation about decisions," or "a systematic procedure for transforming opaque decision problems into transparent decision problems by a sequence of transparent steps." (Howard 1988) Behind these simple definitions lies a vast body of knowledge that assists in structuring, analyzing, and appraising a decision problem with a final result that suggests the best course of action.

History

Modern decision analysis evolved mainly from work in the field of statistics and its applications to economics and physics. However, since then, decision analysis has proved particularly useful in a large number of other areas—such as corporate strategy, R&D projects selection, medicine, and meteorology—to name just a few, leaving economics and physics on the fringes of the mainstream decision analysis activity. In the last twenty years, the development of computers and sophisticated procedures and algorithms allow decision analysis to handle large real problems, thus increasing the practical range of use of decision analysis. Some of the techniques concerning decision diagrams will be discussed further below. Today decision analysis is applied to a wide range of fields, ranging from strategy, R&D decisions for business enterprises, to meteorological studies.

Fundamentals of Decision Analysis

The entire body of decision analysis is derived from a basis of elementary principles. Commonly referred to as Rules of Actional Thought, they encompass five rules that are simple and intuitive to understand (Howard 94). These rules support development of the decision analysis theory. The principles

- permit the use of possibilities and probabilities to characterize information and trade-offs
- enable the ordering of prospects in order of preference to the decision maker (without ruling out that there may be prospects that are equally desirable)
- allow for establishment of preference probabilities among the alternatives (thus establishing a probability that makes a decision maker indifferent between a certain benefit, usually referred to as "certain equivalent" vs. a chance of a win)
- postulate the indifference between an uncertain prospect ("deal") and its certain equivalent, and finally
- justify the preference of a deal that has a higher chance of realizing a better prospect.

In addition to the Rules of Actional Thought, decision analysis is based, among other things, on the clarity of information and commitment to action; without clarity communication is difficult, analysis practically impossible; without a commitment to action, the decision is irrelevant.

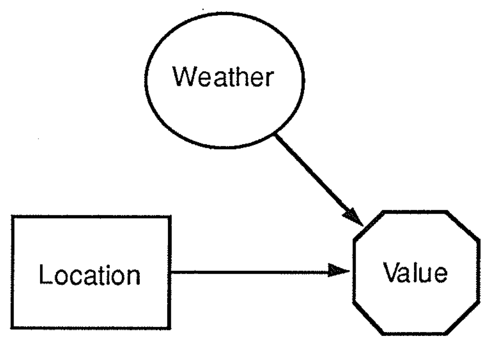
Traditional Approach to Decision Analysis

Decision analysis takes a loosely defined real decision problem as its input and produces a recommendation for real action. The steps that are in between these two endpoints are the decision analysis process (Howard 1988).

A traditional, full-blown decision analysis consists of several phases (Matheson and Howard, 1983). Phase one is the *deterministic phase* ("problem formulation") in which the analyst and decision maker work together to understand and define the scope of the decision. This is a two-way process in which the decision maker communicates the situation, and the analyst suggests ways of approaching the decision situation that are consistent with normative decision-making processes. Together, the decision maker and analyst can generate and define the decision alternatives, determine the variables that affect the outcome, and establish a value measure of that outcome. The alternatives, information and preferences of the decision maker encompass the decision basis which, when properly formulated, guides the decision analysis process.

Decision Diagrams (or Influence Diagrams) have proven to be a useful tool for formulating complex decision situations. These diagrams show the informational, or inferential relationships among variables and decisions. In them, decisions are represented by rectangular nodes, uncertainties by round nodes, and the terminal value node by some other polygon (typically an octagon or a diamond). Arrows between nodes represent a possible inferential relationship. For these diagrams to be quantifiable, the nodes must be rigorously defined. It is the job of the decision analyst to guide the conversation that structures and defines these diagrams. In current practice, decision diagrams have become the primary tool in the decision analysis kit.

One simple and standard decision diagram is that representing "The Party Problem." (Howard 1994). In it, a girl, Kim, is choosing the location for a party (indoors, outdoors, or on the porch) and is concerned about the weather (sun or rain). Her decision diagram is illustrated here.



The decision diagram for the Party Problem.

At the conclusion of the deterministic phase, the decision analyst typically performs a sensitivity analysis on the variables to find the ones that are most important for further study. These variables will be the focus of phase two.

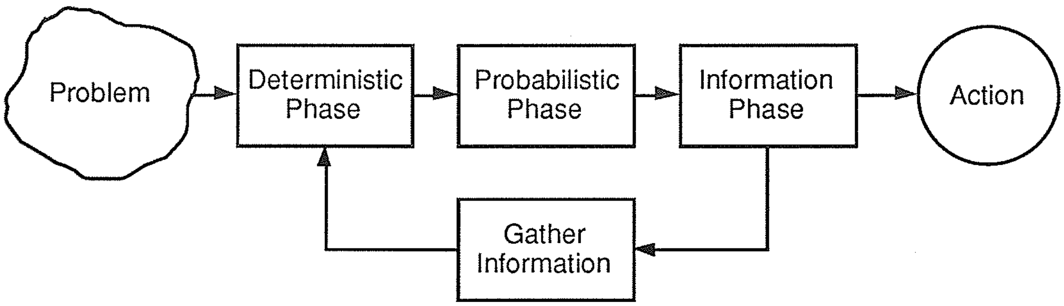
There are several commercially available software packages that can assist the decision analyst in his or her work. These include Applied Decision Analysis' DPL®, SDG's SuperTree®, and many others. Unfortunately, the state-of-the-art in decision analysis software lags behind the state-of-the-art in decision analysis practice. Consequently, the majority of decision analysts do their modeling in one of the many powerful commercially available spreadsheets, such as Microsoft® Excel. The researchers used Excel in this project.

Phase two is the *probabilistic phase* of decision analysis. After separating those variables which cause the greatest swing in the possible decision courses from those which have less impact, the analyst can begin to focus concentration on the appropriate area. Typically, a decision analyst will take the least sensitive variables and "fix" them at their mean values. After that, the analyst will engage various experts in a series of informational conversations. These experts are identified by the decision maker as having the most trusted understanding of one or more of the salient variables. Each conversation consists of the analyst drawing upon his or her experience to elicit an understanding of the expert's opinion about the variable in question. In decision analysis, this understanding is represented by a probability distribution that depicts the range of values that the variable might take. The end result is a series of probability distributions that represent each of the salient variables.

Finally, the decision analyst will take the probability distributions and use them to evaluate the decision and determine a course of action. Absent more information, this is the best known alternative available to the decision-maker, given the current information and preferences.

Phase three of the decision analysis cycle is the *information phase*. In this phase, the decision analyst can examine each of the salient variable to determine their "value of information." This is the amount that the decision-maker should be willing to sacrifice in order to eliminate all uncertainty about that variable. If imperfect tests of the variable are available that might eliminate only part of the uncertainty, the decision analyst can determine the value of performing these tests, as well.

