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IMPROVING DECISION QUALITY IN THE ANALYTIC HIERARCHY PROCESS IMPLEMENTATION THROUGH KNOWLEDGE MANAGEMENT STRATEGIES

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IMPROVING DECISION QUALITY IN THE ANALYTIC HIERARCHY PROCESS IMPLEMENTATION THROUGH KNOWLEDGE MANAGEMENT STRATEGIES

A Dissertation APPROVED FOR THE
SCHOOL OF INDUSTRIAL ENGINEERING

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ABSTRACT

The Analytic Hierarchy Process (AHP) is a multi-attribute decision making method that structures a decision problem hierarchically in terms of its objective, attributes, sub-attributes, and alternatives. The use of the Analytic Hierarchy Process (AHP) by individual and group decision-makers to solve multi-attribute decision problems has been well documented in the literature. Since its introduction in the 1980's, numerous applications of the AHP in a variety of decision problem areas have been described in the literature. The AHP technique has been both criticized and enhanced by many researchers. Criticisms fall into the categories of: (1) the arbitrary nature of the paired comparison process, and (2) rank reversal. The literature offers enhancements to address these two criticisms, as well as to address enhancements in the areas of: (1) sensitivity analysis, (2) consensus building and consistency measurement, (3) eigenvector calculations, and (4) integration with electronic meeting technology.

This experimental research examined two knowledge management strategies for improving the quality of the decision in an AHP implementation. One strategy involved the use of a knowledge self-assessment questionnaire to weight individual pairwise comparison judgments. The other strategy involved the use of electronic meeting technology as a forum for group discussion of areas where significant variations in pairwise comparisons exist among decision-makers. These two strategies were compared to a baseline AHP in terms of the AHP aggregate group consistency index, pairwise comparison variances, mental workload, attribute and sub-attribute priority weighting variances, and task completion time. The goals of this dissertation were to evaluate the

impact of knowledge management strategies on AHP decision cost and quality outcomes and to develop an AHP model selection methodology.

This dissertation research made contributions in two categories: (1) analysis of AHP decision cost and quality, and (2) AHP model selection methodology. The specific contributions within each category are:

Analysis of AHP Decision Cost and Quality

Based on the relative importance of quality and cost, recommendations are made for the use of knowledge management strategies and group size.

- The use of knowledge management strategies did not significantly improve decision quality with respect to group consistency, individual consensus or group consensus.
- A group size of seven versus a group size of five significantly improved decision quality with respect to group consistency.
- The use of knowledge management strategies did not significantly increase mental workload; tasks performed using electronic meeting technology resulted in significantly lower mental workload.

AHP Model Selection Methodology

Two AHP hierarchies were developed to advance knowledge with respect to AHP application.

- A decision hierarchy comprised of four attributes and fifteen sub-attributes was developed and can be used by organizations to assess capital investment projects.
- The application of the capital investment decision hierarchy produced cost and quality measurement data that can be used to evaluate alternative AHP models.
- An AHP model selection methodology, including a decision hierarchy comprised of cost and quality attributes and sub-attributes was developed. The methodology can be used to select the most appropriate AHP model to use in prioritizing capital investment projects from the three AHP models used in this experimental process. AHP model alternative priority weightings with respect

to sub-attributes were established through AHP implementation cost and decision quality data obtained through this experimental research.

- An AHP model selection decision tree was developed to determine the most appropriate AHP model based on cost and quality attribute and sub-attribute priority weightings.

This research model represents advancement to the state of the art and advances the body of knowledge with respect to measuring the impact of knowledge management strategies on AHP implementation. Both the practical and scientific contributions provide knowledge to enhance the effectiveness of the AHP as a multi-attribute decision technique.

IMPROVING DECISION QUALITY IN THE ANALYTIC HIERARCHY PROCESS IMPLEMENTATION THROUGH KNOWLEDGE MANAGEMENT STRATEGIES

CHAPTER 1

INTRODUCTION

The healthcare sector is facing significant challenges to reduce expenses while maintaining or improving the quality of services provided. Modifications to federal regulations and reimbursement methodologies are contributing to the ongoing changes in the healthcare environment. Competition for market share is requiring healthcare administrators to consider new methods of delivering services. Many of the challenges faced by healthcare administrators in implementing new services are related to gaining and maintaining efficiency of operations through determining the best way to organize multiple resources required for quality healthcare delivery.

A typical process for evaluating the economic feasibility of proposed capital investment projects is through the analysis of the Net Present Value or Internal Rate of Return on a five-year timeline. Planning software can generate income statements, cash flows, balance sheets, and statistics and financial ratios, based on the input provided. This type of software can even perform sensitivity analysis by varying the input assumptions. However, this approach for new project evaluation has several limitations. First, it is incorporates only financial attributes of the decision problem. Second, it is based on the judgment of a single decision-maker versus an aggregation of opinions from multiple subject matter experts.

Decisions that impact organizational system performance should be driven by decision support tools that are effective in analyzing the multiple attributes of the decision problem from the perspectives of multiple individuals who have expert knowledge about specific attributes. This dissertation examines knowledge management in the implementation of the Analytic Hierarchy Process (AHP) as a decision support tool to determine the weightings of attributes used to evaluate proposed capital investment projects. The specific knowledge management strategies used were: (1) decision-maker knowledge self-assessment and (2) electronic meeting technology. Chapter 2 defines the specific problem addressed in this dissertation.

Chapter 3 presents a summary of the literature regarding multi-attribute decision techniques, including the AHP. A comparison of the strengths and weaknesses of four techniques is presented with a conclusion that AHP has many advantages over the other techniques. The AHP is discussed in detail in terms of criticisms, enhancements, and applications. In addition, knowledge management is discussed in terms of knowledge generation and transfer, knowledge roles and intra-group relations, and enabling technologies. Chapter 3 also presents mental workload measurement techniques and questionnaire design considerations. Chapter 4 presents the research methodology. This includes a discussion of procedures followed in the experiment and the experimental analyses. Chapter 5 presents the computational methods by which the experimental results were analyzed.

Chapter 6 discusses the conclusions of the experimental results and presents a methodology for selecting the most appropriate AHP model among the three alternative models used in the experiment. The model is based on an AHP decision hierarchy of implementation cost and quality attributes and sub-attributes. The AHP model alternative priority weightings for the sub-attributes are defined by the experimental results. A sensitivity analysis, applying combinations of priority weightings for cost and quality attributes and sub-attributes, was performed and used to develop an AHP model selection decision tree. The decision tree can be used to determine the most appropriate AHP model based on cost and quality attribute and sub-attribute priority weightings. Chapter 6 also identifies limitations of the research and proposed future research.

CHAPTER 2

PROBLEM DEFINITION

The use of the AHP by individual decision-makers and groups of decision-makers to solve multi-attribute decision problems has been well documented in the literature. Since its introduction in the 1980's, the AHP technique has been criticized and enhanced by many researchers. Numerous applications of the AHP, in a variety of decision problem areas, have been described in the literature.

The enhancement of the AHP has proceeded in several directions including: (1) improving the process for generating judgements on paired comparisons, (2) eliminating rank reversal, (3) performing sensitivity analysis, (4) consensus building and consistency measurement, and (5) developing alternative techniques for eigenvector calculations. Minimal research has been performed in the area of improving group consensus and consistency in AHP implementation through the application of decision-maker knowledge weighting or electronic meeting technology.

Although researchers have examined various techniques for measuring group consensus and consistency, research on the use of knowledge management strategies for improving group consensus and consistency was not found. This experimental research examined two knowledge management strategies for improving group consensus and consistency in an AHP implementation. The AHP decision problem used in the research involved determining the weightings for decision hierarchy attributes and sub-attributes used to evaluate proposed capital investment projects. One knowledge management strategy involved the use of a knowledge self-assessment questionnaire for weighting an individual's pairwise comparison judgments. The other strategy involved the use of electronic meeting technology to discuss pairwise comparison judgment. Three models of AHP implementation including baseline, knowledge self-assessment, and electronic meeting technology are compared in terms of group consistency and consensus scores. Mental workload was also measured to determine the impact of knowledge management tasks.

The primary goals of this dissertation were to evaluate the impact of knowledge management strategies in the AHP with respect to cost and quality attributes and sub-attributes and to develop an AHP model selection methodology. The cost and quality attributes and sub-attributes were defined as part of the research. Quality was measured in terms of decision-maker judgment consistency and consensus. Consistency in the AHP is an indication that the process produced logical results. Consensus in the AHP is an indication of group agreement or buy-in. The cost of improving quality in the AHP implementation was also assessed through this research. Cost was measured in terms of mental workload and task time. Mental workload is an indication of the mental effort required to perform the AHP tasks. Task time is a reflection of the cost in terms of required staff time. Significant gains in consistency and consensus of individual and group judgements without compromising cost would be a valid enhancement to AHP. Consistency is a measure traditionally used with the AHP. Consensus, mental workload and task time were introduced in this research as new outcome measures for the AHP.

Five experimental analyses were conducted to investigate the performance of the three AHP models in terms of cost and quality attributes and sub-attributes:

Analysis One

Hypothesis A: The electronic meeting technology model will produce better consistency compared to the baseline and knowledge self-assessment models.

Hypothesis B: The smaller group size will produce better consistency compared to the larger group size.

Hypothesis C: The electronic meeting technology model in combination with a smaller group size will produce better consistency compared to the baseline and knowledge self-assessment models with either group size.

These hypotheses examined the effect of group size and AHP model on decision quality measured in terms of decision-maker group consistency.

Analysis Two

Hypothesis A: The electronic meeting technology model will produce lower pairwise comparison variances compared to the baseline model.

Hypothesis B: The smaller group size will produce lower pairwise comparison values compared to the baseline model.

Hypothesis C: The electronic meeting technology model in combination with the smaller group size will produce lower pairwise comparison variances compared to the baseline model in combination with either group size.

These analyses examined the effect of group size and AHP model type on decision quality measured as individual decision-maker consensus.

Analysis Three

Hypothesis A: The Vice President level of responsibility will produce a lower paired comparison variance compared to the Non-Vice President level of responsibility in the baseline model.

This hypothesis investigated the effects of organizational level of responsibility on decision quality measured by individual consensus.

Analysis Four

Hypothesis A: The electronic meeting technology model will produce a lower mental workload than the baseline and the knowledge self-assessment models.

Hypothesis B: The smaller group size will produce a lower mental workload than the larger group size.

Hypothesis C: The electronic meeting technology model in combination with the smaller group size will produce a lower mental workload than the baseline or knowledge self-assessment models with either group size.

These hypotheses assessed the effects of group size and AHP model on mental workload.

Analysis Five

Hypothesis A: The priority weighting variances for attributes and sub-attributes will differ significantly among attributes and sub-attributes.

Hypothesis B: The electronic meeting technology will produce lower attribute and sub-attribute priority weighting variances than the baseline or knowledge self-assessment models.

These hypotheses assessed the affects of attribute and sub-attributes and AHP model on decision group consensus measured by attribute and sub-attribute priority weighting variances. The statistical significance of using knowledge management strategies in AHP implementation was determined through these analyses.

In addition to the statistical analyses, cost and quality data collected through the experimental process was used to develop an AHP model selection methodology. The AHP model selection methodology, including a decision tree, can be used by an organization to determine the most appropriate AHP model based on the cost and quality priorities of the organization.

CHAPTER 3

LITERATURE REVIEW

This chapter presents a review of the literature that describes the theory, methodology, strengths, criticisms, suggested enhancements, and applications of the Analytic Hierarchy Process (AHP), knowledge management, mental workload and questionnaire design. The first section describes four commonly used multi-attribute decision models. A matrix is provided to compare the models' strengths, weaknesses, automation requirements, ability to handle qualitative and quantitative attributes, and flexibility for use in group and individual decisions. The strengths of the AHP that contribute to its popularity are highlighted. The second section presents a detailed discussion of the AHP to include its supporting theory, methodology, criticisms, enhancements, and applications. The methodology is defined through the use of an example decision problem related to selection of a new healthcare delivery system. Criticisms of the AHP, as well as recommended enhancements are presented. Applications of the AHP are discussed including a definition of the breadth of AHP use, followed by example applications of the AHP in the areas of economics and planning and project selection, and the healthcare industry. Knowledge management, in terms of knowledge generation and transfer, knowledge roles and skills, and enabling technologies is presented next. A summary of the considerations for knowledge management in AHP implementation is provided. Four types of mental workload measurement techniques are also described and compared and justification for the use of subjective workload measurement methods is provided. The last section presents recommendations for questionnaire design and a process for creating a questionnaire.

3.1 Multi-Attribute Decision Methods

Traditional economic analysis methods for evaluating decision problems, such as Net Present Value and Internal Rate of Return, are no longer adequate because they limit the decision-maker to only the financial aspects of the decision. Often there are multiple parameters that must be considered in the decision. Multi-attribute (i.e., multi-objective, multi-criterion, multi-factor, multi-person, etc.) decision techniques have significant potential to address the multi-dimensional nature of complex decision analysis. These techniques provide the capability to consider quantitative and qualitative attributes, incorporate risk and uncertainty, and incorporate perspectives of multiple decision-makers. Several categories of multi-attribute decision analysis models are available for use. These include: (1) utility methods, (2) goal programming, (3) expert systems, and (4) Analytic Hierarchy Process.

