Decision Support System Framework for Construction Technology Transfer and Diffusion

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Advanced construction technologies have emerged over the past decade that cover a wide range of new applications, particularly for the equipment-intensive industry of highway construction. However, the reluctance of highway contractors to implement these technologies has caused their slow diffusion in global construction markets. The thrusts for construction technology transfer and diffusion are identified as are the factors that may impede the transfer and diffusion process. A framework for decision making that incorporates the identified factors is then proposed; contractors can use the framework to evaluate the feasibility of adopting advanced construction technologies. The proposed framework uses the knowledge available on emerging technologies and guides the decision maker into either a rule-based analysis of potential barriers to the technology transfer and diffusion process or an analytic hierarchy process evaluation of factors that promote and impede technology, depending on the perceived level of risk exposure.

The highway construction industry is characterized by its dependency on heavy equipment as the applied resource most vital to construction work. In addition, progress at highway construction sites generally is paced by the output of the equipment and the interdependencies among the construction operations. Emerging technologies for the highway construction industry have been aimed at increasing the productivity rates and efficiency of the equipment used. This increase usually is due to automated processes that rely on sensing and microprocessing technologies. However, the decision to acquire such technologies may be accompanied by a high initial investment requirement and may necessitate a certain level of work force skills needed to safely operate and maintain the acquired systems. Other technical constraints such as governmental regulations, outdated project specifications, and project site conditions may render a technology transfer decision impractical.

In this research, factors that may urge the transfer and diffusion of emerging technologies, as well as those that may act to slow, delay, or impede the process, have been identified. The paper presents a decision support system framework that incorporates the factors in two alternative analysis approaches: (*a*) a rule-based screening of potential barriers and (*b*) an analytic hierarchy process (AHP) evaluation. The proposed structure of the decision process is intended to help highway contractors visualize how an individual decision determinant or group of determinants may cause a variation in the final decision.

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DECISION ENVIRONMENT

Highway contractors operating in highly competitive construction markets must decide the feasibility and timing of investing in emerging construction technologies. The decision environment requires that the drives favoring technological change be weighed against the possible impediments. Although the drives are generally technology-dependent, the impediments are most likely to be related to (*a*) the type and characteristics of construction projects; (*b*) the size, strength, and resources of the construction firm; (*c*) the practices and policies of highway authorities and agencies; and (*d*) the government regulations imposed in the area of work. The final decision, however, may vary depending on how different contractors perceive the risk exposure caused by impediments and on the prevailing condition of the overall construction market. Figure 1 is a schematic representation of the environment within which technology transfer and diffusion decisions are made.

Thrusts for Technology Transfer and Diffusion

Highway contractors favor advanced technologies mainly for the competitive advantage that such technologies offer, both at the domestic and international levels (*1,2*). This advantage may be gained in one or more of the three possible forms: reduced bid prices (*3,4*), shorter construction schedules (*5*), and higher levels of achieved quality (*6*). Although the hourly ownership and operating cost—based on the required initial investment cost and the estimated operation and maintenance costs prorated over the expected life of a technology—may be higher for the advanced technology under consideration, the cost per unit of work may be less than that offered by the conventional technology. This difference is attributed to the higher production rate of the advanced technology and the resulting shorter duration required to accomplish the work. In addition, if the operation that uses the new technology is one of those most likely to be critical, a reduced overall project duration may be realized. Completing a project sooner could be a major advantage to highway contractors if project schedule is a parameter in the bidding evaluation process. Similarly, as new technologies have been aimed at improving the quality of constructed facilities—particularly when such improvement can be translated into lower facility life-cycle costs—competitive advantage can be gained by contractors with a multiparameter bidding system.

Sometimes, new technologies may solve technical problems that can only partially be overcome with conventional technologies. For example, in texturing an existing concrete pavement surface to develop a good bond with a new asphalt concrete layer, the use of

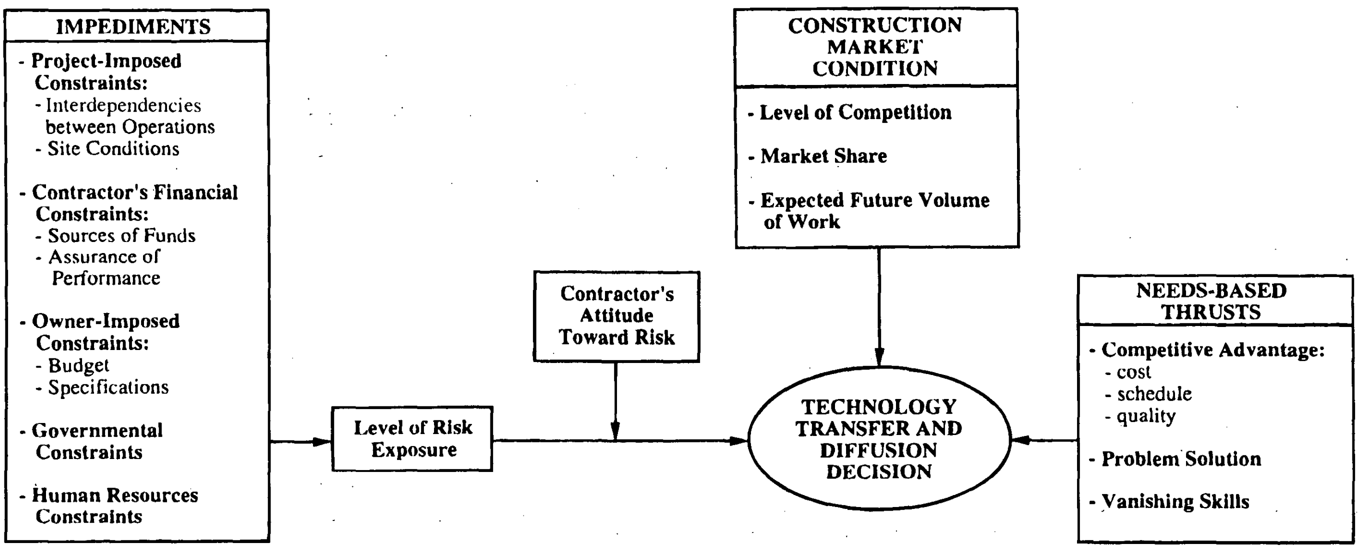

FIGURE 1 Schematic representation of factors affecting technology transfer and diffusion decisions.

a shotblasting robot equipped with automated visual-sensing capabilities could help to ensure a more uniform concrete texture, thus reducing the likelihood of delamination between the old and new surfaces.