Frequently, the value of information for one or more variables will be high enough to warrant delaying the decision for further study. This in itself should be recognized as a decision—a decision to actively seek more information. In this case, the decision analyst can determine what action to take contingent upon the possible results of this study. If several variables are under consideration, the cycle may be iterated with the new information being used to go back and perform a new deterministic phase. Previously settled "framing" issues are reexamined and the process continues. Eventually, analyst and decision maker settle upon a course of action, and the decision is taken.



The decision analysis cycle consists of three phases.

Decision Analysis Modeling Process

Three stages of analysis are at the core of the modeling process: formulation, evaluation, and appraisal. During the formulation stage the problem is formulated with enough detail and clarity to allow effective use of the tools of decision analysis. This includes identifying the objective of the decision (maximize profits of a venture, minimize the time of a patient's therapy, etc.) and identifying the variables (paying particular attention to their definition and clarity) that are influencing the outcomes as well as their relationship. Information on these variables is summarized by probability distributions on their values. Also in this stage, the decision maker's risk attitude is determined; it is crucial in the next step of the decision analysis cycle.

In the evaluation stage the results of the model constructed in the previous stage are obtained. In the third, appraisal, stage, these results are interpreted in the light of the original problem. The principal appraisal techniques include performing sensitivity analyses and determining the value of further information to the decision maker.

After these three steps are performed, in the order listed above, the analysis often initiates a second round of the decision analysis modeling process. The problem is subsequently reformulated—in the light of results and appraisals from the first "cycle"—reevaluated, and reappraised. The second "cycle" could be then also followed by the third, during which any new insights are incorporated into the problem evaluation again.

Although in theory subsequent cycles could be performed many times, usually just a few iterations (two or three in most cases) of the cycle suffice. With each cycle the problem is simplified and less important variables are isolated. The process finally stops when a further cycle adds no significant improvement over the previous one.

One of the major tools in the decision analysis process that is both a conceptual tool and a powerful analytic engine is the decision diagram, a recent and revolutionary addition to decision analysis. (Olmsted 1983 and Schachter 1986) It is analyzed further in the next section.

Decision Diagrams as Tools in the Decision Analysis Process

Decision diagrams are conceptual, graphic diagrams used for presenting complex decision problems in a compact form. They used to be known as influence diagrams—and indeed, some decision analysts still refer to them by that term. However, modern terminology reserves "influence diagram" for a very special class of decision diagrams.

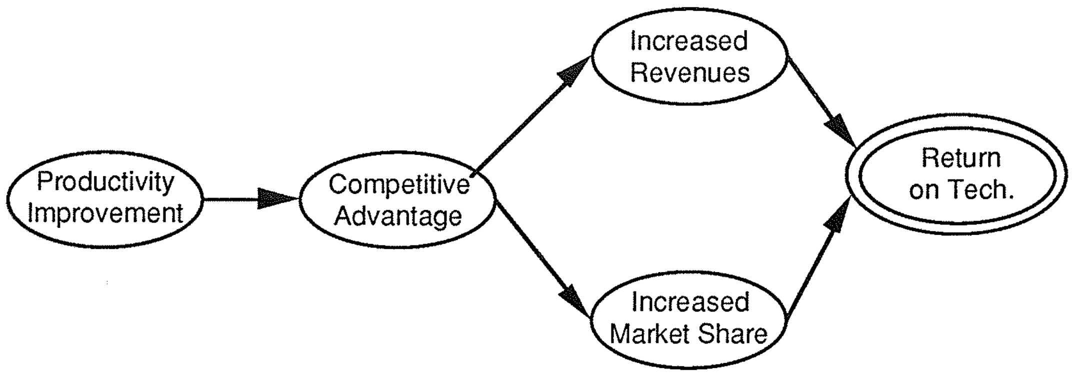
Decision diagrams consist of "bubbles" (or "nodes") that represent:

- a *decision* ("decision bubble" usually denoted by a square)
- a *chance variable* ("chance bubble," usually denoted by an oval)
- a *"deterministic"* variable ("deterministic bubble," usually denoted by an oval with a double edge)
- a *"value" function* ("value bubble," usually denoted by a octagon or a hexagon)

Decision bubbles contain decisions to be made; *chance* bubbles contain variables that are uncertain; *deterministic* bubbles contain functions that are deterministically computed from the values that come by the arrows from other bubbles into the deterministic bubble; finally, *value* bubbles contain the value of every possible outcome—it is the objective that needs to be maximized (or minimized). There can be only one value bubble in a decision diagram.

These nodes are connected by arrows, termed relevances, that represent relationships between the bubbles. For instance, an arrow going from a chance bubble to a decision bubble means that this particular decision is made after the uncertainty in the chance bubble has been resolved; an arrow from one chance bubble to another chance bubble means that the probabilities in the second bubble have been assessed based on the outcomes of the first bubble. A simple example with explanation follows below.

Portion of a Decision Diagram



This diagram portrays the relationship between four variables and a value function. The line between Productivity Improvement and Competitive Advantage indicates that the amount of productivity improvement increases the competitive advantage realized by the company. Similarly, Increased Revenues and Increased Market Share are both influenced by the degree of competitive advantage which a technology provides. And finally, the return on the technology is a function of the increased revenues and increased market share.

An important distinction is that between direct and indirect predecessors. Direct predecessors are those nodes which, as the name implies, directly proceed the node at the point of the arrowhead. Indirect predecessors are any nodes which in some way influence a node even though there is no direct connection between the two. In the above example, competitive advantage is the direct predecessor to increased revenue. An indirect predecessor to increased revenue is productivity improvement. The indirect relationship between the two is mostly easily illustrated by noting that a change in productivity will indirectly influence revenues by affecting the competitive advantage of a company. Although this is a very simple example, it illustrates the point that a node can be influenced by many other nodes besides its direct predecessors.

In reality, each decision maker will choose a different set of variables and relationships between those variables when modeling a decision. However, the authors created a generic diagram which fairly represent the variables and their interrelationships in order to demonstrate the decision analysis concept and provide a general idea of the variables that are often considered in an integration technology decision.

Decision diagrams owe their popularity among decision analysts primarily to the following three reasons:

- They are compact enough so that even some very complicated decision problems can be schematically developed and discussed on a single sheet of paper. This is a tremendous advantage over decision trees which may require an entire wall for adequate representation and thus even obscure the very problem they were intended to clarify.

- They are relatively simple to introduce and explain to people unfamiliar with the probabilistic framework of decision analysis and thus create comfortable common ground for decision makers and decisions analysts alike.

- In addition to their value as a theoretical concept, decision diagrams provide the basis for a number of software packages—including *Supertree* (see McNamee & Celona 1990) . Furthermore, they enable various procedures—such as sensitivity analysis etc.—to be performed quite easily.

Insights Available by Decision Analysis

In addition to pointing out to the best decision—according to the information supplied—decision analysis provides an entire array of very useful information to the decision maker. For instance, given a decision maker's risk attitude (risk averse, neutral, or risk seeking), decision analysis is able to determine the value of expert opinion to resolve some uncertainty in the problem, and in general, the value of information. Thus, it is able to determine the maximum amount of money a decision maker should be willing to pay for some information if he or she intends to keep consistent with stated preferences.