3.1.1 Multiattribute Utility Model

Keeney and Raiffa (1976) have made significant contributions to the theory and practice of using Multiattribute Utility Models (MAUM). Utility theory is based on the concept that the utility, $U(x) = U(x_1, x_2, \ldots, x_n)$, of any combination of outcomes $(x_1, x_2, \ldots, x_n)$ for n attributes $(X_1, X_2, X_3, \ldots, X_n)$ can be expressed as an additive or a multiplicative function of the individual attribute utility functions, $U1(x_1)$, $U2(x_2)$, . . . ,

$U_n(x_n)$. The specific conditions for each attribute pair that must be met for utility theory to be applied are:

1. They must be preferentially independent of their compliments (i.e. the preference order of consequences for any pair of attributes does not depend on the levels at which all other attributes are held).

2. They must be utility independent of their compliments (i.e., the conditional preference for probabilistic trade-offs involving only changes in the levels for any pair of attributes does not depend on the levels at which all other attributes are held).

The methodology for applying the multi-attribute utility model involves establishing utility functions by relating performance levels of the attribute to a utility scale that ranges from 0.00 to 1.00, with 0.00 representing the lowest acceptable level of performance and 1.00 representing the highest level of performance. Each attribute is assigned a weighting factor that represents its importance in relation to the other attributes. Decision alternatives are evaluated by determining the level of attribute performance they can achieve for each attribute and calculating their overall utility through either an additive or a multiplicative mathematical formula. This formula incorporates the attribute weighting and the utility of the attribute performance.

The multi-attribute utility model offers mathematical precision, but presents difficulties in practices. Keeney and Raiffa (1976) state that "the methodology is highly subjective, counterintuitive for a practitioner, and frustrating for the analyst."

3.1.2 Goal Programming

Goal programming (GP) is a specialized version of linear programming. It is a decision analysis technique capable of handling multiple conflicting objectives. Goal programming was first introduced in 1961 for solving linear, multiple-objective, mathematical programming problems. Relatively simple goal programming problems can be solved manually with the simplex method. More difficult goal programming problems can be solved with computer code.

In GP, an objective function is used to minimize the deviations between defined goals and what can actually be achieved within the given constraints of the problem. The objective function, also called the achievement function, contains the deviation variables. The deviation variables are prioritized and represent the differences between goals and what can be achieved within the given set of constraints. Each deviation variable may have up to two dimensions in the objective function: a positive and negative deviation (d^+ and d^-) from each subgoal or constraint. The goal of the objective function is to minimize the deviations.

In GP, the decision-maker must rank and weigh multiple goals. Each goal is analyzed in regard to whether or not under or over achievement of the goal is desired. The deviation variables are assigned according to this analysis. If over-achievement is acceptable, positive deviation is not included in the objective function. Likewise, if under-achievement is acceptable, negative deviation is not included in the objective function. If exact achievement is desired, both negative and positive deviation variables are included in the objective function. The deviation variables are weighted according to their relative priority.

Three steps are used to transform a real-world problem into a mathematical goal programming model. The first step is to define the decision (choice) variables and to determine the magnitude of the constraints for the constraint equations. The constraints may represent either available resources or specified goals. The second step is the formulation of constraint variables, which can be resource (system) or goal constraints. Resource constraint equations define relationships among the restraint variables and the magnitude of the restraints. Goal constraints define the relationship between choice variables and goals. The third step is the development of the objective function. The objective function is simply an equation that defines the deviation variables that need to be minimized.

An example of a goal programming formulation for a decision problem involving schedule the production of two products on three machines is provided:

Minimize $(d_1^-, d_2^-, d_3^-, d_4^-)$,

Subject to

$$5x + 20y + d_1^- - d_1^+ = \$1,500$$

$$0.2x + 0.4y + d_2^- = 40$$

$$0.4x + 0.1y + d_3^- = 40$$

$$0.3x + 0.3y + d_4^- = 40$$

$$x \leq 80$$

$$y \leq 80$$

$$x, y, d_j^-, d_j^+ \leq 0$$

In this example, x = volume of Product 1, y = volume of Product 2; the first constraint represents the profit with \$1,500 considered as satisfactory profit; the second through fourth constraints represent the machining times on all three machines for both products; the fifth and sixth constraints represent the maximum demand for both products. The slack variable, d_j^-, and the surplus variable, d_j^+, measure the deviation from the right-hand sides of the constraints. An upper limit of 40 hours of production capacity cannot be exceeded; therefore, the surplus variables are omitted for j = 2, 3, 4.

Goal programming is superior to other multi-attribute decision models when the decision-maker is faced with multiple incompatible goals because a feasible satisfactory solution is ensured. According to Canada (1989), the most difficult challenge with GP is the formulation of a model for real-world problems.

3.1.3 Expert Systems

Expert systems is an area within a broader field of artificial intelligence (AI). The goal of AI is to use computers to model human behavior by making use of available human knowledge to perform tasks. AI includes robotics, computer perception (i.e., speech, vision, and touch), natural language, and expert systems. Expert systems are computerized systems with specialized problem-solving capabilities. Badiru (1992) describes an expert system as "an interactive computer-based decision tool that uses both facts and heuristics to solve difficult decision problems based on knowledge acquired from an expert."

Expert system applications are categorized by the tasks they are designed to perform. According to Canada (1989), these categories are interpretation (interpret, diagnose, monitor, and predict), generation (plan and design), debug, repair, instruct, control, and learn, in order of increasing complexity. Canada (1989) distinguishes expert systems from conventional computer programs by seven characteristics:

1. They separate the expert knowledge from the reasoning mechanism.
2. They provide complete representation of domain specific knowledge.

3. They use a general-purpose reasoning mechanism (inference engine) to use domain-specific knowledge and gathered facts (evidence) to arrive at a conclusion.

4. They are able to explain and justify conclusions.

5. They are able to handle unreliable, incomplete, and uncertain ideas.

6. They are an easy-to-use natural language human interface.

7. They can be modularized to represent knowledge to support rapid prototyping and refinement.

The components of an expert system include a knowledge base, a control mechanism, an inference engine, a cache, a user interface, and a database. The knowledge base contains the facts (i.e., data and relationships) and heuristics (i.e., judgment, intuition, rules of expertise, and plausible reasoning) about the problem domain. The control mechanism serves as a controller for the inference engine by containing rules about how the inference engine functions. The inference engine specifies an algorithm for system operation that drives the system through lines of reasoning and search methods. The cache is the working memory for the expert system and temporarily stores information (i.e., facts about the conclusions reached by the system) about the current state of a run or consultation of the expert system. The user interface allows the user and the computer to communicate, and it prompts the user to respond to questions. Through this interface, the user drives the expert system to reach a conclusion to a decision problem. The database stores facts relevant to the problem and the results of runs or consultations with the expert system. Databases are not a standard feature of all expert systems but can be very useful in large expert system applications where relevant data is found in already established databases. Such data is available to be shared with the expert system and other software applications.

Canada (1989) states that expert systems are powerful tools for solving problems that are complex and require intuition, experience, and theoretical knowledge of the domain expert. They can make expertise available at remote sites, under emergency conditions, and in multiple locations where the human expert cannot be available at all times. Expert systems can be used to reveal the reasoning of experts in order to help develop training. The limitations of expert systems include the size of the domain, the available inference mechanisms, and the inability to represent less explicit knowledge, such as common sense.

3.1.4 Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) was developed by Saaty (Saaty, 1980). It has been widely applied in various fields, such as transportation planning, portfolio selection, corporate planning, and marketing. It is a technique that structures the decision problem hierarchically. The hierarchy consists of levels that define the problem objective, attributes, sub-attributes, and decision alternatives. The attributes and sub-attributes are often referred to as the hierarchical elements. The elements are scored by making pairwise comparisons of all attributes at each level in the hierarchy to all attributes at the previous level. Pairwise comparisons are made by rating indicating the strength for which one element dominates another element with respect to a higher-level element. The term element includes decision objective, attributes, sub-attributes and decision alternatives. The scaling process is translated into priority weights (scores) for the decision alternatives.

A summary of the steps of the AHP, adapted from Saaty, 1982, is provided in Table 1. A detailed discussion of each step follows.

Table 1. AHP Implementation Steps (Saaty, 1982).

Step	Activity
1	Define the problem objective and specify the decision alternatives.
2	Structure the hierarchy from the overall managerial viewpoint (from the top level of the decision objective down to the level of the potential decision alternatives). Construct a pairwise comparison matrix for each set of related attributes and sub-attributes (i.e., a cluster), and for the alternatives.
3	Obtain all pairwise comparison judgments for the upper right-hand corner of the matrix. If there are many people participating, multiple judgments can be synthesized by using their geometric mean.
4	Determine the priority weightings for elements in the matrix by calculating the matrix eigenvectors.
5	Compute the consistency index for the matrix.
6	Perform steps 3, 4, and 5 for all levels and clusters in the hierarchy.
7	Use hierarchical composition (synthesis) to calculate priority weightings for the alternatives by the multiplying the priority weightings of the next lower level by the next higher level and so on. The priority weighting for an alternative is calculated by summing these products for the alternative for all levels and clusters.
8	Evaluate consistency for the entire hierarchy by multiplying each consistency index by the priority of the linking attribute and adding the products. The result is divided by the same type of expression using the random consistency index corresponding to the dimensions of each matrix weighted by the priorities as before. The consistency ratio of the hierarchy should be 10 percent or less.

The first step of the AHP process is to define the objective of the decision problem (e.g., career choice satisfaction) and the decision problem alternatives. This step also involves the specification of the decision alternatives (e.g., manufacturing, consulting, service industry, graduate college).

The second step of the AHP process is to form the decision hierarchy. The objective forms the first level of the AHP hierarchy and the decision problem alternatives form the lowest level of the hierarchy. The attributes considered important in achieving the overall objective (e.g., money, job security, family life, and work environment) form the second level of the AHP hierarchy. Additional sub-attributes can be created (e.g., within the attribute money are sub-attributes of starting salary, ending salary, and living cost). The sub-attributes can also have sub-sub-attributes. Sub-attributes and sub-sub-attributes form additional levels of the AHP hierarchy. One very important aspect of the attributes and sub-attributes is that they must be independent. Independence means that the attributes and sub-attributes within the same level cannot be affected by the each other. An example of attributes which would violate independence would be cost and profitability because profitability is impacted by cost.

The third step of the AHP process is to establish comparison matrices and to obtain pairwise comparison judgments for the sets of attributes and sub-attributes identified in Step 2. The pairwise comparison methodology requires decision-makers to make pairwise comparisons of all attributes within a hierarchical level in regard to their relative importance with respect to the next higher level in the hierarchy. Two approaches can be used to make the pairwise comparisons. The first approach is to use actual performance data (e.g., money). When using actual performance data, two different approaches can be used, depending on whether a higher or lower value of performance is better. If a higher value is better, a one-step normalization process of the data is used. The priority weights are determined by dividing the individual element's performance by the sum of the performance for all elements. If a lower value of performance is better, a two-step normalization process is used. The first step is to compute the ratio of the best (i.e., smallest) performance value to each alternative's performance value. The second step is to normalize the ratios so that they sum to one.

The obvious advantage to using actual performance data is that it makes the assessment more objective. An important requirement for using actual performance data is that there is a linear relationship between the performance value and its relative weight (e.g., $50 is twice as good as $25). The second approach is to base the pairwise comparisons on a 9-point scale. Saaty's suggested scale for degrees of preference between two attributes (x and y) is shown in Table 2. The pairwise comparisons are placed in a matrix.

Table 2. Saaty's Nine-Point Scale (Saaty, 1980).

If x is ... as (than) y,	the number to assign to n is
Equally important/preferred	1
Weakly more important/preferred	3
Strongly more important/preferred	5
Very strongly more important/preferred	7
Absolutely more important/preferred	9

The fourth step of the AHP process is to determine the element priority weightings by calculating the principal vector (i.e., eigenvector) of each element with respect to each of the other elements. A matrix consisting of one row or one column only is called a vector. A square matrix has an equal number of rows and columns. Eigenvectors and eigenvalues can be calculated for square matrices (Saaty, 1980). The eigenvector provides the priority ordering of the elements in a square matrix. The principal vector (i.e., eigenvector) of the matrix is calculated and then normalized to derive the weightings of each element.

The sixth step of the AHP process involves computing a consistency ratio to determine the degree of consistency present in the subjective judgement of the decision-maker. The eigenvalue is the measure of the consistency of judgment in the matrix. The consistency ratio is a comparison of the "maximum eigenvalue" and a "random index."

If the local consistency ratio is no greater than 0.10, Saaty (1980) suggests the consistency is "generally quite acceptable for pragmatic purposes." Random indexes for various matrix sizes have been approximated by Saaty (1980) and will be discussed in more detail in Section 3.2.2. The AHP process includes computation of a local and a global consistency ratio.