As discussed, a new technology may be geared to reduce the level of labor skills needed to achieve the precision requirements specified (*1,6*). Another example involves the use of a laser-based grader whose blade can be operated in either a fully automated or a semiautomated mode. Such a technology requires little or no operator involvement in initiating an adjustment in the height of the grader's blade, but its use would result in a tremendous productivity gain compared with that of conventional grading, particularly in relation to the level-of-skill input required of the operator.

Impediments to Technology Transfer and Diffusion

Many factors may contribute to rendering the use of an advanced technology unfeasible. Constraints imposed by a project's characteristics may be in the form of an interdependency between two or more construction operations or a physical condition at the construction site. A progress-based relationship between any two project activities is an example of the former constraint, whereby the introduction of an advanced technology to one of the operations may not yield the full benefit intended. That is, shortening the duration of the activity in question in a way that uses the maximum production rate of the incorporated technology may not be possible because of the progress-based relationship with the other activity, for which a compatible, more productive technology has not yet emerged. The latter constraint can be exemplified by a permissible limit of longitudinal grade, among other geometric features, beyond which the higher level of performance of the laser-based grader will be jeopardized.

Other types of project-related constraints are those imposed by the owner (the highway agency). If the primary concern of highway agencies is to award projects on the basis of the lowest bid, technologies that offer marginal schedule and quality benefits but not a reduced bid price probably will be deemed unfeasible by highway contractors, because using such technologies may lower their chances of winning project contracts. Higher bid prices may be the result of a low projected volume of work for which the technology could be used or an additional increment in the initial equipment investment possibly due to high taxes imposed by the government on imported technologies. Another project-related, owner-imposed constraint is the method used by highway agencies to specify execution requirements. Although the performance method of specifying is thought to promote the use of advanced technologies, the descriptive method, when specifying outdated requirements, can severely hinder the application of newer techniques.

Constraints that pertain to a contractor's financial strength can be related to a contractor's ability to secure the funds necessary for acquiring a new technology and to bond the contract against potential performance defaults while experimenting with the new technology. With higher financing and bonding premiums, the possibility is greater that the resulting bid prices will be less competitive. On the other hand, the unfamiliarity of contractors' labor resources with the new technology and their inability to efficiently operate and maintain it pose another setback that could lead to performance defaults and financial losses.

Government constraints may be of two main forms: moderate or strict regulations. Examples include high taxes on imported technologies and bans on the import of such technologies, respectively. Such control to protect could be intended to protect the domestic equipment manufacturing industry or to protect the interest of the local labor-intensive economy, particularly in cases where imported technologies are expected to reduce the labor requirements on construction sites.

Construction Market Condition

Final decisions on new technology made by contractors operating in the same construction market may still vary depending on how each contractor perceives the level of risk exposure involved. In addition, the level of competition, a contractor's share of the market, and the projected volume of work to which a technology can be applied all contribute to either promoting or hindering the technology implementation process (*7*). For example, laser-based grading technology would probably be feasible in countries where the volume of new highway construction work is anticipated to be large. On the other hand, it may not be of interest to highway contractors in areas where the highway networks have matured and where highway agencies would emphasize maintaining and rehabilitating the existing networks.

DECISION-MAKING FRAMEWORK

Existing frameworks of technology-transfer decisions are based on the identification of critical factors affecting the decision process. Building codes, conservatism, and organizational barriers are reported to be major determinants in building construction transfer decisions (*8*). Two organizational approaches—top down and bottom up—have been identified to delineate the possible paths for technology transfer (*9*). In these approaches, the transfer process is shown to vary depending on the position of the individual introducing the technology in the firm's organizational hierarchy. Others argue that the transfer process is to be based on the prevailing market forces and the bidding and contracting systems employed (*2*). Alternative proposed processes are based on an overall consideration of technical, economical, and risk assessment factors using decision monographs and flow charts (*3*), on cost-benefit analyses (*4*), or on pairwise comparisons (*5,10*).

The conceptual framework of the decision-structuring process proposed in this research is shown in Figure 2. The framework incorporates the decision determinants identified in the previous section under alternative approaches to decision making. It starts by studying construction projects at the operation level to select the operations most suitable as candidates for new technology. The selection is done with the help of a heuristic-based module that evaluates the candidacy of operations using the following criteria:

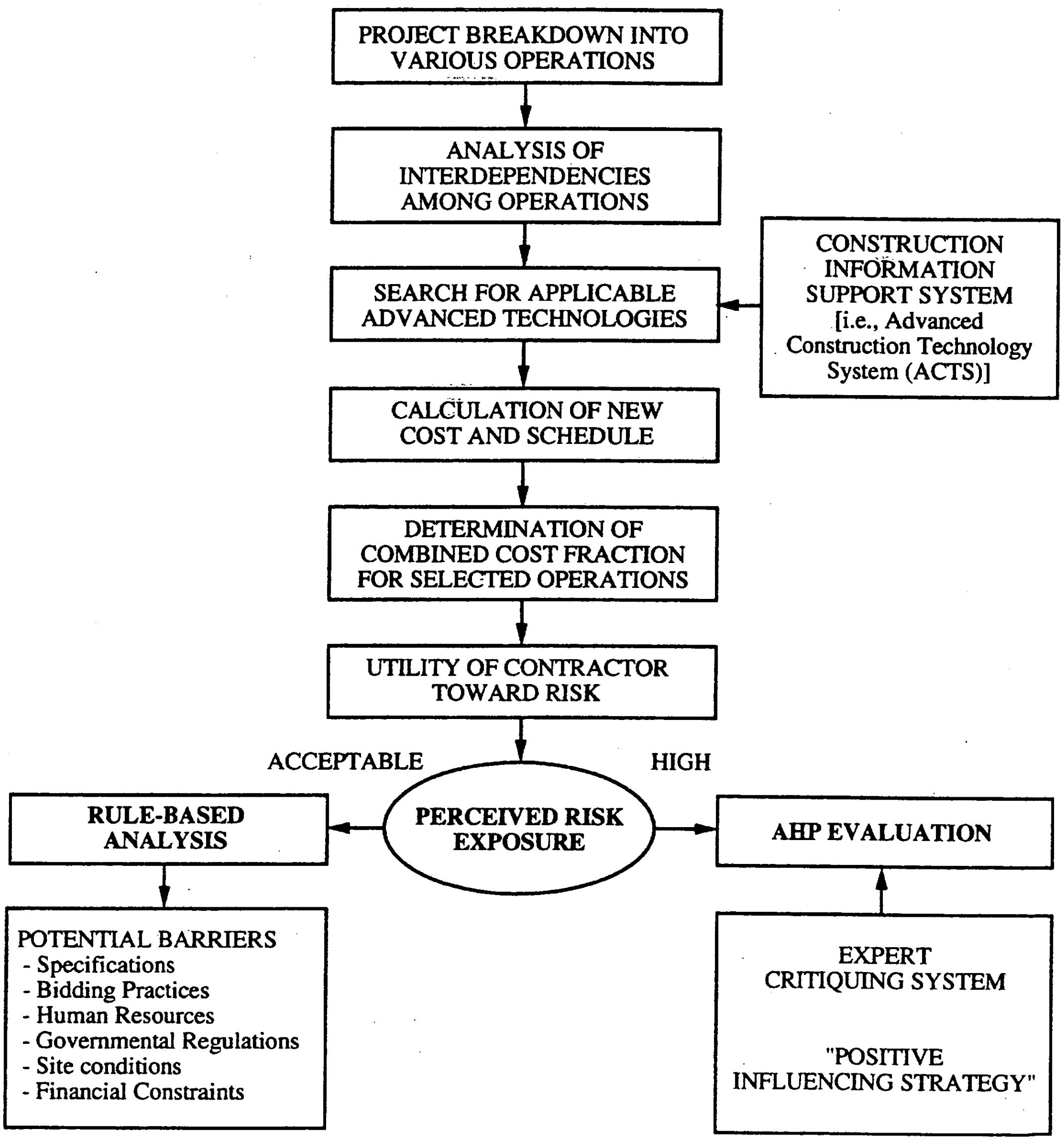

FIGURE 2 Conceptual framework for technology transfer and diffusion decisions.

1. Operation on critical or near-critical paths with a deterministic scheduling analysis, or operation with a high probability of being critical with probabilistic scheduling analyses;
2. Operation duration as a fraction of total project duration; and
3. Operation cost as a fraction of total project cost.

Candidate operations are then analyzed for their interrelationships with other operations. The list of candidate operations is expanded to include those related to the listed operations by start-to-start, finish-to-finish, and other forms of progress-based relationships. This step is particularly important because of the linear characteristic of highway construction work.

Next, a search for applicable advanced technologies is performed. It is proposed that a construction information support system such as the Advanced Construction Technology System (ACTS) be used to retrieve information documented on emerging construction technologies (*11*). The types of information that can be retrieved from ACTS include description, costs, benefits, limitations, experience, and operating environment, among other. The ACTS data base was developed at the University of Michigan with support from the Construction Industry Institute, which is taking steps to make it commercially available to the construction industry.

The new cost and schedule information based on the advanced technologies found to be applicable to selected candidate operations is used to determine a project's revised cost and schedule, which are incorporated in the decision-making process at later stages. To quantify the level of failure risk that contractors may assume by choosing to incorporate new technologies in the implementation of prospective projects and therefore decide on the level of vigorousness needed for the evaluation process, the combined cost fraction for the selected operations is determined (*4*). This figure is believed to represent the portion of the project's worth that contractors would be risking by applying new technologies; consequently, it is used along with a contractor's utility to judge which decision analysis approach would have to be chosen to satisfy the contractor's concern.

The utility of a contractor is approximated by examining a contractor's replies to a series of questions dealing with possible levels of loss of wealth. The observations are solicited using the probability equivalent method, and the utility examination is performed by determining the best fit from three families of mathematical functions: exponential, logarithmic, and polynomial. The three functions have different implications about the risk attitude of a contractor. Of a particular interest are the quadratic and fourth-order functions of the polynomial group, in which the risk aversion of decision makers increases as the level of wealth grows. Such behavior is thought to be not uncommon in an industry in which equipment dependency is intensive. Yet, even though the growing number of technological innovations may be rendering the existing technology obsolete, contractors may be reluctant to abandon con-

TABLE 1 Qualifiers and Typical Rule of Knowledge-Based Specifications Module

SPECIFICATIONS MODULE		
	Qualifier	**Qualifier Applicable Options**
1	The method used for specifying the execution requirements is	performance/descriptive/reference standard/proprietary
2	The descriptive requirements used are evaluated to be	• lenient or restrictive in a way that it allows the use of the new technology • restrictive in a way that it does not allow the use of the new technology
3	The reference standard is	up-to-date (not up-to-date) that it allows (does not allow) the use of the new technology
4	The proprietary specifications used are	closed/open
5	The closed proprietary spec does	allow (not allow) the use of the new technology
6	Alternates to the specified execution requirements are	named (not named) in the specifications
7	The alternates named do	incorporate (not incorporate) the new technology
8	The open proprietary specifications do	permit (not permit) the bidder to submit requests for substitutions
9	The open proprietary specifications do	control (not control) candidate substitutions by having to meet performance requirements
10	The new technology under consideration does	meet (not meet) the performance requirements prescribed by the open proprietary specifications

A Typical Specifications Module Rule
RULE NUMBER: 3 IF: The method used for specifying the execution requirements is descriptive and The descriptive requirements used are evaluated to be restrictive in a way that it does not allow the use of the new technology THEN: SPECIFICATIONS DO REPRESENT A BARRIER - Confidence = 10/10

ventional technologies that still have remaining physical lives. The loss associated with a contractor's 50 percent utile is compared with the combined cost fraction of operations incorporating new technologies. If the cost fraction is less than the 50 percent utile loss, the level of risk may be judged acceptable, and the rule-based analysis of potential barriers is activated to advise the contractor on technical and other types of obstacles to the technology-transfer decision. For a cost fraction higher than the 50 percent utile loss, the AHP approach is initiated wherein technology-thrust factors are weighed against technology-impediment factors with direct input and judgment received from the decision maker.

RULE-BASED ANALYSIS OF POTENTIAL BARRIERS

The rule-based module for the analysis of potential barriers was developed using EXSYS, a general-purpose expert system development shell. Six potential barriers were investigated as part of this analysis: specifications, bidding practices, human resources, governmental regulations, site conditions, and financial constraints. It is presumed that any or a combination of these factors could render the decision to implement a new technology technically unfeasible, even if the contractor accepts the associated risk.