Another useful insight from decision analysis concerns sensitivity of the decision to the given inputs. Namely, it enables solving questions of the type "will my decision change at all if the information about a particular variable is just half as reliable as we initially assumed?" It is able to determine not only if the decision will change, but also, if it does, how "bad" of a situation would result from pursuing the current plan of action. By providing the value of information, decision analysis would show how valuable it is for the decision maker to ascertain the reliability of the variable.

Applications of Decision Analysis

As mentioned earlier, decision analysis has been used in a very wide variety of areas and is constantly being used to shed insight into problems arising in new fields. It finds a particularly rich field in the issues and decisions facing management in the construction industry. And, even though it has not been used substantially in construction, it is very likely indeed that this will change in the near future.

Chapter 3

Variables in an Adoption Decision

The decision to adopt an integration technology involves complex influences between market forces, company culture, and the type of technology under consideration. Initial variables are the cost of the technology, both the up front cost and the cost of decreased productivity during the implementation of the technology. Although "at a detailed level, the issues will vary from company to company," and "every [decision] is a unique one," (Jacobus 1991, pg. 1) the following section attempts to summarize and describe the variables in an integration technology decision as collected from various case studies and relevant literature.

The following nodes make up the decision diagram for integration technology decisions (see Figure 1). The node descriptions include a general discussion of the significance of the node as well as qualitative factors that can help to determine a range of values for the node. For all nodes, expected values for the outcomes of each node must be estimated by the decision maker. Then, probabilities are assigned to these possible outcomes according to the user's estimation of the likelihood of each outcome.

Decisions

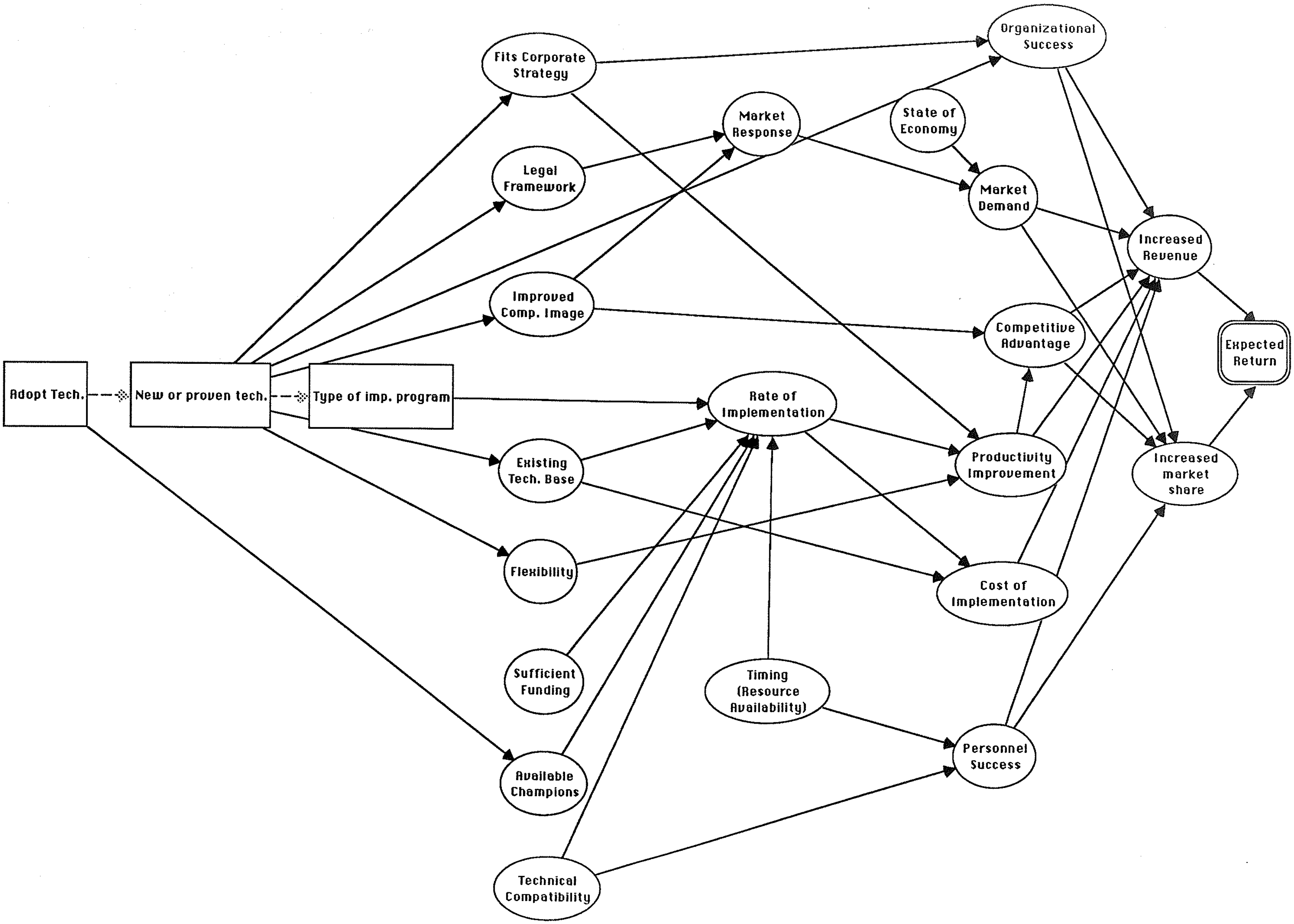
The decisions on the diagram include adopt technology, new or proven technology, and type of implementation program.

Adopt Technology

This decision node is the seed for the entire diagram, as it represents the decision to adopt or not adopt an integration technology.

New or Proven Technology

If the decision was to adopt an integrated technology, then the company must choose whether it wishes to adopt a technology that is new to the market and could provide larger returns but also has larger risks of failure/loss, or a technology already proven in the marketplace which appears to fit the company's needs and will provide more moderate returns and lower risk of a net loss on investment.



Adopt Tech.
New or proven tech.
Type of imp. program
Fits Corporate Strategy
Legal Framework
Improved Comp. Image
Existing Tech. Base
Flexibility
Sufficient Funding
Available Champions
Technical Compatibility
Market Response
Rate of Implementation
Timing (Resource Availability)
State of Economy
Market Demand
Organizational Success
Competitive Advantage
Productivity Improvement
Cost of Implementation
Personnel Success
Increased Revenue
Increased market share
Expected Return

Type of Implementation Program

An implementation strategy for the technology is vital. A typical decision in this node is whether to adopt the technology comprehensively and at a rapid pace, or to adopt a step by step implementation program which gradually incorporates the technology into the company. Rapid implementation will encourage adoption of a unified system and quicker streamlining of operations. However, there is likely to be a decrease in worker productivity during the initial training and use of the software. Gradual implementation prevents a larger, but less drastic loss in productivity, but the system may not be adopted uniformly at all branch offices. In either case "ongoing implementation of automation, such topics as training, cost and automation planning must also be addressed." (Jacobus 1991, pg. 2)

Chance Variables

The decision diagram for integration technology includes the 19 chance variables described below.