The seventh step of the AHP process involves computing the overall priority weights for each alternative by 1) taking the attribute weights calculated in Step 6, 2) multiplying them by the sub-attribute weights, and 3) summing the result over all attributes. The alternatives are then rank-ordered by the total sum.

The eighth step involves the computation of the global consistency ratio. The aggregate global ratio is computed by taking the ratio of an "aggregate consistency index" for the entire hierarchy to an aggregate "random index." The calculation of the aggregate consistency index involves calculating consistency indexes for each cluster (i.e., sub-attributes and their linking attribute), and adding this value to the product of the vector of the cluster priority weights and the vector of the lower-level consistency indexes. The aggregate inconsistency index is divided by an aggregate random index. The aggregate random index is calculated similar to the aggregate inconsistency index; however, random indices are used in place of consistency indices. If the global consistency ratio is less than or equal to 0.10, Saaty suggests the consistency of the hierarchy is acceptable.

3.1.5 Comparison and Contrast of Multi-Attribute Methods

Table 3 presents a comparison of each of the multi-attribute decision models against the criteria of strengths, weaknesses, software support, attribute flexibility, and group decision capability. The Analytic Hierarchy Process offers several advantages in comparison to the other models:

1. It can incorporate qualitative and quantitative attributes.
2. It can be used by a group of decision-makers, as well as by an individual decision-maker.
3. It can have multiple levels of decision attributes.
4. Judgmental consistency can be quantified and evaluated for acceptability.
5. It facilitates communication of the decision problem through the use of a hierarchical approach to defining the components of the decision.

"The strength of the AHP method lies in its ability to structure a complex, multiperson, multiattribute, and multiperiod problem hierarchically (Canada, 1989)." Canada (1989) identifies benefits of the AHP as:

1. It is simple to use and understand.
2. It necessitates the construction of a hierarchy of attributes, sub-attributes, alternatives, and so on, which facilitates communication of the problem and recommended solution(s).
3. It provides a unique means of quantifying judgmental consistency.

Chan and Lynn (1993) claim that the AHP is superior to other ad hoc weighting schemes for multiple criteria decision making because it ensures consistency and transitivity of responses through the use of pairwise comparisons. It also is a useful tool

Table 3. Comparison of Multi-Attribute Decision Models.

Criteria	Utility Models	Goal Programming Models	Expert Systems	Analytic Hierarchy Process
Strengths	• Presents outward appearance of mathematical precision	• Relatively simple, flexible, efficient, and straightforward • Consistent with typical real-world problems • Capability to handle decision problems with a single goal and multiple sub-goals • Objective function may contain non-homogenous units of measurement	• Powerful tool for solving problems that are complex, require intuition, experience, and theoretical knowledge of the domain expert • Can make expertise available at remote sites, under emergency conditions, and in multiple locations where the human expert cannot be available at all times • Can make powerful training tools • Can be used to test the line of reasoning of an expert • Can be incrementally approved as existing knowledge in developing field expands	• Simple to use and understand • Construction of the hierarchy of attributes, sub-attributes, and alternatives facilitates communication of the problem • Provides a unique means of quantifying judgmental consistency
Weaknesses	• Methodology highly subjective, counterintuitive for a practitioner, and frustrating for the analyst (Keeney and Raiffa, 1976)	• Methodology separates the decision-maker from the analysis • Difficult to quantify strategic and risky considerations • Focus on optimization supercedes need for "satisficing" for problems with multiple, competing objectives	• Limitations in size of the domain • Available inference mechanisms • Ability to represent common sense, and learn readily from experience	• Manner in which the weights are elicited and assessed • Rank reversal • Situations in which benefits and costs are attributes; can be eliminated by using an incremental benefit-cost analysis
Automation Requirements	• No requirements	• Requires computer capability for analyzing the linear programming model if the decision problem is not simple • Simple decision problems can be solved manually through the Simplex Method	• Requires computer capabilities for knowledge base, working memory, and inference engine	• All calculations required for the AHP can be performed manually • Software has been developed specifically for the AHP which can make the required calculations (eigenvectors, consistency ratios) more efficiently compared to a manual method
Qualitative versus Quantitative Attributes	• Attributes must be quantitative	• Objective function requires quantification of attribute priorities and constraints	• Decision attributes have to be capable of being modeled using computer code	• Attributes can be qualitative and quantitative
Group Decision Capability	• Restricted to individual decision-maker	• Restricted to individual decision-maker	• Restricted to individual decision-maker; however, the algorithms and heuristics can incorporate the knowledge of multiple domain experts	• Can be used for individual and group decision-makers.

where qualitative factors have a significant impact on the decision. The Analytic Hierarchy Process will be discussed in more detail in the following section.

3.2 Analytic Hierarchy Process in Detail

The Analytic Hierarchy Process was developed for the purpose of establishing a theory and providing a methodology for modeling unstructured problems in the economic, social, and management sciences (Saaty, 1980). According to Saaty, the theme for the AHP was "decomposition by hierarchies and synthesis by finding relations through informed judgment." Saaty believed that "models must include and measure all tangible and intangible, quantitatively measurable, and qualitative factors to be realistic." This section describes the AHP in detail with respect to its concepts and theory, methodology, criticisms, and enhancements.

3.2.1 Theory and Concepts

Saaty (1986) described three principles that are used in problem solving. They are the principles of decomposition, comparative judgments, and synthesis of priorities. The principal of decomposition is used in the AHP through structuring a hierarchy to define the basic elements of a problem and the relationships among the elements.

The principle of decomposition can be accomplished within the AHP by first working down from the top of the hierarchy. The top of the hierarchy begins with the attributes and descends through the sub-attributes and sub-sub-attributes. Adjacent levels of the hierarchy should be homogeneous or not too disparate from a qualitative perspective. The bottom of the hierarchy usually contains the alternatives for the decision problem.

The principle of comparative judgments is accomplished by setting up a matrix to form the pairwise comparisons of the relative importance of elements in one level of the hierarchy to the next higher level (e.g., the relative importance of elements in level two to elements in level one). If there are no scales of measurement that can be used to evaluate relative importance (e.g., dollars, customer satisfaction ratings, and percent of market share), Saaty (1980) recommends the use of his 9-point scale. The end result of the pairwise comparison process is the establishment of relative priorities (i.e., the eigenvector) of elements within a level to the elements in the previous level.

The principle of synthesis involves the multiplication of the element priorities in a hierarchical level by the priorities of elements in the next higher level, and adding them for each element in a level according to the attribute that it affects. This produces a composite or global priority of an element, which is used to weight the priorities of the elements in the level below, continuing recursively to the bottom level.

The AHP uses the consistency index to assess which judgments need further discussion and reassessment. Saaty (1980) defines "being consistent" as "when we have a basic amount of raw data, all other data can be logically deduced from it." This concept of consistency can be best explained through the use of an example. If attribute A1 is 3 times more dominant than attribute A2, and attribute A1 is 6 times more dominant than attribute A3, then A1=3A2 and A1=6A3. Consequently, it should hold true that 3A2=6A3 or A2=2A3 and A3=1/2A2. If the numerical judgment in the (2,3) position of the comparative matrix was other than 2, then the matrix would be inconsistent.

Saaty (1980) indicated that in general, informed judgment leads to better consistency. Judgment consistency represents the transitivity of preference in the pairwise comparison matrices. The AHP includes both a local measure of consistency for the individual comparison matrices and a global measure of consistency for the entire decision problem.

In order to understand the process for measuring consistency in the AHP, several terms must be defined. A reciprocal matrix is a matrix where $a_{ji} = 1/a_{ij}$ with $a_{ii} = 1$. The matrix is positive if $a_{ij} > 0$ for all i and j. An eigenvector of a matrix A is a non-null vector w such that $Aw = \lambda w$ or $(1/\lambda) A$ transforms to w to w, or leaves w fixed. The values of λ corresponding to w are called the eigenvalues of A. Thus, w would be an eigenvector if it is a nonzero solution of $(A-\lambda)w = 0$ for some number λ. A perfectly consistent positive reciprocal matrix satisfies the requirement that its maximum eigenvalue (λmax) equals the number of attributes, n. The closer λmax is to n, the more consistent is the matrix.

Departure from consistency can be measured by calculating a consistency ratio for the matrix. The consistency ratio is the ratio of the consistency index to the average random index. If the consistency ratio is no greater than 0.10, Saaty (1980) suggests "the consistency is generally quite acceptable for pragmatic purposes." The consistency index equals $(\lambda\text{max} - n)/(n-1)$. The consistency index of a randomly generated reciprocal matrix from the scale 1 to 9, with reciprocals forced, is called the random index (RI). The average values for random indexes have been determined by the Oak Ridge National Laboratory for square matrices of size 1 to 15 using a sample size of 100 and by the Wharton School for square matrices of size 1 to 11 using a sample size of 500. Saaty

(1980) has approximated the values for the random indexes (RI) for various matrix sizes, N, based on the simulation runs of Oak Ridge and the Wharton School and a large number of simulation runs. These approximations are provided in Table 4. Transitivity can not be measured unless the number of attributes is greater than 2.

Table 4. Random Indexes for Various Matrix Sizes (Canada, et al., 1996).

N	1	2	3	4	5	6	7	8	9	10	11
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

The AHP is based on four axioms, which are often the source of the criticisms launched against the AHP. Saaty (1986) provides a thorough discussion of these axioms and the theorems and their proofs that are derived from them. These axioms are:

1. the reciprocal property, which is basic in making paired comparisons;
2. homogeneity, which is characteristic of decision-maker's ability to make comparisons among things that are not too dissimilar with respect to a common property;
3. dependence of a lower level on the adjacent higher level; and
4. the idea that an outcome can only reflect expectations when the latter are well represented in the hierarchy.

3.2.2 Methodology and Example

The steps of the AHP are presented in more detail through their application to an example decision problem. The example decision problem involves the selection of a model for a new healthcare delivery system from among three alternatives. The objective is to determine "the best healthcare delivery system" considering multiple quantitative and qualitative factors. Three alternative healthcare delivery systems are under consideration. The breadth of the alternatives, from a service delivery perspective, increases incrementally from the first to the last alternative. The alternatives are:

> Alternative #1: Build a new facility that offers strictly outpatient services for all medical specialties.
>
> Alternative #2: Build a new facility that offers outpatient services for all medical specialties and obstetric inpatient services.
>
> Alternative #3: Build a new facility that offers outpatient services and inpatient services for all medical specialties.

The steps for performing the AHP example are illustrated in the following text.

Step 1. Define the problem objective and specify the alternatives.

The decision problem is to select the best healthcare delivery system in terms of specified quantitative and qualitative attributes. The alternatives, in terms of services provided, are: (1) Outpatient, (2) Outpatient and Labor and Delivery, and (3) Outpatient, Labor and Delivery, and Inpatient.

Step 2. Structure the hierarchy from the overall managerial viewpoint (from the top level of the problem objective to the bottom level of the decision alternatives).

The decision problem has quantitative and qualitative factors. The three-level hierarchy that has been constructed for this example multi-attribute decision problem is presented in Figure 1. Level I of the hierarchy states the focus of the decision problem. The objective is to determine the best healthcare delivery system. Level II of the hierarchy shows the attributes that are important to the objective. These are market, financial, core learning and growth, and stakeholders. Level III of the hierarchy shows the sub-attributes to each attribute. The sub-attributes are Market Share and Customer Acquisition (Market). Cost and Profitability (Financial). Employee Satisfaction and

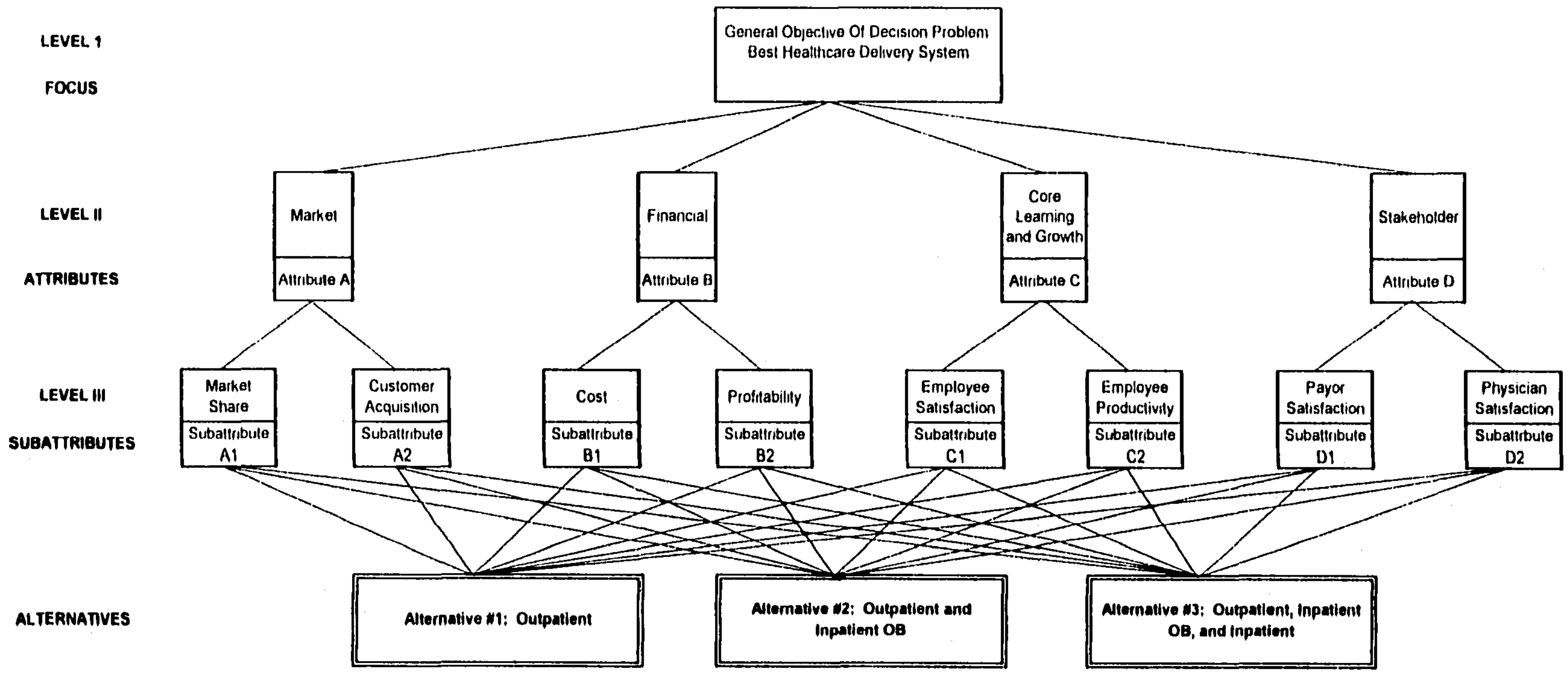


Figure 1. Hierarchy of Example Decision Problem.