Rule-based modules were developed that test each of the potential barriers considered, with the exception that the financial constraints module was designed as a recommendation to be displayed upon the request of the user. Each of the rule-based modules consists of a set of qualifiers that describe the factor in question and a number of rules generated using the named qualifiers. The qualifiers were identified from the extensive literature search performed as part of this research, and the rules were validated using the expertise of the authors. Rules were generated in a hierarchical format that would ensure the consideration of all technically and conceptually feasible combinations of qualifiers. The user is given access to additional information related to qualifier interpretations and expanded rule recommendations that can be retrieved using a special help command. The set of qualifiers and a typical rule for three of the five rule-based modules are described in Tables 1, 2, and 3. The confidence of a rule's recommendation is expressed as a fraction of 10. Any negative recommendation accompanied by full confidence (10/10) implies that implementation decisions are not feasible; the opposite is true for a full-confidence positive recommendation. For all recommendations with imperfect, assigned confidence, the user is advised on how to overcome those uncertain situations.

The governmental constraints module consists of rules derived from qualifiers dealing with the forms of government control on the import of new technologies, which may be high customs fees or a total ban on importation. The control could be to protect a labor-intensive economy or domestic equipment manufacturing. In addition, the site condition module is based on only two qualifiers dealing with site accessibility and geometric features.

Finally, the recommendation concerning the financial constraints factor emphasizes that contractors should be capable of objectively

TABLE 2 Qualifiers and Typical Rule of Knowledge-Based Bidding Practices Module

BIDDING PRACTICES MODULE		
	Qualifier	**Qualifier Applicable Options**
1	The cost per unit of work using the new technology is	higher(lower) than that using the conventional technology
2	The bidding evaluation system incorporates	• more than one parameter • only one parameter (cost)
3	The other parameter(s) incorporated in the bidding system is (are)	• schedule • quality • both schedule and quality
4	The schedule required to accomplish the specified work is	shorter (longer) using the new technology
5	The quality parameter is	important (not important) in relation to • the life-cycle costs of the facility • the aesthetic aspects of the facility • both
6	The quality obtained using the new technology is	better than (worse than) that obtained using the conventional technology

A Typical Bidding Practices Module Rule

IF: The cost per unit of work using the new technology is higher than that using the conventional technology
and The bidding evaluation system incorporates more than one parameter
and The other parameter(s) incorporated in the bidding system is (are) both schedule and quality
and The quality obtained using the new technology is better than that obtained using the conventional technology
and The quality parameter is important in relation to the life-cycle costs of the facility
and The schedule required to accomplish the specified work is shorter using the new technology
THEN: BIDDING PRACTICES DO NOT REPRESENT A BARRIER - Confidence = 9/10

TABLE 3 Qualifiers and Typical Rule of Knowledge-Based Human Resources Module

HUMAN RESOURCES MODULE		
Qualifier		Qualifier Applicable Options
1	The existing workforce at your firm is	able (not able) to operate the new technology
2	The existing workforce at your firm is	able (not able) to maintain the new technology
3	The existing workforce at your firm is	acquainted (not acquainted) with safety procedures in operating and maintaining the new technology
4	The basic educational knowledge and skills of your workforce are	enough (not enough) for them to learn how to safely operate and maintain the new technology
5	Incentive programs that help your workforce be motivated to adapt to the new technology do	exist (not exist) in your organization
6	Your firm is	equipped (not equipped) to handle the training of your workforce on operating and maintaining the new technology
7	Outside training centers in the country or abroad are	economically available (not available) to train your workforce on operating and maintaining the new technology
8	Local labor with needed knowledge and skills to operate the new technology are	available (not available) in the market
A Typical Human Resources Module Rule		
IF: The existing workforce at your firm is not able to operate the new technology or: The existing workforce at your firm is not able to maintain the new technology or: The existing workforce at your firm is not acquainted with safety procedures in operating and maintaining the new technology and The basic educational knowledge and skills of your workforce are enough for them to learn how to safely operate and maintain the new technology and Incentive programs that help your workforce be motivated to adapt to the new technology do exist in your organization and Your firm is equipped to handle training of workforce on operating and maintaining the new technology THEN: HUMAN RESOURCES DO NOT REPRESENT A BARRIER - Confidence = 9/10		

judging the effect of possible marginal increases in bid prices on their chances of winning contracts. It is recommended that contractors' judgment be dependent on (*a*) the probable increment in bid price that can be attributed to higher financing and bonding premiums, relative to the total bid price; (*b*) the uncertainty inherent in the total bid price that is attributed to the technical aspects of the project; and (*c*) the policy adopted for markup determination along with the level of competition and need for work.

AHP EVALUATION

Background and Structure of Hierarchy

The AHP is a methodology for solving complex problems that involves many criteria using the knowledge, expertise, and judgment of the decision maker. By applying this technique to the technology transfer and diffusion problem, highway contractors are provided with hierarchy (Figure 3) in which all the relevant factors are organized in a logical and systematic way from the goal to the factors and subfactors, and down to the alternatives of technology choice.

Expert Choice, an AHP-based decision analysis software, was used to conduct automated analyses of the designed hierarchy; the basic principles of AHP are covered in the literature (*5,12*). In the AHP evaluation procedure, contractors are asked to judge the elements of the hierarchy as to their relative importance with respect to a higher-level criterion or property. The judgments are made using pairwise comparisons on a 1-to-9 numerical scale or its verbal equivalent. The pairwise comparisons are then synthesized to rank the alternatives from which the choice is to made.