Fits Corporate Strategy

To what extent does adoption and implementation of the technology fit the long-range business strategy, also known as the vision, of the firm? This is a very basic question because the benefits of the integration technology will not be realized without a high level management idea of how the technology can be used to help obtain the firms strategic objectives. As mentioned in a technology newsletter, "the vision is a starting point for every decision regarding hardware or software."(Jacobus 1991, pg. 3)

Flexibility of Technology

Does the technology have the "capability to be used across multiple disciplines and multiple business lines?"(Jacobus 1991, pg. 1) Also, is the technology mainframe or workstation oriented (workstations are transportable). This node influences how useful the tool will be for the variability of project types and location that is intrinsic in the construction industry.

Sufficient Funding

Is there enough funding for proper implementation of the technology into the company workface? Implementation includes personnel training and hardware and software purchase. The funding level required for successful implementation is best determined by studies of the amounts required by previous firms.

Available Champions

Are there technical, business, and executive champions available who will promote the project? Technical champions are those who familiar with the technology so that they can help hurdle any barriers caused by a lack of technical understanding. Business champions push the economic feasibility of the project. Executive champions promote the benefits of the project among the management levels of the firm. (Mahoney 1990)

Legal Framework

Is the technology acceptable from a legal standpoint? Will it be accepted in contracts and other legal documents which are an essential part of the project process?

Improved Company Image

Will adoption of the technology provide a boost to the company's image from the perspective of clients, competitors, and subcontractors. For example, will the technology portray the firm as an industry leader in high technology innovation?

Existing Technological Infrastructure

"Infrastructure includes not only existing hardware and software, but also workforce skills." (Jacobus 1991, pg. 2) Does the firm already have some expertise in computer technology applications for construction? The primary benefit of infrastructure is how it can help or hinder the rate and cost of implementation.

Timing

This node addresses the availability of slack resources, i.e. resources which are currently not used for other purposes and are therefore available to assist in the implementation of the technology. For example, if all resources are employed on current projects, then implementation time will be affected.

Technical Compatibility

To what degree is the technology technically compatible with other systems that the firm currently employs. That is, does the new technology lend itself to internal standardization with other software and hardware used by the firm? This could also include how to best integrate with the client.

Rate of Implementation

Will the technology be implemented quickly, or will the process be relatively slow. This node is influenced by several predecessors (see diagram), and in turn is influential for several following nodes. A decision maker should consider the existing technological base of the company, the funding available for implementation, champions in the organization who are willing to push for implementation of the technology, and the type of implementation program which the firm has chosen to pursue.

Market response

How will the market respond to the use of a new integration technology which may effect how jobs are done. One might consider the firm's existing market share in this node, as well as the expected direction of the industry and owner's desire for increased use of integration technologies. An important consideration here is the possibility of creating a niche in the market as a result of a specific service or product specialization.

Market demand

What will market demand be for the integration capability? As illustrated in the diagram, this node is influenced by market response as well as the expected trends for the national/regional economy and the construction industry. Market response(the previous node) could be enthusiastic, but other influences such as economic trends could decrease the actual market demand.

Competitive advantage

How much of a competitive advantage will the integration technology provide? Consider specifically advantages in terms of meeting project objectives in terms of cost, quality, safety and schedule. As mentioned in an integration technology primer, the bottom line is: "If you can prove to your customers that your use of automation adds value to their project, then you gain a competitive advantage."(Jacobus 1991, pg. 3)

Productivity improvement

To what extent will the technology improve productivity within the firm, as indicated by reducing workhours required for design and construction. Productivity in an overall sense could result from such factors as: honing estimates and cost changes, improving materials procurement and management, compressing and optimizing schedules, and enhancing communication and coordination.

Cost of Implementation

What are the expected costs of implementation (implementation defined as full integration into the company structure)

Organizational success

What is the likelihood that the organization of the company is conducive to the adoption and use of the technology? "There are many cultural changes, made possible by integration ... to take advantage of these [automation] tools, the design and construction process *must* change."(Jacobus 1991, pg. 3) Inherent in evaluation of this node is the possibility of a modification of the firm's organization (i.e. restructuring of departments, creation of incentives for use of the technology, etc.) in order to permit more effective use of the technology.

Personnel acceptance

How will company personnel react to incorporation of the technology. Will they adopt it efficiently and enthusiastically into their daily operations or shun it as a threat to their jobs and reduce its effectiveness?

Increased revenue

What is the chance of increased revenues(losses) as a result of incorporation of the technology. The user should pick several possible values for revenue increase and assign values to each.

Increased Market Share

What is the chance of the firm increasing its share of the market due to adoption of the integration technology? The existing market share often plays a large role in the technology strategy of a firms, the general consensus being "For firms having a strong competitive position, a more aggressive technology strategy is indicated." (Allio and Sheehan 1984, pg. 19) The user must also determine the value to the firm (in terms of the company-wide strategy) of an increased market share.

Deterministic Variable: Expected Return

This node returns the expected value of the investment after the values of the decision tree valuation process has been completed. This value should be compared to various benchmarks commonly use to evaluate investments (IRR, PV, etc.) to determine whether the technology will achieve the necessary rate of return.

An important concept is that the information for each of the variables (the values and probabilities of possible outcomes) are obtained by tapping the knowledge of the decision maker. The decision analyst does not provide any information, but merely serves as a facilitator who extracts the relevant information in an useful form from the decision maker.

Chapter 4

Analysis of General Contractors Decision Regarding Computerized Estimating System

Introduction

The researchers investigated a general contractor's decision regarding a computerized estimating system to evaluate the usefulness of decision diagrams for integration technology decisions. Decision analysis techniques have already been proven useful in many industries for a wide variety of high-level, strategic decisions, but before this study no documentation was available involving technology adoption decisions in the construction industry. Therefore, one aim of this research was to conduct a case study with two goals in mind: 1) to determine the usefulness and applicability of decision analysis for technology decisions, and 2) to report on construction executive's opinions about the use of decision analysis in construction. The case study involved a small company that placed high value on being technologically elite and had previously made a decision to adopt a particular type of integration technology. Analyzing a previous decision is considered poor practice in the decision analysis field because once a decision is made, the preferences and probabilities of the decision maker begin to change. As the results of the decision become more clear over time, the decision maker's values and probabilities of the outcomes often change significantly, even though s/he is trying to "replicate" the values from the original decision. To mitigate the effects of post-decision biases, we attempted to obtain probabilities and valuations from a decision technique that the company had used for the actual decision.

The firm queried for the study, DPR Construction, is a general contractor currently ending its fourth year of operation. The company focuses on commercial building construction and has established a market niche in pharmaceutical projects. It is a unique firm because although recently founded, the company has a considerable amount of construction experience, including a solid background in the use of computer technologies in construction. Its growth since founding has been impressive, and part of the success is due to a highly professional attitude. Employees of the firm mentioned that part of their professionalism is the desire to be on the cutting edge of computer technology that is relevant to their line of business.