Employee Productivity (Core Growth and Learning), and Payor Satisfaction and Physician Satisfaction (Stakeholder).

Step 3. Construct a pairwise comparison matrix and obtain the pairwise comparison judgments for the matrix.

The matrices for all elements at all levels are contained in Appendix A. The first matrix compares the Level II attributes (Market, Financial, Core Growth and Learning, and Stakeholder) to each other with respect to the decision problem objective to identify the best healthcare delivery system. The second set of matrices compares Level III sub-attributes to linked Level II attributes. The last set of matrices compares Level III sub-attributes to the alternatives.

Step 4. Obtain the matrix priority weightings by calculating the eigenvectors.

The pairwise comparisons are provided in Appendix A for each matrix. In this example, there was only one decision-maker. Had multiple decision-makers been involved, geometric means should be used at this point. The detailed eigenvector calculations are also provided in Appendix A. The eigenvectors establish the relative priorities of the elements with respect to the next higher level in the hierarchy (λ *max)*.

Step 5. Compute the consistency index and consistency ratio for the matrix.

The consistency calculations for this example are provided in Appendix A. The consistency index and consistency ratio for the Level I attribute matrix are shown in Table 5. The consistency index is greater than 0.10, which indicates that a review of the pairwise comparison judgments should be made to identify those that are inconsistent.

Pairwise comparisons have also been made for each sub-attribute (Percent Market Share, Customer Acquisition, Cost, Profitability, Employee Satisfaction, Employee Productivity, Payor Satisfaction, and Physician Satisfaction) by determining the relative

Table 5. Attribute Priority Weightings With Respect to Objective.

Attributes & Consistency Measures	Priority Weighting
A. Market	0.223
B. Financial	0.580
C. Core Growth and Learning	0.055
D. Stakeholders	0.142
λ_{max}	4.344
Consistency Index	0.115
Consistency Ratio	0.128

importance of each sub-attribute compared to the three alternatives. The eigenvector is found for the pairwise comparison matrix, which determines the relative weightings of each sub-attribute. The relative priorities of the sub-attributes with respect to the attributes are summarized in Table 6. The relative priorities of the sub-attributes with respect to the alternatives are summarized in Table 7. The local consistency indices and ratios computed for each matrix are summarized in Tables 6 and 7 and indicate a high amount of inconsistency in judgment (i.e., all consistency indices > 0.10). In addition, the consistency ratio is non-applicable when the quantity of attributes for a matrix is two.

Table 6. Sub-attribute Priority Weightings With Respect to Attributes.

Sub-attributes & Consistency Measures	Priority Weighting
A1. Market Share	0.500
A2. Customer Acquisition	0.500
λ_{max}	2.000
Consistency Index	0.500
Consistency Ratio	Non-applicable (n=2)
B1. Cost	0.333
B2. Profitability	0.667
λ_{max}	2.000
Consistency Index	0.500
Consistency Ratio	Non-applicable (n=2)
C1. Employee Satisfaction	0.167
C2. Employee Productivity	0.833
λ_{max}	2.000
Consistency Index	0.500
Consistency Ratio	Non-applicable (n=2)
D1. Payor Satisfaction	0.143
D2. Physician Satisfaction	0.857
λ_{max}	2.000
Consistency Index	0.500
Consistency Ratio	Non-applicable (n=2)

Table 7. Sub-attribute Priority Weightings With Respect to the Alternatives.

	Priority Weightings		
Sub-attributes	**Alternative 1**	**Alternative 2**	**Alternative 3**
A1. Market Share	0.068	0.275	0.657
		λ_{max}	3.044
		Consistency Index	0.022
		Consistency Ratio	0.038
A2. Customer Acquisition	0.065	0.199	0.735
		λ_{max}	3.072
		Consistency Index	0.036
		Consistency Ratio	0.063
B1. Cost	0.726	0.201	0.074
		λ_{max}	3.009
		Consistency Index	0.005
		Consistency Ratio	0.008
B2. Profitability	0.143	0.286	0.571
		λ_{max}	3.000
		Consistency Index	0.000
		Consistency Ratio	0.000
C1. Employee Satisfaction	0.100	0.300	0.600
		λ_{max}	3.000
		Consistency Index	0.000
		Consistency Ratio	0.000
C2. Employee Productivity	0.062	0.236	0.701
		λ_{max}	3.072
		Consistency Index	0.036
		Consistency Ratio	0.062
D1. Payor Satisfaction	0.056	0.242	0.702
		λ_{max}	3.217
		Consistency Index	0.108
		Consistency Ratio	0.187
D2. Physician Satisfaction	0.070	0.206	0.723
		λ_{max}	3.217
		Consistency Index	0.108
		Consistency Ratio	0.187

Step 7. Use hierarchical composition (synthesis) to calculate the priority weightings for the decision alternatives.

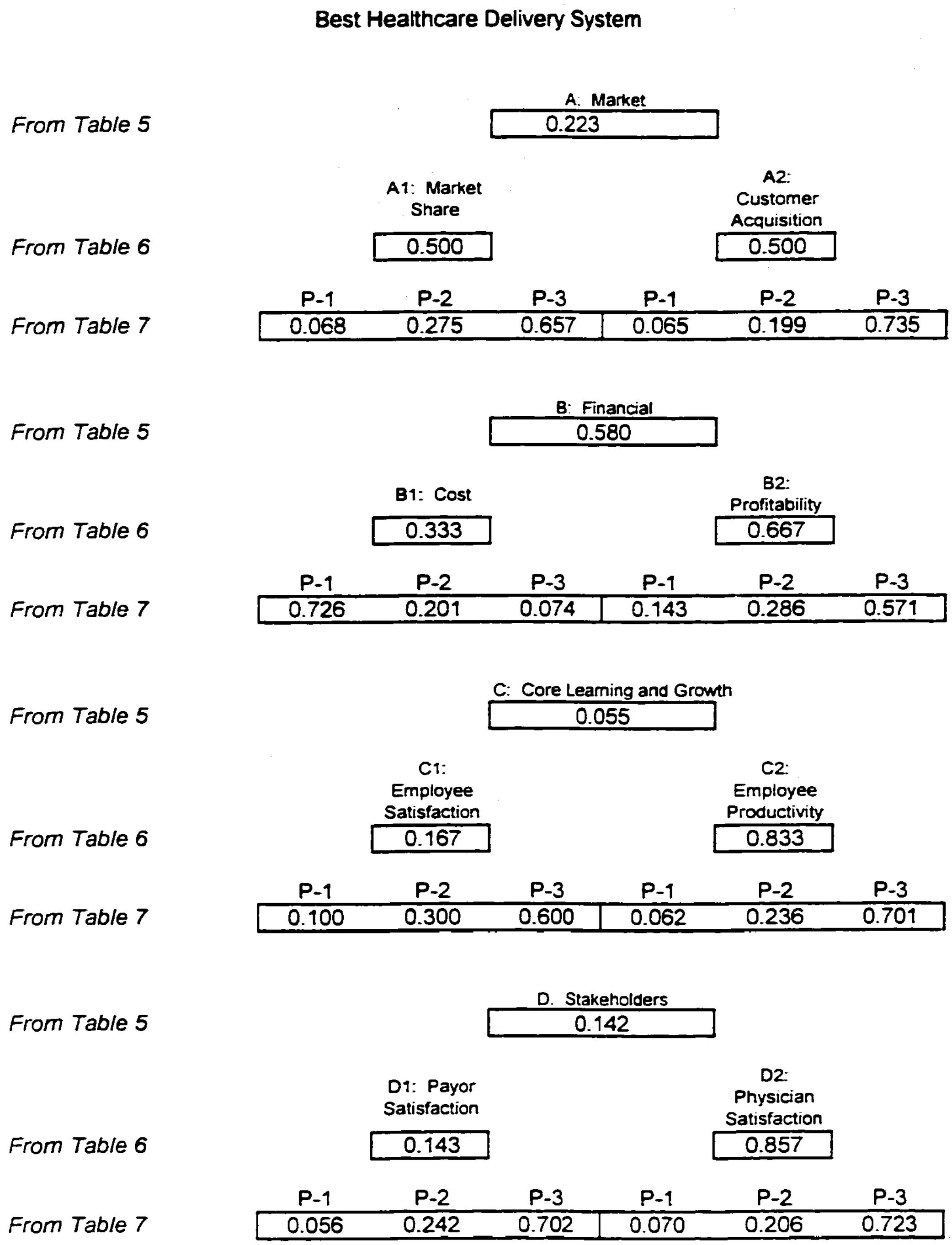
The alternative total weightings are obtained by working from the bottom to the top of the hierarchy. The lowest level priority is multiplied by the priority weighting of the associated next higher level all the way to the top of the hierarchy. The AHP weighting calculations are provided in Appendix A. The total weighting for each alternative is provided in Table 8. In this example, Alternative #3 has been identified to be the best healthcare delivery model, based on the maximum priority weighting. Figure 2 presents the hierarchy with the derived priority weightings

Table 8. Alternative Total Priority Weighting.

Alternative	**Total Priority Weighting**
Alternative #1: Outpatient	0.224
Alternative #2: Outpatient and Labor and Delivery	0.246
Alternative #3: Outpatient, Labor and Delivery, Inpatient	0.530

Step 8. Evaluate the global consistency index of the entire hierarchy by multiplying each consistency index by the priority of the corresponding attribute and adding the products.

The measurement of consistency can be applied to the entire decision hierarchy. Canada, Sullivan, and White (1996) defines the global consistency ratio of the hierarchy (CRH) as the ratio of an aggregate consistency index (M) for the entire hierarchy to an aggregate random index ($\overline{M}$). If the ratio is 0.10 or smaller, then the consistency of the hierarchy is generally acceptable.



Results:	
Alternative	Priority Weight
P-1: Outpatient	0.224
P-2: Outpatient and OB	0.246
P-3: Outpatient, OB, and Inpat	0.530

Figure 2. AHP Hierarchy Weightings.

Both M and $\overline{M}$ can also be calculated for clusters of the hierarchy. A cluster is a linked portion of the hierarchy (i.e., all elements at one level that are linked to a previous level element). The values of M and $\overline{M}$ calculated for

lower level clusters can be used in conjunction with other clusters and/or levels of the hierarchy to obtain the CRH for the entire hierarchy. The formula for calculating M is:

$$M = n\text{-level Consistency Index} + (\text{vector of } n\text{-level priority weights}) \times (\text{vector of } n+1\text{- level Consistency Indices})$$

The formula for calculating $\overline{M}$ is:

$$\overline{M} = n\text{-level Random Index} + (\text{vector of } n\text{-level priority weights}) \times (\text{vector of } n+1\text{-level Random Indices})$$

The process for calculating M and $\overline{M}$ for the entire hierarchy involves calculating the M and $\overline{M}$ values for the third level hierarchy clusters (e.g., Market Share, Customer Acquisition, Cost, and Profitability). The M and $\overline{M}$ values calculated for this level are used to calculate the M and $\overline{M}$ for the second level. These data are then used to calculate the M and $\overline{M}$ values for the entire hierarchy. Table 9 contains all calculations required to reach the Global Consistency Index, CRH. The Global Consistency Index (0.632) and the Ratio of the Hierarchy (0.703) are both greater than 0.10. This indicates that the hierarchy is not acceptable.