Example Evaluation Problem

To illustrate how this evaluation is performed, the problem of selecting between the laser-based grading technology and the conventional technology is analyzed, and the analysis results are sum-

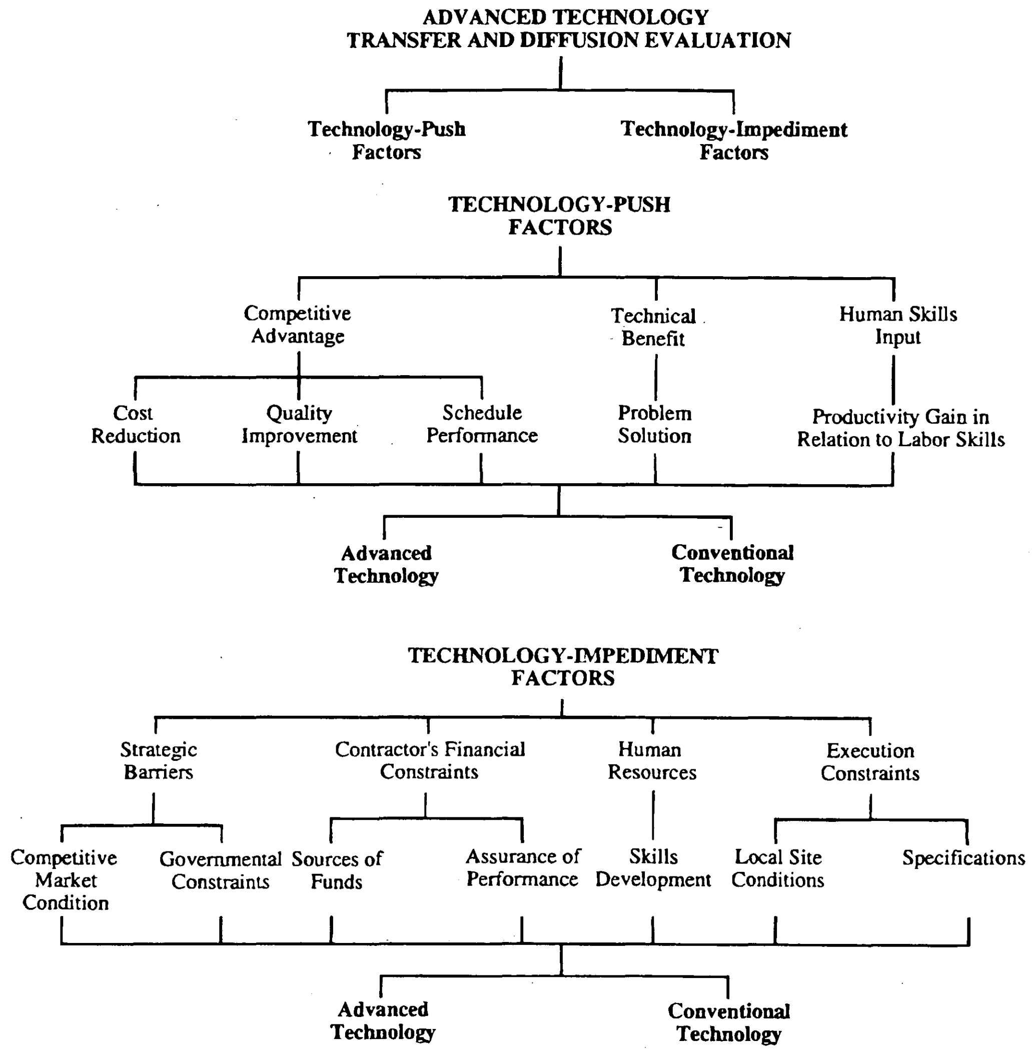

FIGURE 3 AHP for technology transfer and diffusion evaluation.

marized in Figures 4 through 6. Documented information on the technical properties and limitations of the advanced grading technology was assimilated from the literature and used, when appropriate, in the evaluation process (*1*). The abbreviations used in Figures 4 through 6 correspond to the elements of the hierarchy in Figure 3.

Three types of pairwise comparisons were used to provide judgments, examples of which are included in Figure 7. The term "importance" was used when comparing one criterion with another "preference" for comparing technology alternatives, and "likelihood" for comparing uncertain criterion occurrences. All comparisons are made with respect to higher-level criteria. Expert Choice tests the consistency of comparisons and helps the user improve it through an inconsistency measure.

In Figure 4 the AHP results synthesized at the factor and subfactor levels show the relative priorities of factors at the local (with respect to the next higher-level factor) and global (with respect to the goal) levels. For example, compared with the likelihood of being a barrier to the technology-transfer decision, the financial constraints factor, among the impediment, has a local priority of 0.649, which is higher than those of the other factors. This resulted from the comparisons given in Figure 7 with the financial constraints factor judged, with a value of 6, to be more important than all other factors in its group. In turn, the higher calculated priority indicates a greater contribution by this factor to the final decision. Similarly, the competitive advantage factor possesses the highest local priority, of 0.615, in the assessment of the thrusts for technology transfer.

The AHP results synthesized at the subfactor and alternative levels for the promotion and impediment subhierarchies are presented in Figures 5 and 6, respectively, with background information on typical comparison judgments also illustrated in Figure 7. As can be seen in Figure 6, the competitive market condition factor has a synthesized local priority of 0.833 compared with 0.167 for the government regulations factor. This higher priority is also attributed to the judgmental evaluation of the former factor to be strongly more likely (score of 5) to be a strategic barrier (relative to the next higher level). At the lowest level in the hierarchy the new technology is evaluated to be equally preferable to the old technology, as indicated by the judgment of 1.0 shown in Figure 7.

Figures 4, 5, and 6 refer not only to the local priorities calculated for the variables, but also to the global priorities that represent the