As part of their computer technology goals, the firm chose to purchase an estimating software package. The company had a rather well-defined concept of the type of system it desired, and had defined two possible software packages that would fulfill its criteria. At the time of our initial interview, the firm had already chosen to adopt the Timberline package.

We interviewed two employees at DPR. Eric Lamb, manager of preconstruction services, provided information about the variables that DPR used in their decision. He also provided some preliminary values to some of the outcomes and variables. We interviewed Jim Kilpatrick, senior estimator, twice; once to obtain more detail about the decision that DPR made, and a second time to ascertain DPR's probabilistic value assessments and risk attitude for the decision analysis model.

Because we were analyzing a decision which had previously been made, our approach to this case involved first understanding DPR's decision-making process and then using the decision analysis method to create a model of the decision. Our interaction with DPR closely followed the scheme established by the decision analysis cycle described earlier in this report. Our analysis involved two cycles. The following sections describe the specific information obtained from the two cycles and the subsequent analyses.

DPR Analysis After the First Decision Analysis Cycle

The analysis of DPR's software technology decision was performed by two different methods. First analysis was done by following the method used by DPR itself. The second method was by solving the DPR's decision tree using SUPERTREE software. Both analyses, methods and conclusions, are analyzed further below.

Method 1: DPR Solution Method

This method is represented in Table 1 below. The procedure is as follows: Each variable (or characteristic, given in column "Item") is assigned a particular weight, reflecting its importance. Weights are given in the "Weight" column. Subsequently, both products, Timberline and G2, are graded in each category independently, on a scale from 0 to 10—with 10 being the best (columns labeled "Timberline" and "G2," respectively, give these grades). In the next step each grade is multiplied by its weight (see columns labeled "Timb. Product" and "G2 Product"). Finally, these products (weighted grades) are then added, and preferred product is then made known through its higher grade (row "TOTAL" at the bottom of the table).

The conclusion from this method is that Timberline is a better choice and that DPR should adopt it over G2. Mr. Kilpatrick did point out that the two software products came very close in DPR's original analysis, as is also the case here.

Weight	Item	Value for Timber-line	Weighted Evaluat-ion for Timber-line	Value for G2	Weighted Evaluat-ion for G2
16	Digitizer	10	160	9	144
16	Capacity	10	160	10	160
16	IBM Compatible	10	160	10	160
15	Sorting	8	120	4	60
14	Workpackages	10	140	6	84
13	Format of Reports	3	39	8	104
12	DPR Clout	5	60	10	120
11	Flexibility to Revise Costs Outputs. Database	10	110	10	110
10	Ease of Use	7	70	7	70
9	Company Support	5	45	10	90
8	Cost	5	40	6	48
7	Accounting Interface	7	49	2	14
6	Company Viability	9	54	4	24
5	Minimal Initial Time Commitment	5	25	5	25
4	Industry Recognition	8	32	2	8
3	User Group Availability	7	21	0	0
2	Demo. Packages Available	10	20	10	20
1	Direct Contact to Company	10	10	10	10
	TOTAL		1315		1251
	NORMALIZED VALUE		100%		95%

Table 1. DPR Decision Method.

Note: see Table 2 for a description of the variables listed in the "Item" column

Variable	Explanation
Digitizer	Does software allow use of digitizer with estimate?
Capacity	Is the capacity of the software and database sufficient?
IBM Compatible	Extent of compatibility with IBM systems
Sorting	Ability of the software to sort data according to different criteria
Workpackages	Does software contain the feature which allows creation of various estimating workpackages?
Format of Reports	What is the appearance and flexibility of the report format?
DPR Clout	To what extent does the use of the software contribute to DPR's clout among owners?
Flex. to Rev. Costs Outs. Dbse	What amount of flexibility is there to revise costs outside of the general database?
Ease of Use	How simple is the software to use on a day-to-day basis?
Company Support	What kind of vendor support would DPR receive?
Minimal Initial Time Commitment	What is the minimum amount of time required to learn basic operation?
Industry Recognition	Would use of the software increase recognition within the industry?
User Group Availability	Are there user groups with whom DPR can exchange information/problems?
Demonstration Packages Available	Are there demonstration packages for trial use before purchase?
Direct Contact to Company	Would DPR have direct contact to the software company in order to bring up problems/improvements to software?

Table 2. Description of Variables

Method 2: Decision Analysis

In this analysis the problem was represented as a decision diagram and input as a decision tree into SUPERTREE. For computational purposes it was simplified because professional SUPERTREE (used here) can handle at most 1000 model runs, and the original decision diagram required more than 1000 runs. Variables that were eliminated were (names analogous as in Table 1 above):

Digitizer, Capacity, and IBM Compatibility (For DPR, these were prerequisites rather than variables; the elimination was furthermore justified by the assigned probabilities), Cost (both Mr. Lamb and Mr. Kilpatrick said the cost was not important; assigned probabilities were a further justification in elimination), Demo. Packages Available, and Direct Contact to Company (analogous reasons). Judgment was necessary in eliminating the other four: Company Viability, Minimal Initial Time Commitment, Industry Recognition, User Group Availability; their weights were low and either Mr. Lamb or Mr. Kilpatrick mentioned they were not of great importance. The resulting model that was actually run was the largest that SUPERTREE could still process.

The recommendation from this run indicated that Timberline was superior. It gave the value function of 653.6 vs. G2's 477.80 (100% vs. 73%). Here, the difference between the software packages was significantly greater than in Method 1.

Findings from Analysis of Decision Regarding Computerized Estimating System

The decision analysis methodology is equivalent to the DPR method at the end of the first DA cycle. That is because all the variables were defined as independent and in the initial information encoding were given two value levels only.

Both DPR and decision analysis methods gave the same result: that Timberline was the preferred option. The decision analysis method gave greater emphasis to the reasons for the preference. Refinements in the next DA cycle should include: three outcomes for each variable, a monetary objective function (so that an informative value of information and sensitivity analysis can be performed), and utility function (risk tolerance) encoding.

DPR Analysis After the Second DA Cycle

The second decision analysis cycle started with evaluating the results of the first DA cycle in light of the model and then performing a sensitivity analysis to narrow down the number of variables that are significant in the decision making process. The researchers then refined information on variables and ran the resulting model. Outcomes of the decision were represented in dollar terms, and risk tolerance was incorporated in the model. Further description of the process and results are given below.

Data

Significant variables were: Sorting, Availability of Workpackages, Format of Reports, Ease of Use, and Accounting Interface. (These have, respectively, received weights of 15, 14, 13, 10, and 7 in the decision making method used by DPR.) The value of these variables (as characteristics in the software) was determined to be, respectively, $700, $3,000, $5,000, $6,000, and $2,500.