Table 9. Calculation of Global Consistency Ratio of the Hierarchy (CRH).

Value	Cluster	Consistency Index Calculation
M	A	0.500 + [(0.500)(0.022) + (0.500)(0.036)] = 0.529
M	B	0.500 +[(0.333)(0.005) + (0.667)(0.000)] = 0.502
M	C	0.500 + [(0.167)(0.000) + (0.833)(0.036)] = 0.530
M	D	0.500 + [(0.143)(0.108) + (0.857)(0.108)] = 0.557
M	Hierarchy	0.115 + (0.529)(0.223) + (0.502)(0.580) + (0.530)(0.055) + (0.557)(0.142)] = 0.632
$\overline{M}$	Hierarchy	0.900 + [(0.529)(0.000) + (0.217)(0.000) + (0.530)(0.000) + (0.557)(0.000)] = 0.900
CRH ($M/\overline{M}$)	Hierarchy	0.632/0.900 = 0.703

3.2.3 Criticisms

Since the introduction of the AHP in 1980, it has been a target of criticism. The criticisms of the AHP fall into two primary categories: (1) rank reversal and (2) the arbitrary nature of the rankings. A chronological review of the criticisms within both of these categories follows.

Belton and Gear (1982) criticized the AHP based on a problem with rank reversals. Rank reversal occurs when a new alternative introduced in the procedure causes results that reverse the priority rankings of alternatives previously evaluated. Belton and Gear (1982) believed that the interpretation of weights based on multi-attribute utility methods creates imprecision. Their recommendation for handling the rank reversal problem was to use a modified procedure to normalize the eigenvectors so that the maximum possible value is 1.0, rather than the values summing to 1.0.

In addition, they recommended a more specific question for decision-makers when making the pairwise comparisons. They advocated using a more specific definition of weight as the value of a unit on a scale used to measure the attribute. They also advocated relating the weight to the mean value on each attribute. This is in agreement with the interpretation of weight advocated by Saaty, Vargas, and Wendell (1983). They defined weight as the ratio of the average contribution of the alternatives to the value of attribute A_i and the average contribution of the alternatives to the value of attribute A_j.

Dyer and Wendell (1985) raised serious questions about the validity of the AHP and partitioned their critique into two parts. The first part concerned implementation problems that can lead to two types of errors in the responses of the subjects. However, they believed this concern could be overcome by a skillful analyst familiar with concepts of multi-attribute utility theory. The first implementation error occurs due to lack of a well-defined comparison scale. They believe that comparison of two alternatives using a ratio scale is difficult to operationalize in an unambiguous and meaningful way if the zero point is not defined. The question "How much better is A_i than A_j with respect to the next higher level attribute?" cannot be adequately responded to without the specification of some type of relative value unit (i.e., a definition of the zero point). The second implementation error is due to the use of attributes that lack independence. These independence conditions are required for using an additive multi-attribute model (Keeney and Raiffa, 1976; Dyer and Sarin, 1979).

The second critique by Dyer and Wendell (1985) concerned the more substantial problem of rank reversal. Dyer and Wendell (1985) believed that "the AHP violates one of the most basic assumptions of rationality: the independence of the procedure from irrelevant alternatives." They believed that rank reversal is a fatal error that makes the results of the analysis meaningless. They recommended a solution to this problem that involves normalizing the attribute weights and the scores of the alternatives with respect to the attributes using the same range of alternative values.

Two methods were used to operationalize this approach. In the first method, the decision-makers were asked to specify the ranges over which it is assumed the alternatives might vary on each attribute. The evaluation of the alternatives proceeded in the usual AHP method. In the second method, the decision-makers were told the ranges over which the alternatives under consideration actually vary. Then they were asked to make the pairwise comparisons by considering the relative importance of a change from the least preferred to the most preferred values for attribute A_i compared to a similar change for attribute A_j. The eigenvectors for the attributes were scaled by subtracting the smallest component in each eigenvector from all components in the eigenvector. This modified eigenvector was then divided by its largest component. This is similar to the modified normalization approach recommended by Belton and Gear (1982), except that the smallest component is initially subtracted from all components of the eigenvector in order to scale the alternative scores on each attribute from 0.0 to 1.0.

Watson and Freeling (1982) contended that when comparing two attributes, one must ask "how much is one attribute (in some specified units) worth compared to a particular amount of some other attribute (in some other specified units)?" They maintained that paired comparison judgments are meaningless without the specification of measurement scales. Their rationale is that decision-makers are actually comparing the attribute's scale intervals rather than comparing the attributes, themselves. The priority weightings must depend on the actual attribute measurement units and cannot be found without reference to these units. The point made by Watson and Freeling (1982) is "that it is impossible to know just what value function to construct without being explicit about the ranges being compared."

Bernhard and Canada (1990) believed that two features are missing from Saaty's procedure. One is the consideration of incremental benefit/cost ratios. The other is the inclusion and consideration of a cutoff ratio with regard to the decision-maker's relative preferences for benefit increments versus cost increments. The cutoff ratio defines the decision-maker's relative willingness to incur various levels of costs in order to receive corresponding levels of benefits. They disagree with Saaty's recommendation to compute ratios of the benefit and cost vector elements for respective alternatives and to chose the alternative with the highest ratio.

Dyer (1990) reviewed several areas of operational difficulty with the AHP and focused on the arbitrary rankings that occur when the principle of hierarchic composition is assumed. Hierarchic composition is one of the main assumptions of the AHP. It assumes that the weights of the attributes do not depend on the alternatives under consideration. Dyer stated:

> "The AHP is flawed as a procedure for ranking alternatives in that the rankings produced by this procedure are arbitrary. This flaw can be corrected, but not by moving away from traditional methods of analysis. The key to the proper use of the AHP relies on its synthesis with the concepts of multiattribute utility theory."

Another area of operational difficulty that Dyer (1980) addressed is the ambiguity of the questions that the decision-maker must answer in completing the paired comparisons. He claimed that the questions posed in classical utility theory are well defined in comparison to the AHP. In classical utility theory, the comparisons among alternatives depend on a choice by the decision-maker, rather than on a subjective response on a ratio scale. Dyer believed that the AHP paired comparison judgments have more in common with questions used to determine a strength of preference function, requiring a subjective estimate of strength of preference on a cardinal scale. Dyer (1980) made reference to the fact that preference theory, based on the concept of strength of preference, has not been in favor in the literature due to the inherent difficulty with direct subjective estimates.

Another area of operational difficulty mentioned by Dyer (1980) is the determination of a zero reference point that the decision-maker must make either implicitly or explicitly. He suggests that there needs to be a standard/clear definition of a zero reference point. However, Dyer (1980) was most concerned by the generation of rank orderings that are not meaningful with respect to the underlying preferences of the decision-maker. This deficiency is evidenced by the phenomenon of rank reversal.

Murphy (1993) demonstrated that Saaty's bounded 9-point scale inherently gave results that were outside the accepted consistency standard of less than or equal to one-tenth of the mean consistency index of randomly generated matrices. She pointed out that the problem is most severe with large matrices, but that it could occur with small matrices. Murphy noted through an example, where the ratios were between 7 and 9, that inconsistency makes the smallest weight higher and the highest weight smaller. She constructed a table which compared the bounds of λ_{max} calculated by Vargas (1982) with the minimum λ_{max} which can be obtained when the adjacent alternatives are "slightly more important (semantic scale of 3) and "strongly favored over one another (semantic scale of 5). The comparison showed that when the AHP ranks three or four alternatives with the 9-point scale, they should average less than "strongly favored" over their closest competitor. When more than four alternatives are compared, the 9-point scale is unsuitable for use unless the adjacent alternatives are, on average, closer in value than "slightly more important."

Triantaphyllou and Mann (1994) criticized the both the AHP and the modified AHP proposed by Belton and Gear (1983). Belton and Gear's modification of the original AHP methodology involved dividing each column of the AHP decision matrix by the maximum entry of that column. This alteration was introduced as a method for eliminating rank reversal. Triantaphyllou and Mann (1994) investigated the rank reversal phenomenon in both the original AHP and the modified AHP. They found that the rank reversal rate increased with an increase in the number of alternatives. Neither the number of attributes nor the decision making method used (i.e., original AHP or modified AHP) affected the rank reversal rate.

Perez (1995) adopted a position that Saaty's AHP method of handling criteria weights was undesirable, but not invalid. Perez commented on the fact that although there have been multiple criticisms of Saaty's AHP due to the rank reversal problem, there has been no consensus reached on how to avoid this problem. Perez commented that it was well known that almost all ordinal aggregation methods exhibit rank reversal, but less well known that all "multi-district proportional elections" suffer from some form of rank reversal. He provided examples of three different methods of handling a multi-district election.

One method used a ballot box in every division and votes from each of the boxes are first counted separately and then totaled jointly. Each candidate obtains a number of seats proportional to the total number of votes obtained. Another method assigns a certain number of seats to each division proportional to the division's electorate. Each of the candidates obtains a number of seats by multiplying their proportion of seats by their number of votes divided by the total number of votes cast for the division. The third method assigns a variable number of seats to each division computed by distributing the total number of seats among the divisions in proportion to a coefficient. The coefficient for a division is calculated as: $c_i = (\beta * \text{Total votes for division}) + (1-\beta) * \text{Electorate of division}$. The parameter β is a calibration parameter, which takes values in the closed interval [0,1]. This parameter allows an equilibrium to be attained between the democratic principle which states that all votes should have the same value, and the need for some intermediate bodies (divisions) to play an important role in the decisions.

The three election methods did not elect the same candidate even though the voting results were consistent among methods. The variation in the results was due to how the proportions were determined and introduced in the calculation of votes. Perez believed that the suitability or correctness of multicriteria aggregation methods should be analyzed not only on formal grounds, but also in the real context in which they are applied.

Dodd, Donegan, and McMaster (1995) recognized a problem with "inverse inconsistency." Inverse inconsistency occurs when the input data is opinion-based rather than from physical measurement. Inverse inconsistency is defined as the difference between the dominant eigenvectors (right and inverted left). The terms right and left eigenvector are defined by the way in which the question to complete the paired comparisons is asked. The consequence is that the order of the final priority vector will depend on the original framing of the questions, leading to some arbitrariness. Inverse inconsistency is different from Saaty's inconsistency. Rank reversal can occur in a matrix that is not inconsistent, but has inverse inconsistency.

Dodd et al. (1995) advocated a more structured approach for determining the pairwise comparisons referred to as the "Principle of Priority." This approach involves considering the issue deemed to be more important relative to the issue deemed minor. If this approach is adopted, all the entries in the judgment matrix which are at least equal to 1 are selected by judgment; those entries less than 1 are derived as the reciprocals of the existing entries. The problem is illustrated by considering that it is easier to compare attributes against one another when using whole numbers (e.g., 5 compared to 7 or 9) compared to fractions (e.g., 1/5 compared to 1/7 or 1/9). The AHP assumes pairwise comparisons are entirely multiplicative and their inverses are entirely multiplicative. However, a large difference can occur between paired comparisons, particularly when comparing extreme values.

Tung and Tang (1998) examined a problem known as "Right and Left Eigenvector Inconsistency." They identified a deficiency throughout Saaty's work in that only right eigenvectors are used. They contradicted a common viewpoint that both right and left eigenvector approaches yield the same result for ranking a set of alternatives. This posed a question, "which eigenvector approach is better to solve AHP problems?" Reference was made to yet another modified version of the AHP developed by Dogg, Donegan, and McMaster (1992). This modified AHP (MAHP) involved using a set of new scales by mapping Saaty's nine-point scale to new values determined by a function that has a multiplicative co-domain. This mapping was claimed to have overcome the problem with Saaty's scale in that it is partly linear and partly harmonic. The function converts the entries in the judgmental matrix so they belong to a multiplicative co-domain. Tung and Tang established 42 test models (21 for a pre-arranged order of attributes and 21 models for a less obvious order of attributes) which produced 294 reciprocal matrices. They concluded that the MAHP was no better than the AHP based on the consistency of right and inverted left eigenvectors (no rank reversal).

Critics of Saaty's AHP, from its inception in the early 1980's to present day, have found fault primarily with the ambiguity of the process for developing the paired comparisons. They have faulted Saaty's 9-point scale, the impact of variation in the manner in which the question used for attribute comparison is asked, and the lack of clearly defined reference points for comparison. Another area of concern is the phenomenon of rank reversal, which, in some cases, is believed to be a symptom of the ambiguity of the paired comparison process and other cases, is believed to be indicative of any multi-attribute decision technique. Despite these criticisms, numerous applications of the AHP have occurred and many enhancements will be discussed in section 3.2.5. The next section will address the enhancements to the AHP which have been documented since its introduction in 1980.

3.2.4 Enhancements

Enhancements to the AHP in the literature fall into six categories of: (1) paired comparison process, (2) rank reversal, (3) sensitivity analysis, (4) consensus building and consistency measurement, (5) eigenvector calculations, and (6) integration with electronic meeting technologies. The most frequently occurring enhancements have concerned the paired comparison process. The specific enhancements for each category are discussed in detail.