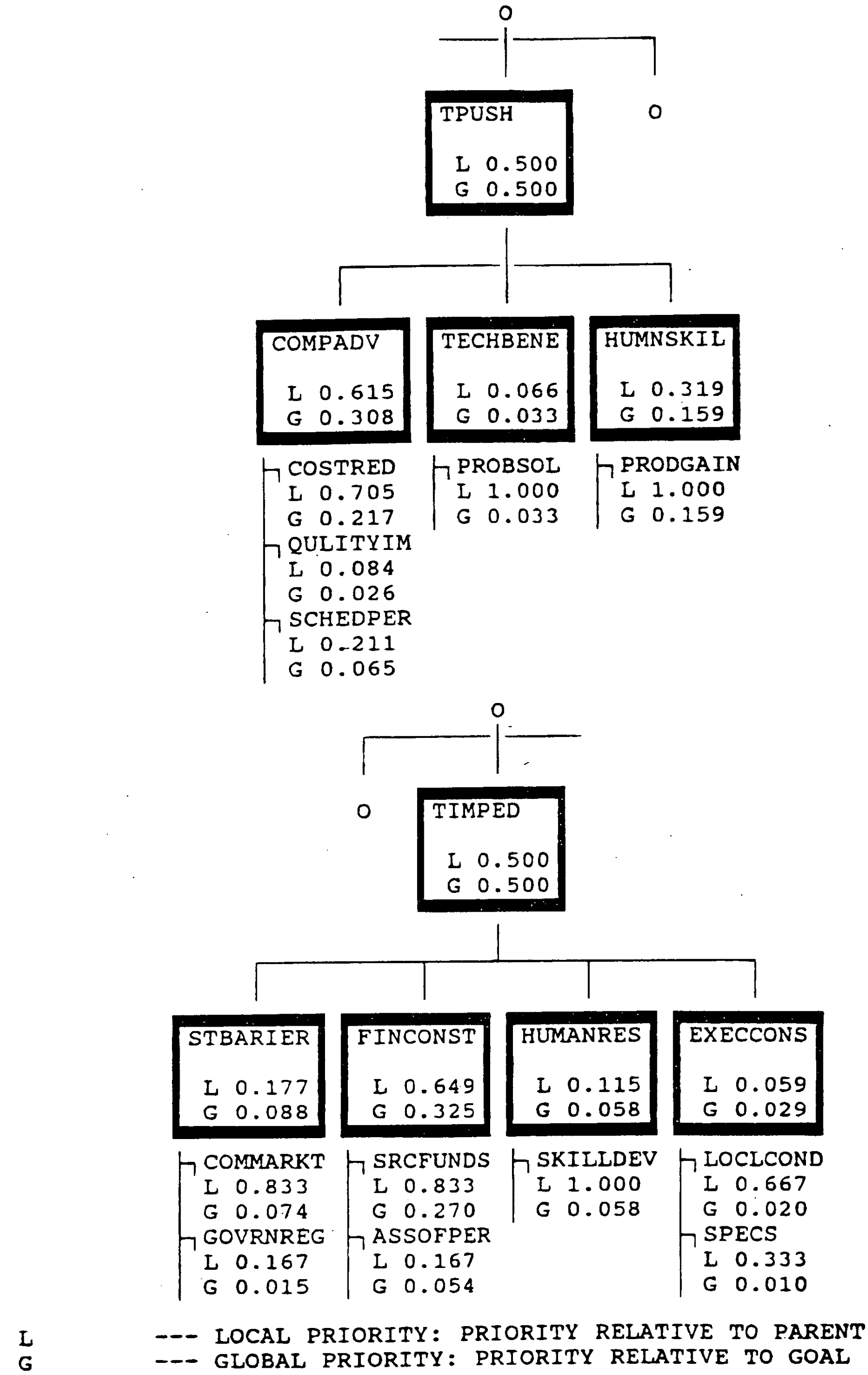

FIGURE 4 Synthesis of AHP evaluation results at factor and subfactor levels.

portion of the priority inherited by the various nodes. From the judgments used in this example, the synthesis of the evaluation with respect to the goal yielded a priority of 0.568 for the advanced technology, which compares with a priority of 0.4322 for the conventional technology, indicating that the former is slightly more preferred to the latter.

Sensitivity Analyses

Extensive analyses were performed to study the sensitivity of the decision to the input judgments used. The priorities of 0.568 and 0.432 generated at the goal level are based on equal weights given to both the negative and positive factors. The sensitivity of these

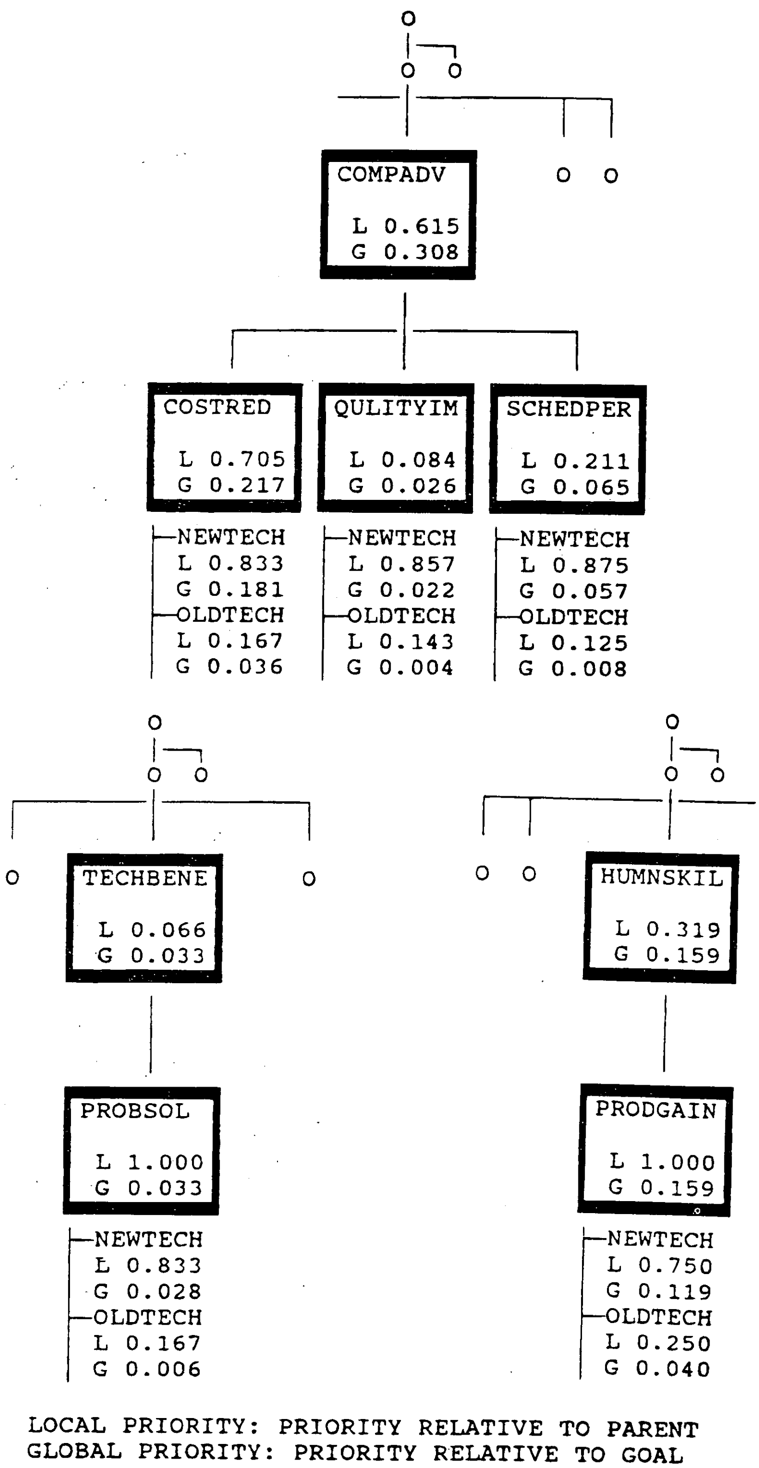

FIGURE 5 Synthesis of AHP evaluation results at technology promotion subfactor and alternative levels.