DPR's risk tolerance was assessed as being $100,000. (Namely, DPR is indifferent between taking and passing up a lottery with a 50% chance of winning $100,000 and a 50% chance of losing $50,000.)

Results

The result of the second cycle was:

- Value of Timberline to DPR: $87,000 (100%)
- Value of G2 to DPR: $52,500 (60%)

This result is consistent with the decision that DPR has made, namely to adopt Timberline software. Furthermore, DPR purchased Timberline for a price (approximately $50,000) that was lower than the value of Timberline to DPR, so DPR "made a good deal."

The above results are quite robust to the changes in DPR's risk tolerance as they essentially do not change over vast intervals of risk tolerance values. (Timberline is a better decision for DPR than G2 for all values of risk tolerance greater than one dollar, and the values of the two options, given above, do not change significantly over the range of risk tolerance greater than $1000.)

The decision to adopt a computerized estimating system described in this chapter gave an opportunity to evaluate application of decision analysis to one type of decision regarding advanced information technology. The next chapter describes the second application considered in this research, analysis of a decision regarding a CAD system.

Chapter 5

Analysis of Shipping Company's Decision Regarding CAD System

The researchers next applied decision analysis to an important, operational facility decision within a large company. This application explored the usefulness and practicality of this technique was for this class of decisions. Although a full-blown, large-scale decision analysis is not economically feasible for this decision, this research demonstrated significant value in using the technique to frame the decision and focus on important issues.

Introduction

Decision analysis was used over a nine-month period to help a major package shipping company evaluate a multi-million dollar facility decision. This was a real decision faced by the company, and represented a significant allocation of their resources over the next few years. Although it was not a large decision for the company as a whole, it did highlight some of the strengths and flaws of using decision analysis in this arena.

General Shipping Company (GS) faced a decision about what system to use for computer aided design (CAD) of new package sorting facilities and modifications to existing facilities. This decision regarding CAD system included both hardware and software. Managers in the firm recognized some limitations in their current system, and saw opportunities to take advantage of newer technologies. However, they also recognized the substantial costs that might be incurred by switching systems.

Until now, GS has used a large mainframe system to create, edit and store facility designs. The mainframe required a great deal of highly specialized maintenance, was very expensive, did not represent the latest technologies and functionality, and was not particularly useful for anything else. Alternatives considered by the firm included a different mainframe system, a network of UNIX workstations, or a network of personal computers, all of which could be standardized using one of several CAD software packages.

Decision analysis is a normative methodology for evaluating complex decision situations and choosing alternatives under uncertainty. As such, it has been successfully applied to strategic decisions—involving risk to a substantial portion of a company's resources—in thousands of cases. We felt that the application of decision analysis to decisions such as that faced by General Shipping showed great promise for clarifying their best course of action.

Implementation for this Facility Decision

General Shipping's core business is shipping packages. The choice of CAD software would have no direct impact upon their core business. It would affect a relatively small group of people whose job it is to support the core business by designing shipping centers. However, the choice of a poor software package could conceivably delay the design and availability of new centers, thus indirectly impacting the shipping business. Similarly, the choice of an excellent CAD package could enhance future facilities and allow them greater flexibility and availability, which could positively impact the core business.

The first phase of decision analysis is to identify and structure the problem, and to make initial judgments and estimates. Computer hardware and software were the key variables. GS had several CAD software packages available on several hardware platforms. Each software package and each hardware platform had associated costs and benefits. After careful discussion with General Shipping's CAD expert we identified and determined ranges for these costs and benefits.

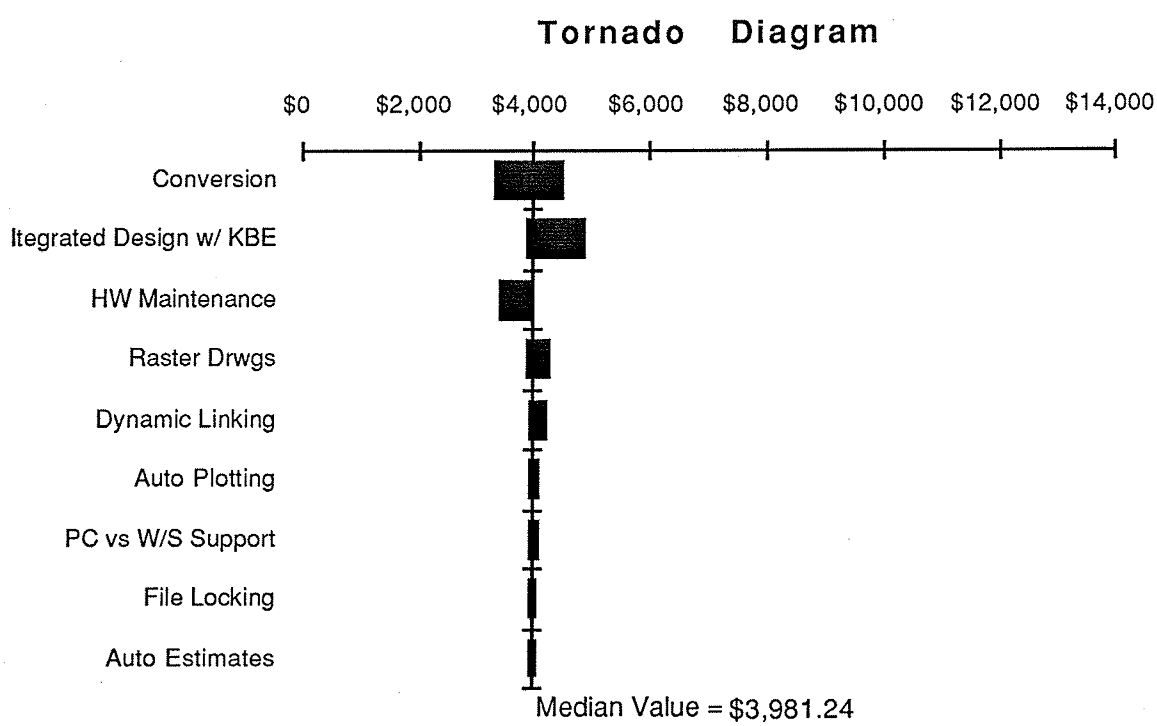
The hardware platforms that GS was considering included the host mainframe already in use (or a similar machine), a network of workstations, or a network of personal computers. Likewise, General Shipping considered using a version of CADAM (host, pro-CADAM or micro-CADAM), AutoCAD, Intergraph, ADRA, or ARRIS. Not all versions of software were suited for each of the hardware platforms. In addition, GS was interested in examining the benefits of slightly different environments. For example, they wanted to understand the effects of using Microsoft Windows vs. MS-DOS, and the difference between competing PC vendors.

It was obvious even in the initial problem formulation that, relative to the other factors under consideration, there was no significant difference between DOS and Windows or different PC vendors. However, the cost of including these scenarios in the analysis at this early stage was so low that it warranted inclusion if only to ease the minds of the General Shipping team. As a result, a total of twenty-six alternatives were considered in the initial deterministic analysis. But this represented at most twelve real alternatives, with the remainder being slight variations on those twelve.