3.2.4.1 Paired Comparison Process

Three types of enhancements have been made to the paired comparison process: (1) reduction in the ambiguity of the comparison scale, (2) introduction of uncertainty through interval versus point estimates of priority, and (3) reduction in the required number of paired comparisons that decision-makers must make.

Several individuals have addressed scale ambiguity. Toshiyuki, Turo, and Shneiderman (1995) described the use of computerized treemaps as a visualization method for large hierarchical data spaces to augment the capabilities of the AHP. Visualization was used to promote ease of comprehension for the decision-makers. The treemaps were used to simultaneously represent both the hierarchical structure and each element's quantitative information in a two dimensional rectangular space. The rectangular space was sliced either horizontally or vertically to create smaller rectangles for the next lower level attributes.

Toshiyuki et al. (1995) developed two direct manipulation tools referred to as the "pump" and the "hook" to support AHP sensitivity analysis. The pump was used to alter the attribute importance. The hook was used to alter the attribute sibling weights. These tools allowed decision-makers to dynamically change the importance of attributes on a two-dimensional treemap and immediately see the impact on the outcome of the alternative selection. Their study, using a prototype AHP with six subjects, found that the treemap representation was acceptable from a visualization and data operation perspective.

Webber, Apostolou, and Hassell (1996) reported results from three related experiments that investigated whether differences in the scale used (numerical, verbal, or graphical) or the format order of paired comparisons yields significant differences in the AHP models. Three research questions were addressed:

1. Are AHP models significantly different when produced by numerical, verbal, or graphical response scales?

2. Are AHP models significantly different when the paired comparisons are presented in a random versus nonrandom format?

3. Are AHP models significantly different if the paired comparisons are presented in a top-down versus a bottom-up format?

Three different experiments were conducted to answer the research questions. The experiments used subjects who were enrolled in an introductory management course in the College of Business at a large, urban university. The research task was to select a car to purchase using a two-level AHP with five attributes in the first level and 17 sub-attributes clustered within each of the Level 1 groupings. The independent variables were scale (numerical, verbal, graphical), format (random, nonrandom) and order (top-down, bottom-up). The weights of the AHP models were the dependent variables. The consistency ratio and demographic variables were covariates. The results of the experiments showed no evidence of scale, format or interaction effects for Level 1 attributes, and provided only slight evidence that scale was important in the Level 2 sub-attribute analysis. There was some evidence that different weights were associated with the type of scale for both Level 1 and Level 2. In addition, there was evidence that a random versus a nonrandom format produced different weightings at Level 1.

Huizingh and Vrolijk (1997) explored the consequences of individuals having different numerical interpretations of the verbal expressions used to elicit preferences in making the paired comparisons. Saaty's nine levels were labeled with numbers (the numerical mode) and with preference phrases (the verbal mode). Seven different hypotheses related to the comparability of verbal versus numerical modes of elicitation were tested using 180 University of Goningen students. The decision task was the selection of a room to rent. They found that the 1 to 9 conversion table often used in the AHP tends to overestimate differences in preference. In comparing numerical versus verbal methods of elicitation of preferences, the numerical mode showed better results than the verbal mode, but the difference was not significant.

Zahir (1999b) extended the AHP to an Euclidean vector space and developed formulations for aggregating the alternative preferences with the attribute preferences. His model was termed the "Vector Space Formulation of the AHP (VAHP)." The procedures, similar to procedures used in physics, added a geometric meaning to the AHP. Zahir claimed that it is possible to represent any human decision by a preference vector in multidimensional object space. The VAHP used the same type of normalization that is used in the AHP. However, the preferences of the decision-maker were represented by the squares of the relative preference scale values. The similarity measure for two decision-makers was determined by calculating the cosine of the angle between them.

As discussed, the reduction in scale ambiguity has been addressed by introducing computerized graphical methods of portraying the hierarchy and its weights within the hierarchy, by comparing numerical, graphical, and verbal scales, and by using geometry in combination with statistical methods. Each of these enhancements relied on a measure of consistency to assess the degree to which decision-makers used a common framework for making pairwise comparisons.

Decision-maker uncertainty in regard to making pairwise comparisons was recognized as a significant factor in AHP decisions early on. Saaty and Vargas (1987) investigated the effect of uncertainty in judgment on the stability of the rank order of alternatives. They claimed that uncertainty in judgment was expressed in two ways: (1) as a point estimate with a probability distribution function, or (2) as an interval estimate without a probability distribution. Saaty and Vargas indicated that most of the work had focused on the point estimation with a probability distribution. However, the research produced little practical application. The distributions were difficult to determine, and even if a distribution was determined, the derivation of the principal eigenvector from pairwise comparisons was "complicated and not amenable to a direct synthesis of probability distributions."

The interval estimation technique was identified by Saaty and Vargas (1987) as being easier to implement through the use of simulation. The simulation must assume that the random variables are uniformly distributed. In their research, Saaty and Vargas (1987) applied the Kolmogorov-Smirnov test to determine if the eigenvector components were normally distributed. Once the distribution of the eigenvector components was determined to be normally distributed, the probability of rank reversal was determined. Saaty and Vargas calculated the probabilities that an alternative exchanges rank with other alternatives and that the alternative changed rank at all. The final ranking was determined by combining the priority of the importance of each alternative with the probability that it did not change rank.

Arbel (1989) explored approximate articulation of preference by having the decision-maker state preferences as ranges of values versus a single precise value. The concept of transitivity was discussed from the perspective of defining weak and strong sensitivity. Weak sensitivity implied a consistent ordered relationship among alternatives (e.g., if A is preferred to B, and B is preferred to C, then A is preferred to C). Strong sensitivity implied a quantitative relationship among alternatives (e.g., if A is preferred to B by a ratio of 2:1, and if B is preferred to C by a ratio of 3:1, then A is preferred to C by a ratio of 6:1). Arbel claimed that strong sensitivity and perfect consistency are identical. Three classes of preference articulation and their resultant priority derivation were defined. The classes and examples through mathematical expressions are:

1. precise articulation: $w_1/w_2 = 2$, $w_1+w_2= 1$
2. loose articulation: $w_1 \geq w_2$, $w_1+w_2=1$
3. approximate articulation: $1 \leq w_1/w_2 \leq 2$

Attributes were compared using inequalities similar to the above examples. Arbel (1989) showed that comparison of n attributes requires $1/(2n(n-1)$ inequalities. The inequalities were used as a set of constraints that were solved by using a Linear Programming approach. Arbel provided several theorems and proofs related to the feasible region associated with the inequalities. The conclusions of this research were that the approximation approach might be useful in allowing the decision-maker to derive priorities to be used in an AHP analysis without forcing the statement of an exact preference using the 1 to 9 comparison scale. This approach enables the decision-maker to get an idea of the preference structure without underlying priorities.

Zahir (1991) extended the AHP into stochastic analysis by incorporating unavoidable uncertainties into the decision judgments expressed in the relative weights of the pairwise comparisons. Attributes were categorized as either tangible factors, which were measured exactly, or intangible factors, which required subjective evaluations. Uncertainty in tangible attributes was derived from the error in data of measurements. Uncertainty in intangible attributes was derived as an expression of the confidence level in the subjective pairwise comparison of any two attributes. He also developed an algorithm to incorporate into the priorities of the alternatives the resulting uncertainties.

Arbel and Vargas (1993) explored two new approaches for priority derivation when preferences are expressed as interval judgments. The first approach was based on use of simulation. The simulation approach assumed that interval judgments were uniformly distributed. The second approach was based on mathematical programming, which generated a region that enclosed all priority vectors derived from inequalities representing the original interval judgments. There was a high degree of similarity between the simulation and mathematical programming approaches of Arbel and Vargas (Arbel and Vargas, 1993) and vector space formulation of Zahir (Zahir, 1999b).

Badiru, Pulat, and Kang (1993) presented a simulation-based decision support system for the AHP. The software, named Dynamic Decision-Making (DDM), is applicable to dynamic decision scenarios where probabilistic interactions exist between the attributes in the AHP hierarchy. The DDM software generates decision scenarios using probability data specified by the decision-maker. Attributes were referred to as events and sub-attributes are referred to as subevents. Simulation was used to generate events (i.e., attributes) that occur. A set of weights is derived for each alternative and the alternative with the highest weight is determined for each scenario. The simulation produces relative frequencies of selection for each alternative. The histogram of the alternative frequencies is used by the decision-maker to make a final alternative selection. The visualization provided by the histogram enables the decision-maker to also incorporate his/her disposition to risk in the final alternative selection. The DDM software is limited to four hierarchical levels.

Hauser and Tadikamalla (1996) used simulation to demonstrate the superiority of distributions of feasible judgments versus single point estimates. Discrete values were randomly generated from the uniform or triangular distributions of a provided point estimator of the paired comparisons. Matrices were determined, priorities were found, and rank was recorded by 500 simulation runs. Only runs with inconsistency ratios of less than 10% were considered, leaving 418 runs. Hauser and Tadikamalla defined the terms expected score, expected weight, and expected rank. The expected score was calculated using the following equation:

$$ES_i = \sum_{1}^{n} p_{i,k}(n+1-k)$$

where ES_i is the expected score of the ith alternative and $p_{i,k}$ = the proportion of the trials that the i^{th} alternative had rank k. The expected weight was the normalized expected scores. The expected rank was the index of the ith alternative once sorted in descending order of the expected weight. This research concluded that for partially or completely uncertain environments, simulation is a preferred method for providing a measure of confidence in alternative rank and for providing expected weights and ranks.

Several individuals recommended the use of interval scales. Chang (1996) introduced a new approach for handling fuzzy AHP which involved using triangular fuzzy numbers for pairwise comparisons. Chang used "extent analysis" to calculate fuzzy synthetic extent values. Mathematical formulas using the synthetic extent values determined fuzzy evaluation matrices similar to the pairwise comparison matrices of the traditional AHP. Priority vectors were derived for each fuzzy evaluation matrix. The same methodology that is used in point estimate AHP was used by Chang to determine the alternative rankings. Chang claimed that the Extent Analysis Method (EAM) was superior to the Logrithmic Least Squares Methods (LLMS) used by his predecessors as measured by the statistic of "time complexity." Time complexity was a measure of the number of times multiplication occurs in the analysis.

Stam and Silva (1997) presented a methodology for analyzing AHP rankings if the pairwise preference judgments are uncertain (stochastic). Their methodology involved asking decision-makers for information to construct a probability distribution over the range of each judgment interval. Sampling from the assumed probability distributions over the interval of judgments produced a stochastic estimate of the principal eigenvector. These estimates were used to determine the probabilities of rank reversal. The preference elicitation procedure was not limited to uniformly distributed judgment intervals. Simulation was used to generate principal eigenvectors. A mathematical equation was applied to determine the probability that the decision-maker prefers one alternative to another. Confidence intervals were constructed on the probabilities of rank reversal.

Van den Honert (1998) proposed a multiplicative variant of the AHP that expressed a group's pairwise comparisons as random variables with associated probability distributions. This method developed interval judgments for the alternative weighted scores, which were used to identify the probability that a rank reversal could occur. The model included only rank reversals caused by group rank uncertainty. The mean and variance of the distribution of each pairwise comparison were calculated from the complete set of responses of all the individual decision-makers. The measure used to determine the group's overall consensus was the probability of no possible rank reversal in the system due to lack of unanimity in the group's responses.

Haines (1998) addressed the problem of extracting preferences for alternatives from interval judgment matrices in the AHP. She examined in detail two specific distributions, the uniform distribution and the distribution of random convex combinations with coefficients, producing uniform spacing. Haines made enhancements to the methodology of Arbel (1989) by establishing a statistical distribution for the priority weights of the alternatives in a feasible region. Simulation was used to estimate the mean, standard deviation, correlation matrix, and probability that the weight of one alternative exceeds the weight of another alternative for the distributions of weights on the feasible region. These statistics were used to assess the ranking of the alternatives.

In summary, uncertainty in making pairwise comparisons by individuals and groups was addressed in many ways. The simplest approach was for decision-makers to express their judgements as an interval versus a point estimate. The next level of complexity was to establish statistical probability distributions for the pairwise comparisons. The uniform and triangular distributions were used, as well as specified probabilities for intervals within a range of values. Other statistical methods to address uncertainty included fuzzy triangular member sets and the distribution of random convex combinations with coefficients. Simulation was used to generate scenarios of pairwise comparison matrix scenarios and associated eigenvectors based on the probability distributions. Global priority weightings for alternatives were derived from the simulated eigenvectors. Confidence intervals were used to express uncertainty in the pairwise comparisons and to estimate the probability of rank reversal. Histograms were used to provide a visualization of alternative ranking frequencies. Time complexity was used as a measure to compare the performance of methods.