priorities to a change in the importance of the financial constraints factor is illustrated in the upper portion of Figure 8. The new technology becomes more preferable to the old one for lower calculated priorities of the financial factor, whereas the preference level decreases for higher priorities. However, the slopes of the goal priorities are not steep enough to intersect and, thus, induce a change of preference between the two choices (the new technology will always be preferred to the old one). In this dynamic analysis, when the priority level of the financial criterion is decreased or increased, the priorities of the remaining criteria increase or decrease proportionate to their original priorities, respectively. Under the impediment subhierarchy, the decision

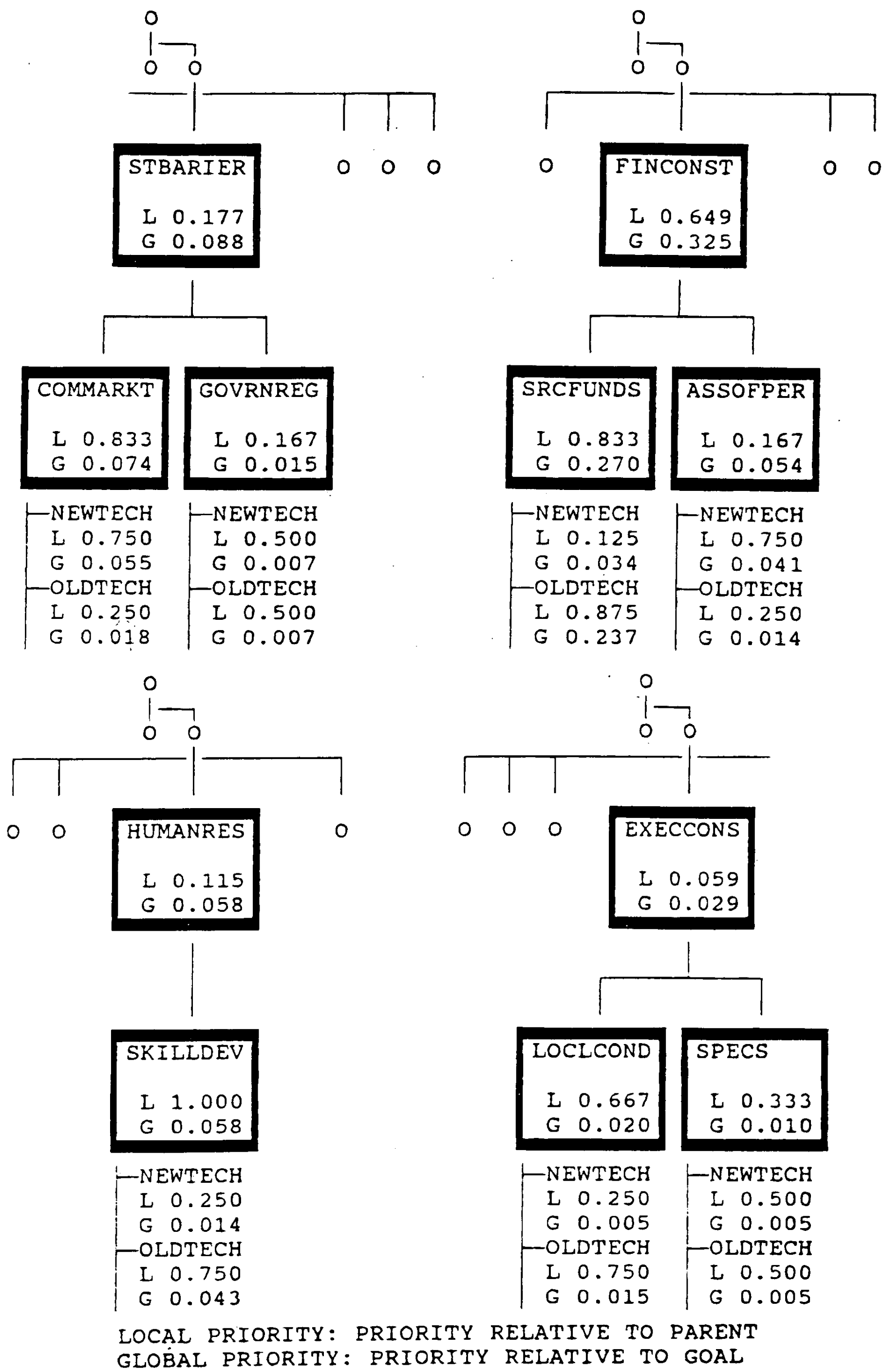

FIGURE 6 Synthesis of AHP evaluation results at technology-impediment subfactor and alternative levels.

was found to be similarly sensitive to the strategic barriers criterion and slightly sensitive to the human resources factor. However, almost no sensitivity was observed to the execution constraints criterion.

If the priorities are changed to 0.7 for the impediment node and 0.3 to the promotion node, the slopes of the goal priorities intersect as depicted in the lower portion of Figure 8. Here, the indication is that when the priority of the financial constraints factor is decreased to 0.487, the two technologies will be equally preferable. For higher priorities associated with the financial criterion, the decision will favor the old technology.