The hardware and software alternatives were evaluated along twenty-five dimensions. Again, many of these were only valid for certain hardware/software configurations, so there was a great deal of redundancy in the data. Two simplified tornado diagrams show how some alternatives were clearly dominant over others. The diagrams display the effect of variations in a few of the most relevant dimensions for the value of each alternative. Also, the units are a relative scale in thousands of dollars, and are for purposes of comparison only.

Each tornado diagram represents a single alternative. The "median value" is the value of the alternative if each of the variables took on its median value. The black horizontal bars show how the value of the alternative could change if that single variable took different values, leaving the remaining variables at their median value. In some alternatives, variables may interact in a manner that results in large joint value swings. For example, if price and quantity of a product were both variables, they would be multiplied to get revenue, the value for this example. Consequently, the effect on revenue of a change in both price and quantity variables simultaneously could be larger than the effect of a change in either one by itself, or even than the sum of the individual effects.

Scenario: 17—ARRIS, Compaq 486/66, Token Ring Network



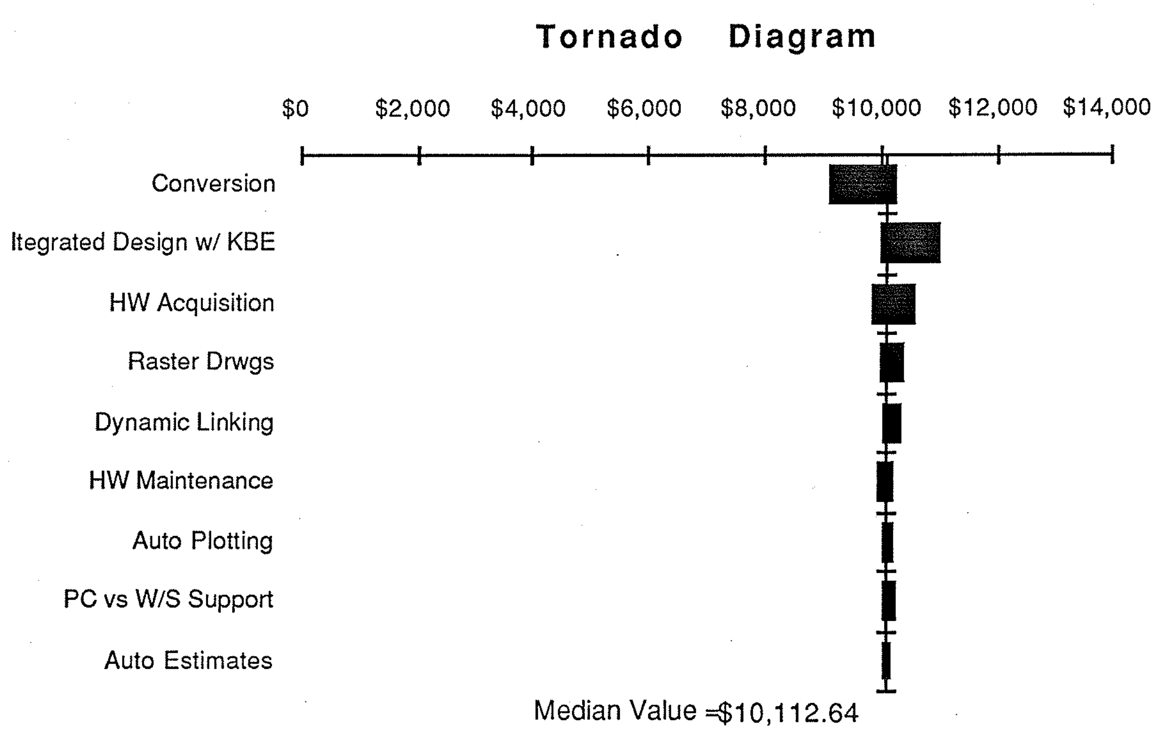
This tornado diagram shows a clearly inferior alternative.

In the case with General Shipping most of the variables were added together to get costs and benefits. Consequently, the effect of changes in several variables is sum of the individual effects.

The deterministic analysis indicated that General Shipping faced several equivalent alternatives. For example, they were initially concerned about which of several personal computer vendors would be the best choice. We were able to show that this concern paled in comparison to the differences among the various CAD software packages—by several orders of magnitude.

We were also able to rule out several alternatives. In some cases the higher-median alternatives dominated the lower-median ones by a factor of three of more. The additive nature of the variables allowed us to think about their effects independently, so we were able to state that the higher-median alternatives should receive the most attention in future efforts.

Scenario:24—Micro-CADAM, IBM RS6000 on Ethernet Network



This tornado diagram shows a better alternative.

Both of these were useful insights. Eliminating some alternatives allowed GS to focus on more important tasks. Recognizing that some of the remaining alternatives were basically equivalent removed the mantle of concern from GS, so that they could focus on seeking the best answer without concern that they might make a "bad decision."

The next phase of a decision analysis would normally be used to understand the uncertain nature of the problem—where information is lacking. In this case, the cost of performing this analysis far exceeded the cost of simply gathering more information about the sensitive variables. As a result, the recommendation was to either make a decision now or gather more information explicitly. Gathering more information should make the differences between the alternatives clearer.

This observation had ramifications for this class of decision analyses—namely that the greatest benefit for the cost may come in the structuring and initial assessment of the decision situation rather than the full-blown probabilistic analysis.

Findings from Analysis of this Decision

Decision analysis provided a useful tool for understanding the problem General Shipping faced. The emphasis on decisions as allocations of resources and the need to evaluate decisions along a single dimension (such as profit) proved useful concepts for evaluating the GS decision.

The strength of decision analysis comes in the realm of strategic decisions. These are one-time decisions that involve a substantial organizational risk. General Shipping did face a one-time decision. However, while the organizational issues in the GS decision were not insignificant, they also had no impact on the bottom line for GS. Consequently, true risk was fairly minimal: the GS decision was more operational that strategic.

A full-blown decision analysis, involving several full-time professionals, substantial expert interviews and extensive modeling was not appropriate for the GS decision. Instead, a quick solution was required that would capture the rough values, costs and tradeoffs to GS of switching CAD systems. However, decision analysis still proved useful for framing the decision, identifying the key alternatives while eliminating others, and determining the value of gathering certain information. It also allowed for a rough ordering of the alternatives based upon the information available at the time. This last was useful to answer the question "If we had to make the decision today, what would we do?"

To formulate the problem, an analyst can work with someone familiar with the decision problem for a couple of days. Between them, they can develop a decision diagram that makes clear the relationship among the variables. They can then do simple sensitivity analysis to determine the key issues and clarify the course of action. While this may not provide the full power of decision analysis, it is a reasonable trade-off between rigor and practicality.

Chapter 6

Conclusions and Recommendations

This chapter presents overall conclusions from this research regarding the use of decision analysis techniques for the evaluation and selection of integration technology. It includes conclusions regarding application of the technique, ways to implement, and future research.