Another significant challenge in AHP implementation occurs when the decision problem is defined by a large sized hierarchy. The process of making paired comparisons for large sized hierarchies can be extremely arduous. Several researchers made recommendations to reduce the quantity of paired comparisons decision-makers must make. Weiss and Rao (1987) addressed a number of design issues involved in the implementation of the AHP for large-scale systems. They proposed two techniques for reducing the size of the comparison problem. One technique used incomplete experimental designs for simplifying data collection and evaluated the effects of reducing the size of the hierarchy through attribute deletion. The method of balanced incomplete block designs (BIBD) was applied. BIBD involves administering a subset of the attributes in any level. to each decision-maker and collecting judgments from all the pairs in the subset. Every pair of attributes is replicated the same number of times in the design to ensure equal standard errors in measuring the difference of scale values for any pair.

The second technique involved deleting certain attributes from the hierarchy. Weiss and Rao (1987) found that attributes in a hierarchy might be deleted safely if they provide no new information for the decision. The important issue is the degree to which the attribute will alter the weights at the next lower level (the degree of interaction between the attributes at the two levels).

Lim and Swenseth (1993) presented a methodology for identifying the point at which an alternative becomes so dominant that it cannot be overtaken as the preferred choice, regardless of the effects of the remainder of the alternative comparisons. This point is known as the stopping criterion and its identification enables the problem size to be reduced, which reduces the decision making time. Lim and Swenseth referred to their methodology as the Iterative AHP (IAHP).

The IAHP procedure involved calculating the eigenvector for a subset of the attributes, determining the highest ranking attribute, evaluating sub-attributes against the highest ranking attribute, and comparing the differences between the two highest ranking sub-attributes to the total weight of the attributes remaining to be considered. If the difference between the two highest-ranking sub-attributes is greater than the total weight of the attributes remaining to be considered, the process stops. The effectiveness of the IAHP was measured by determining the percentage of comparisons required to perform the IAHP compared to the AHP. Lim and Swenseth randomly generated 202,500 problems and found that the average percentage of comparisons required to achieve the dominant solution ranged from 40% to 80% of the maximum number of comparisons. The number of comparisons decreased as the number of Level 1 attributes increased.

Carmone, Kara, and Zanakis (1997) used Monte Carlo simulation to investigate the effect of reduced sets of pairwise comparisons in the AHP. They investigated the trade-off between reduced accuracy and the length of the data collection process. The Incomplete Pairwise Comparison Algorithm (IPC) developed by Harker (1987a, 1987b) and Millet and Harker (1990) was selected as the data reduction model for evaluation because it was deemed to be the most useful for practical, marketing orientations of the AHP. The investigation incorporated three different comparison matrix sizes, four types of error distributions, three standard deviations of error, and five rules of deletion order. The percent of deletions was fixed at 5.26% and the number of Monte Carlo replications to generate paired comparison values was 100. Carmone et al. (1997) found that as much as 50% of the comparisons can be deleted without reducing the accuracy of results if no assumptions are made about how decision-makers are evaluating the pairwise comparisons. They found that even more accuracy can be preserved and more comparisons can be eliminated if assumptions (e.g., exclusion of smallest comparison values) are made by decision-makers.

Sanchez and Soyer (1998) provided a way to measure and assess judgment accuracy in order to know when to stop the process of pairwise comparisons. They used the concept of relative entropy or cross entropy to assess whether a priority vector changes significantly as a result of the pairwise comparisons provided by the decision-maker. The Kullback-Leibler (KL) discrimination measure was used to determine the entropy. The entropy represented the information increase from one priority vector to the next. A small KL value implied that two priority vectors are close to each other and that the data collection process can stop.

Ra (1999) developed a shortcut technique named "chainwise (paired) comparison" in which only n, versus $n(n-1)/2$, paired comparisons forming a closed chain are needed for n decision attributes. Ra provided a table of formulas that are used in the chainwise comparison calculations. Ordinal consistency is the statistic used to determine the degree of acceptability (inconsistency) of the chainwise comparisons. The advantages of Ra's technique were (1) a simpler, straightforward calculations that can be conducted using a spreadsheet format, (2) quick, visual way of determining ordinal consistency that is not available in the eigenvector method, (3) a simple and intuitive measure of (in)consistency that is bounded by 0 and 1, and (4) in cases of inconsistency, the provision of alternative comparison ratio values of full consistency. The performance of Ra's method was tested on Saaty's (1980) wealth of nations example and Harker's (1987a) incomplete pairwise comparison method and was found to be identical in terms of the rankings and weightings.

Several techniques have been developed to reduce the time and effort required to make pairwise comparisons for large-sized hierarchies. The techniques involved data reduction methods and establishment of cutoff points for which additional data collection did not alter the resulting rankings of alternatives. Several authors concluded that the number of pairwise comparisons required to provide accurate results ranged from 40% to 80% of the maximum number of possible comparisons.

3.2.4.2 Rank Reversal

Several researchers have identified methods for overcoming the rank reversal problem. Schenkerman (1994) believed that rank reversal was caused by the normalization process used in the conventional AHP. The normalization used in conventional AHP scales each attribute arbitrarily. Schenkerman believed the attribute weights should be adjusted for the arbitrary scaling. Four methods were proposed to make the adjustment. These methods are: (1) referenced AHP, (2) normalization to maximum entry (Belton and Gear, 1982), (3) normalization to minimum entry, and (4) linking pins. Each method uses a different approach for eigenvector normalization and avoids rank reversal by undoing the arbitrary scaling effects of normalization. Schenkerman discussed the linearity assumption inherent in the methodology for the conventional AHP. He stated "An additive value function exists only if the criteria are pairwise preferentially independent, that is, if and only if each marginal rate of substitution is independent of the levels of all other criteria." He claimed that often, this assumption is not valid.

Vargas (1994) responded to Schenkerman (1994) and discussed the "rank invariance principle," which is the belief that once the ranking of a set of alternatives is obtained, it should forever remain the same. Vargas disagreed with this belief and claimed that this was the basic belief of utility theorists. Vargas believed the problem with Schenkerman's approach was that "his methods of arithmetizing absolute measurement are not directly applicable to relative measurement." Absolute measurement is a result of setting an agreed upon measurement units and method. When no measurement units exist, as with intangible attributes, relative measurement is the only alternative. Vargas pointed out that the basic fundamental difference between AHP and Utility Theory is that Utility Theory needs tangible criteria and AHP does not.

3.2.4.3 Sensitivity Analysis

Triantaphyllou and Sanchez (1997) presented a methodology for performing sensitivity analysis on the weights of the decision criteria and the performance values of the alternatives expressed in terms of the decision criteria. They demonstrated this methodology on three widely used multi-criteria decision models, including the weighted sum model (WSM), the weighted product model (WPM), and the AHP. The first problem that they researched was how to determine the most critical attribute in the decision problem. The most critical attribute was defined in two ways. The first definition was based on if the attribute has the power to change the top alternative. The second definition was based on whether the attribute has the power to change the ranking of any alternative. Their proposed sensitivity analysis examined the impact of changes in the weights of importance of the attributes and the measures of performance of the alternatives in terms of a single decision attribute at a time on the final ranking of the alternatives. Triantaphyllou and Sanchez concluded that the choice of the multi-criteria decision model or the number of alternatives had little influence on the sensitivity results. The most sensitive attribute was the one with the highest weight, if weight changes are measured in relative terms ,and it is the one with the lowest weight, if changes are measured absolute terms. Another conclusion was that the number of decision attributes is more important than the number of alternatives. They recommend that sensitivity analysis conducted at an early stage of the problem can reveal the attributes that have a tendency to be more critical to the final decision.

3.2.4.4 Group Consensus and Consistency Measurement

Islie and Lockett (1988) addressed the problems with the meaning of consistency and large data requirements by presenting a new method of calculating preference vectors. This method made the data requirements "less onerous" and provided feedback permitting a greater understanding of the data inputs. Their method of calculating preferences was based on minimizing least square deviation. Islie and Lockett suggested that:

1. the requirement of providing all entries in the upper right triangular half of the paired comparison matrix was very demanding on the decision-maker,
2. Saaty's definition of a consistency index/ratio provided a crude measure with limited statistical properties, and
3. it was arguable whether empirical evidence justified the assumption that judgements were reciprocal in real life situations.

They claimed that their method, referred to as the Geometric Least Square (GLS) method, overcame these problems. The GLS method involved development of linear equations to describe the relationships in the paired comparison matrix with a normalizing constraint that the weights of all attributes sum to one. The GLS method used successive input data to compute a Standard Error of Attributes which was used as a measure of consistency. The decision-maker could stop the analysis at any point that the results are believed to be satisfactory.

Khorramshahgol and Moustakis (1988) integrated the Delphi Method with the AHP to assist decision-makers in systematically identifying the organizational objectives and then setting priorities for the objectives. The Delphi method, a systematic procedure for acquiring expert opinions iteratively, was conducted prior to the AHP. The participants in the Delphi procedure were provided with specific task statements that asked them to list attributes to be considered in a decision problem. Three rounds of attribute weighting were conducted. The final weights for the attributes were determined by multiplying the percent of participants who favored the attribute by the average weighting across all three rounds. A final Delphi procedure was used to obtain the pairwise comparison matrix for the top five weighted attributes. The individual value judgments provided by the participants were averaged to determine the overall pairwise comparison matrix.

Saaty and Marino (1979) found the mean inconsistency for samples of 500 randomly filled matrices of various sizes of attributes. Saaty recommended that inconsistency should be less than ten percent of the mean inconsistency. The inconsistency ratio, which is the matrix's mean inconsistency divided by the mean random inconsistency should also be less than ten percent according to Saaty. They suggest these hypotheses regarding AHP matrices:

H_o: The decision-maker's choices are random.

H_1: The decision-maker's choices are not random.

Alpha levels can be chosen based on the decision problem. Minimizing a type I error with the smallest possible alpha verifies that the decision-maker's choices are non-random. A type II error requires the decision-maker to provide more consistent importance ratios. Lane and Verdini (1989) investigated the distribution of random inconsistency and decision rule implications. They generated null distributions (distributions that are correct if the null hypothesis is correct) of the test statistic to find critical values (inconsistencies below which the null hypothesis can be rejected). Their findings suggested that stricter consistency requirements should be used for three- and four-attribute criteria matrices. They provided acceptable consistency values based on the quantity of attributes and the desired alpha level. For five or more attributes, Saaty's rule of thumb of ten percent is stricter than the statistical-rationale rule with alpha = 0.01 and they recommend keeping Saaty's rule.

Carlsson and Walden (1995) discussed the inability of a decision support system to have any influence on political decisions. They described a decision problem that involved the determination of a new ice hockey arena. A group of local administrators used the AHP to determine the best location for the arena. Despite the use of a structured AHP method, the decision-makers selected the third ranked site. Carlsson and Walden concluded, "in politics, the natural outcome is either a negotiated compromise or a bargain for future favors, which the various factors reach with the help of short or long-term alliances." Their conclusion was that rationality, logical consistency, optimality, and systematic evaluations with multiple criteria carry little weight in the political arena.

Madu and Kuei (1995) developed a method for generating invigorating debates on an issue before weight assignments are made. This method overcame some of the subjectivity of group decisions and put more emphasis on the stability and reliability of group decisions. The method used replication and quality confidence intervals. The individual judgments of the decision-makers were plotted on control charts with confidence intervals calculated at the 95% confidence level. Those decision-makers with priority indices outside the confidence levels were identified and asked to lead the discussion in determining the source of the variation. The presence of outliers in the attributes suggested the need for further discussions to share ideas and understand the sources for these disagreements. The outliers were not necessarily bad, and may have indicated that a decision-maker had privileged information other decision-makers may not have.

After discussion, new weights were assigned and the process continued. If all priorities fell within the confidence levels after three iterations, the process was repeated one more time. This iteration was conducted to ensure the ranking of attributes was still stable and that outliers did not exist. If stability was not achieved after three iterations, the arithmetic mean of all of the decision-makers' priorities was used. The concept was that the learning associated with the discussion about variation helps to improve the quality of group decision making process.

Bryson (1996) proposed a method for using consensus relevant information embedded in the preference data to assess the current level of group consensus and to support the process of consensus building. He offered a set of similarity measures and consensus indicators that can be used by the group process facilitator to develop strategies for increasing the level of group consensus. He explored the possibilities of using consensus relevant information embedded in the preference data. He proposed that facilitators of group decision-making processes should use these measures and indicators to increase the level of group consensus.

The three indicators to estimate the level of group consensus were: 1) group strong agreement quotient, 2) group strong disagreement quotient, and 3) group strong disagreement indicator. Each of the indicators required the use of a similarity function that enabled assessment of the level of agreement between pairs of preference vectors. Threshold values for strong agreement and strong disagreement were specified. Similarity values for individuals were compared to the threshold values. The similarity values for a pair of vectors were estimated by euclidean distance, L-1 norm distance, the cosine, sine, and angle between vectors.

Bryson defined two main types of influences on group behavior: 1) informational influence, and 2) normative influence. Informational influence was based on acceptance of evidence from others as evidence about reality. Normative influence was based on the desire to conform to the expectations of the group. Bryson claimed that in face-to-face meetings, preference tasks are more affected by normative influences. Electroncially mediated communications reduced the effects of individual status and normative influences.