Expert Critiquing System

As discussed, the decision may be sensitive to the judgmental inputs used in quantifying the relative importance, likelihood, and preference of the identified criteria. Therefore, contractors considering the

```
                         JUDGMENTS WITH RESPECT TO
                              TIMPED < GOAL

            STBARIER   FINCONST   HUMANRES   EXECCONS
STBARIER               ( 6.0)       2.0        4.0
FINCONST                            6.0        6.0
HUMANRES                                       3.0
EXECCONS

Matrix entry indicates that ROW element is ___
  1 EQUALLY  3 MODERATELY  5 STRONGLY  7 VERY STRONGLY  9 EXTREMELY
more IMPORTANT than COLUMN element unless enclosed in parentheses.
```

```
                         JUDGMENTS WITH RESPECT TO
                         STBARIER < TIMPED < GOAL

            COMMARKT   GOVRNREG
COMMARKT                 5.0
GOVRNREG

Matrix entry indicates that ROW element is ___
  1 EQUALLY  3 MODERATELY  5 STRONGLY  7 VERY STRONGLY  9 EXTREMELY
more LIKELY than COLUMN element unless enclosed in parentheses.
```

```
                         JUDGMENTS WITH RESPECT TO
                  GOVRNREG < STBARIER < TIMPED < GOAL

            NEWTECH    OLDTECH
NEWTECH                  1.0
OLDTECH

Matrix entry indicates that ROW element is ___
  1 EQUALLY  3 MODERATELY  5 STRONGLY  7 VERY STRONGLY  9 EXTREMELY
more PREFERABLE than COLUMN element unless enclosed in parentheses.
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FIGURE 7 Three types of pairwise comparisons used in AHP evaluation.

feasibility of diffusing a new technology may have cognitive biases inherited in their intuitive judgments. Computer critics can be used to help overcome these biases. For the AHP evaluation, critiques can be made at all levels of the hierarchy. Namely, preference-based critiquing may be useful for weighing impediments against thrusts; likelihood-based critiquing may be employed for assessing factors and subfactors representing possible conditions and practices; and technical critiquing based on knowledge available on and experience gained with new technologies may be exercised to judge the preference of choices with respect to the various subfactors in the next higher level.

An expert critiquing system is under development that is intended to reduce the bias in the intuitive judgments used in the proposed hierarchical analysis. The critiquing system, which will be described in a future publication, with coverage of automation and interfacing properties of the support system, is designed to monitor the decision analysis process and counsel contractors on their reasoning and judgment in a way that positively influences the decision outcome (*13*).

SUMMARY AND CONCLUSIONS

A framework for structuring the process of technology transfer and diffusion decisions has been proposed. It incorporates a number of criteria identified to be significant to the decision-making process. The incorporated criteria are analyzed using either of two evaluation approaches that employ documented relevant construction information. Through an expert critiquing system, the information generated along the decision process—especially that of the rule-

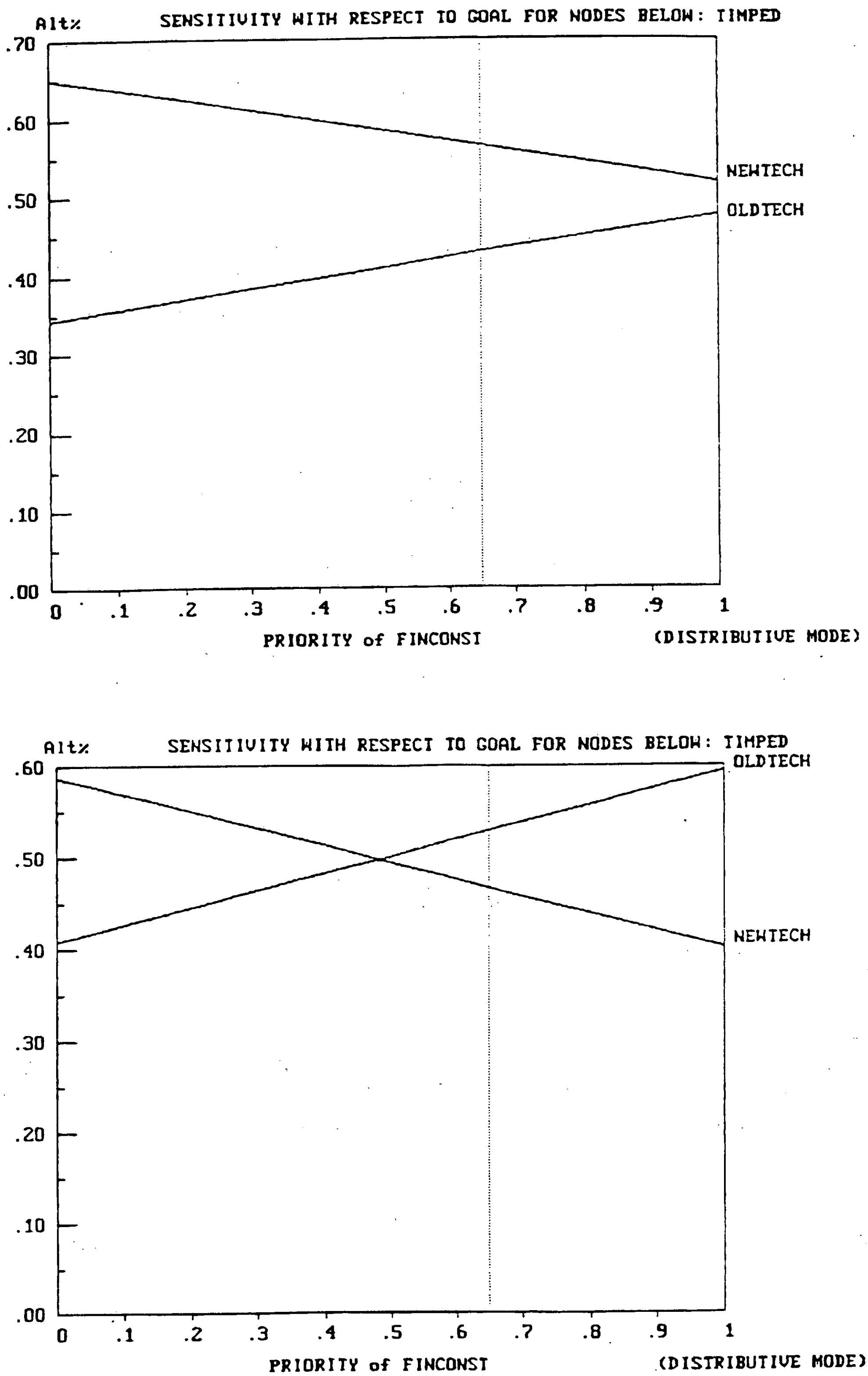

FIGURE 8 Dynamic sensitivity analyses showing interaction between hierarchy levels.

based analysis—can be made useful in the hierarchical evaluation approach to help remove possible bias from intuitive judgments.

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