Conclusions from the Research

The results of this research include conclusions regarding the most beneficial application of decision analysis techniques and use of this method for decisions related to acquisition and implementation of integration technology.

Applications of Decision Analysis Techniques

The adoption or development of integration technologies within a construction firm offers chances for a significant competitive advantage resulting from gains in productivity, improvement of company image, and a boost of moral within the firm. However, such technologies also require a significant investment of time, capital, and will to change on the part of many employees in the company; failure to make a logical decision or to correctly implement the decision can be disastrous. A decision of such magnitude requires thorough and systematic consideration of all significant variables.

Although many managerial decision makers have well-developed decision making skills, they often impart unintentional, unobserved subjective influences in the decisions they make. Certainly all decisions are subjective, but certain methods, when applied to the decision process, create a more consistent and logical decision than purely intuitive reasoning. These methods are encompassed in the decision analysis technique, a process designed to model a decision using the decision maker's knowledge to establish values for and apply probabilities of the possible outcomes. By methodically defining variables and their relationships, the final decision analysis product results in higher levels of objectivity and consistency in decision making than purely intuitive reasoning.

Decision analysis is particularly useful in decisions that are sufficiently complex to make the effort invested into the careful examination of the decision pay off. A "small" decision, involving just a single decision, two or three possible outcomes and a simple uncertainty structure is usually quite well handled by intuitive reasoning. Of course, decision analysis can be used even for a simple decision, but the formal process is perhaps too involved for such a problem.

The most beneficial application of decision analysis is for decisions with a more complicated structure: multiple decisions, an intricate connection of a multitude of uncertainties affecting outcomes, etc. In these cases it is usually fairly difficult to intuitively reason and consistently progress through the contingencies, bearing in mind all the options, relevances, objectives, and risk attitude. In cases like this, decision analysis provides a clear procedure for analyzing such a decision and is not only of tremendous benefit, but also perhaps the only method that leads to the decision consistent with the information and preferences the decision maker supplied.

It is not economically justified to spend the time and energy necessary for a "full" decision analysis on operational decisions. The cost of the analysis could easily rival or exceed its benefit. This does not mean that decision analysis cannot or should not be employed. Quite the opposite; a lot can be gained through the use of decision analysis in operational decisions. But it should be applied in a manner that is consistent with the nature of operational decisions, which is not the way the majority of decision analysis is practiced.

Application to Decisions Regarding Integration Technology

Decisions to acquire and implement integration technology may have strategic implications for some firms. Investments in this technology may require a large portion of available resources and may provide major competitive advantages for the firm. The acquisition of a computer estimating system investigated in this research illustrated this condition. Although small and cash constrained, the firm invested in a full capability system that can satisfy needs over the long haul.

Comparing results from the method used by the contractor for this decision (weighted evaluation of key variables) with decision analysis techniques revealed the additional insight and information that decision analysis provides. This included better understanding of risk tolerance, increased awareness of outcome sensitivity to changes in values of the variables, and ability to compare the value of the decision outcome with the actual cost of the system. These benefits illustrate the advantages of using decision analysis for strategic decisions regarding integration technology.

The second application of decision analysis in this research, for decisions regarding a replacement CAD system by a facility owner, indicated benefits for operational decisions. Although technologies for design and completion of facility projects are not strategic for this very large shipping company, they are important decisions. This case highlighted the importance of recognizing the influence of existing the existing technology base in the firm, including the large number of CAD files for existing facilities. The new technology must allow use of these data in the design of renovations for existing facilities.

Possible investments in CAD systems are perhaps the most complex decisions regarding integration technology because of the large number of options for hardware and software. Decision analysis techniques proved very valuable in highlighting the most significant differences and simplifying the decision by not considering essentially equivalent options. This illustrates a significant benefit in applying decision analysis for initial assessment of the situation and structuring of the decision process to focus on critical variables.

Thus the two applications considered this research, for strategic and operational decisions, indicated benefits of decision analysis. The results also indicate a need to consider the degree of decision analysis and the options to obtain this decision support.

Implementing Decision Analysis for Integration Decisions

A construction firm interested in incorporating decision analysis procedures into their decision making framework can obtain decision analysis expertise in three ways:

- training existing company personnel in decision analysis techniques
- hiring a decision analysis expert
- employing the services of a decision analysis consulting firm.

Each of these options has certain advantages and disadvantages. The first option is advantageous since existing company personnel will have a better feeling for the way the company currently makes decisions, and can gauge the company's risk preference more accurately than an outsider. The disadvantage to training existing personnel are due principally to the lack of experts in the decision analysis field and the geographical location of those experts. One other option for educating an employee is to send the person to a decision analysis consultant for a short-term, intensive seminar. Such a seminar would provide general instruction about the use of decision analysis tools, but would not provide breadth or depth of knowledge regarding use of the technique. There is no guarantee that the employee will learn decision analysis to an extent that s/he can effectively operate as an expert decision analyst within the company.

The second option, hiring an existing expert in decision analysis, provides the advantage of obtaining an individual with an viewpoint unbiased (at least initially) by the company culture and past experiences. Such an objective viewpoint is generally advantageous when performing the decision analysis process. The disadvantages of hiring an expert are limited primarily the risk of not effectively utilizing the decision analyst. If the firm doesn't make enough high-level, complex decisions, or if the decision analyst is consistently used to model relatively simple, low-level decisions, then the potential benefit of the decision analyst will not be realized.

A second danger is the risk of the analyst mixing the roles of decision analyst and management consultant as the individual with time adopts the company culture and strategic intentions of the firm. It is important to note that a decision analyst is not a management consultant, and the two roles should not be assumed by the same individual. The decision analyst is only responsible for modeling the decision as presented by a decision maker. The analyst should not provide informational input or suggestions for the model. On the other hand, a management consultant would be an expert in the industry who specializes in providing probability or valuation information. For a decision analyst who also takes on the role of a management consultant, the risk of subconsciously influencing the decision-making model may significantly reduce the usefulness of decision analysis.

The last option, hiring a decision analysis consultant, eliminates the disadvantages of the previous two options. The AEC firm can engage an objective individual who has little knowledge of the construction industry. Such an individual will therefore obtain all of the information for the decision from the decision maker, as should be the case when using decision analysis. This appears the best option for a firm with only intermittent strategic decisions that merit the use of decision analysis.

Before selecting any of the three options, the essential question to answer is the level of decision making at which decision analysis is preferred over intuitive reasoning. As mentioned previously, decision analysis can be used for any type of decision, but practically speaking there is a point at which the potential outcomes of a decision no longer merit the effort required to employ decision analysis. The size of the firm plays a considerable role in determining the most appropriate option.

Additional Research

Possible research topics pertaining to decision analysis for technology adoption and other strategic decisions include an investigation of the type of decision outcomes significant enough to justify the use of decision analysis. A survey of the cost of the various options for obtaining decision analysis expertise along with a survey of firms that could benefit from decision analysis techniques would be useful. Case studies for implementation decisions would complement the adoption decisions modeled in this research.

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