Basak (1997) developed a method for determining whether or not various groups of individuals are alike in judgments. Basak offered an approach for forming clusters of homogenous groups when groups are not alike, and for establishing a particular order of preferences for alternatives in a homogenous group of individuals. The purpose of his research was to develop a rank-based statistical methodology for testing relevant hypotheses in the context of the AHP. Rank-based procedures do not require any assumptions for statistical distributions of the pairwise comparisons.

Finan and Hurley (1997) investigated the possibility of using an artificial means for adjusting the decision-maker's final pairwise comparison matrix to improve the reliability of the weights. They used Monte Carlo simulation to model a decision-maker who picks random judgments out of a distribution centered on his/her true judgment for each element of a pairwise comparison matrix. For each iteration of the simulation, the consistency ratio (CR^k) and the mean square error (MSE^k) of the resulting weightings were calculated. A regression was calculated using the following formula: $MSE^k = a + b$

(CR^k). The results of the simulation indicated that there is a significant positive relationship between the two variables (the estimates of *a* and *b* are positive and significant). In other words, a reduction in the consistency ratio will lead to a reduction in the mean square error, improving the reliability of the analysis. The simulation results suggested that the final consistency ratio could be reduced through artificial manipulation.

Bryson and Joseph (1999) used the AHP in a group situation by aggregating individual priorities into a set of group "consensus" priorities. They presented an integrated logarithmic goal programming-based model (LGPM) for generating the "consensus" priority point vector and contrasted this method to the eigenvector method (EM) and the logarithmic least-squares method (LLSM). The LGPM method does not require that the pairwise comparison matrix be reciprocal, as does the EM method. The LGPM method does not require any statistical computations, as does the LLSM method. The LGPM method is also resistant to the presence of outliers unlike the EM and LLSM methods. The LGPM also provides a consistency indicator for the group data.

Yeh, Lin, Kreng, and Gee (1999) proposed a new method for aggregating group judgments that used the genetic algorithm (GA) and a utility function to synthesize preference weights. The GA is a stochastic searching algorithm, which systematically hops from point to point by way of three operators: reproduction, crossover, and mutation. The search method simulates the laws of natural selection and genetic information recombination within the population. The genetic algorithm procedure involved representation, reproduction, crossover, mutation, and parameter selection. Representation used fixed length binary strings to represent the variables of solutions.

Reproduction was the selection of specific solution strings according to their fitness function value to construct the next generation. Crossover produced the next offspring (solution string) by rearranging the sequence of solution strings. Mutation was implemented to escape the local optimal by randomly changing the chromosome value. The GA was used to derive a set of synthesized weights. Yeh et al. (1999) claimed that their method was a preferred means for synthesizing the decision-maker's preference weights when they are unwilling to accept each other's judgments directly or to reach consensus by deriving the geometric mean of their preference weight.

Zahir (1999a) discussed an algorithm to group individual judgments into natural clusters using a similarity measure. He also developed a method for measuring the cohesiveness of a homogeneous cluster. The main goal of his research was to validate a deterministic and geometrical procedure for group decisions within the framework of the Euclidean Vector space (VAHP). Natural clusters were defined to mean "clusters of individuals formed naturally without being subject to coercion, pressure or artificial means." Zahir specified a "membership parameter" that was used to determine if a decision-maker is included in a cluster or not. The VAHP enabled the analysis of similarities between decision-makers in terms of the scalar product of two preference vectors. If the cosine of the angle between the preference vectors was greater than the specified membership parameter, the two preference vectors were clustered together. A mathematical equation was provided to calculate the "coherence" of a cluster.

Consensus and consistency have been used as surrogate measures for the quality of the decision. Researchers have measured consensus both at the end of the decision process and during the process. Measurement during the process enables group facilitators to assess the level of agreement and determine whether or not additional knowledge about the decision is needed. Various statistical methods have been used to measure consensus and or consistency, including regression analysis, confidence intervals, control charts, hypothesis testing, and comparison of the actual consistency to a desired threshold level. Some researchers have developed techniques to identify clusters of homogenous groups within the larger group of decision-makers to determine consensus.

3.2.4.5 Eigenvector Calculation

Schoner and Wedley (1989) addressed the two related streams of criticism of the AHP relating to: (1) the ambiguity in the meaning of the relative importance of one criterion as compared to another and (2) rank reversal. They analyzed three different methods for generating composite priorities for alternatives. The first approach was referenced as the "conventional AHP" and had no constraints on the interpretation of the relative importance of attributes. The second and third approaches, "referenced AHP" and "Belton-Gear modified AHP," required the relative importance of attributes to be consistent with derived equations. Their research showed that there is a necessary correspondence between the manner in which criteria importances are interpreted and computed and the manner in which the weights of the options under each criterion are normalized. If this relationship is ignored, incorrect weights are generated for alternatives under consideration regardless of whether new alternatives are added or deleted.

With tangible attributes, there is often a need to apply scaling factors to convert measurement on an attribute to units of an objective. Schoner and Wedley (1989) used as an example the need to convert the fuel consumption (gallon/mile) of different cars to fuel cost over the five-year life of each car by applying scaling factors of 5 years and $1.50 per gallon and 10,000 miles per year. The relative importance of an attribute must be proportional to the product of its scaling factor and the sum (or average) of the absolute values of alternative measurements on that attribute. This condition distinguished referenced AHP from conventional AHP. However, rank reversal occurs when the addition or deletion of an alternative causes this proportion to change. The Belton-Gear modified AHP enabled attribute weights to change with the addition or deletion of alternatives, similar to the referenced AHP. The only circumstance where this did not occur was when the alternative which was added or deleted, was not the largest in terms of any of the attributes.

Kumar and Ganesh (1996) presented a simulation approach to compare Saaty's two methods for calculating priorities: (1) the approximate eigenvector method (AEV) and (2) the exact eigenvector method (EEV). They claimed there was a need to evaluate the two methods because the decision-makers using AHP have access only to the nine-point discrete scale, although they are making fine, continuous scale distinctions in their minds. The AEV method is more popularly known as the Geometric Mean Method or Method of Least Squares. Many users of AHP have preferred the AEV due to its computational simplicity. A simulation analysis used the concept of approximating a continuous pairwise comparison (CPC) matrix by its closest discrete pairwise comparison (CDC) matrix. The results confirmed Saaty's theoretical argument that the EEV method is preferred over the AEV for the calculation of priority vectors.

Forman and Peniwati (1998) discussed two different methods for synthesis of individual judgments. They claimed that the choice of method depends on whether the group acts together (aggregating individual judgments as a unit, AIJ) or as separate individuals (aggregating individual priorities, AIP). An example of a group acting together as a unit was a group of department heads meeting to decide on corporate policy. An example of a group acting as separate individuals was representative constituencies with stakes in welfare reform, such as taxpayers. Forman and Peniwati stated that both the geometric mean and the arithmetic mean are appropriate for use when working with ratio scales. The Pareto principal of social choice has been applied in conjunction with the AIP method. The Pareto principal of social choice theory was defined as "given two alternatives, A and B, if each member of a group of individuals" prefers A to B, then the group must prefer A to B. Forman and Peniwati claimed that neither the AIP or the AIJ violate the Pareto principal. However, they made the point that the AIJ loses individual judgments and identities with each stage of the aggregation, beginning with the establishment of the hierarchy. Since individual priorities are irrelevant, they claim that the Pareto principal is irrelevant. Further, since the group becomes a new individual, the reciprocity requirement for the judgments must be met. This implies the geometric mean rather than the arithmetic mean must be used with the AIJ. Forman and Peniwati also discussed the use of the weighted geometric mean or weighted arithmetic mean when group members are not equally important due to variances in expertise, experience, previous performance, persuasive abilities, effort on problem, etc.

Basak (1998) proposed a new approach for eliciting and synthesizing expert assessments for an AHP group decision process. His method is applicable to any type of scale used in the AHP and involves a seven-step process to pool the opinions of experts. Bayesian methods were used to synthesize the opinions of the experts. The updated probabilities for specified intervals were input into a Monte Carlo simulation, which generated a set of pairwise comparison matrices. The generated matrices were held to a maximum inconsistency ratio of 0.10. A priority vector was estimated for each matrix using the logarithmic least squares regression technique. An overall vector was estimated based on the set of matrices, which produced frequency distributions of the ranks of the alternatives. Hypothesis testing was used to determine the significant order of preference for the alternatives.

Researchers have examined various techniques for enhancing the eigenvector calculations. Application of scaling factors when using tangible attributes was claimed to be a necessary component to eliminate the effects of rank reversal when adding or deleting alternatives. The question of whether to use an arithmetic or geometric mean was addressed from the perspective of the Pareto principal of social choice. It was concluded that either arithmetic or geometric means could be used without violating the Pareto principal. Additionally, Monte Carlo simulation was used to generate a set of pairwise comparison matrices and an overall priority vector for the set of matrices, which produced statistical distributions of the ranks of the alternatives.

3.2.4.6 Integration with Electronic Meeting Technology

Increasing numbers of organizations are using computers to support face-to-face meeting. However, the rate of adoption of tools, such as group support systems (GSS), group decision support systems (GDSS), or electronic meeting systems (EMS), to facilitate these meetings has decreased (Grise and Gallupe, 1999). Grise and Gallupe claimed that the reason for the reduced adoption rate is the lack of knowledge of how to properly use these tools. They studied the problem of information overload within the context of an idea-organization task in a face-to-face electronic meeting facilitated using electronic brainstorming, a GSS tool. Their belief was that real GSS gains in effectiveness could be made only if the problem of information overload in group meetings is studied and managed. They claimed that "information overload is fueled by the increased communication capabilities of computers and accelerated by people's limited information-processing capabilities."

Using integrative complexity theory as the theoretical foundation, Grise and Gallupe (1999) developed an information overload model for group support systems. Integrative complexity theory considers how people process information, the mental structures that aid processing, and the situational characteristics that influence processing. The information overload model represents how GSS tools should be designed based on a theoretical understanding of information processing, particularly under conditions of high stress. They used the National Aeronautics and Space Administration Task Load Index (NASA-TLX) mental workload measurement tool to determine mental workload for their experimental tasks. Grise and Gallupe (1999) concluded that people experience information overload in electronically facilitated meetings and found that the information overload is dependent on not just the flow of information and ideas, but on the task domain itself.

Expert Choice is decision support software based on the AHP. Expert Choice 2000 was released in June, 2000 by Expert Choice, Inc. (Expert Choice 2000 Product

Brief, 2000). The Expert Choice software provides an interactive capability to build the AHP hierarchy, guide the decision-makers through a series of pairwise comparisons, incorporate any type of quantitative or qualitative performance data for the decision problem, combine and synthesize the judgments of any subset of decision-makers or the entire group to provide a full spectrum of different perceptions of the problem. Using Expert Choice, pairwise comparisons can be made three different ways:

1. Verbal - Decision-makers compare hierarchical elements for their relative importance and alternatives for their relative preferences using words (Equal, Moderate, Strong, Very Strong, and Extreme).

2. Numerical - A nine point numerical scale is used to define the relative importance of the hierarchical elements.

3. Graphical - Judgments are made by adjusting the relative length of two bars until the bars represent how much more important one element is to the other.

An alternative method for evaluation is to use a data grid feature to create one of the following scales to prioritize each alternative:

1. Ratings - This is used to rate alternatives using descriptors such as Excellent, Very Good, Good, Fair, and Poor. This is often used for subjective aspects of an evaluation or when there is no hard data. Pairwise comparisons are used to develop ratio scale priorities for the rating descriptors.

2. Step Functions - A step function is similar to ratings in that it consists of a scale of priority intensities. However, the step function translates the data into the appropriate rating intensity for each alternative.

3. Utility Curves - Utility curves translate data into priorities. As opposed to the step function, which is discrete, the utility curve is continuous.

4. Direct - This is used to enter priorities directly.

Expert Choice also provides sensitivity analysis to enable what-if testing of the selected alternative to changes in priorities of the hierarchical elements.

In addition to Expert Choice software, other decision support software systems have been coupled with AHP to increase the effectiveness of the AHP methodology. Choi, Suh, and Suh (1994) applied the AHP in a real world group problem using Group Decision Support Systems (GDSS). The decision problem was to select a city as a new provincial seat for South Korea. The decision problem was delicate and political, and required a fair and rational selection methodology. They concluded that integrating AHP into existing group communication-aid tools or electronic meetings would elevate the effect of AHP. AHP was identified as the selection methodology because it can absorb the opinions of many decision-makers, it can generate a common conceptual model, and it has objective mathematical analysis techniques. Important GDSS functions were identified as: (1) time saving, (2) removing communication barrier, (3) providing more information, (4) equal participation of members, (5) conflict resolution, (6) supporting problem identification/analysis, (7) reducing group discontent, (8) providing techniques for structuring analysis, and (9) agenda setting.

3.3 Analytic Hierarchy Process Applications

Zahedi (1986) reviewed the AHP and its applications in diverse decision problems. At that time, Zahedi stated that "the AHP, for the most part had remained outside the mainstream of decision analysis" because it was not firmly rooted in utility theory. Zahedi went on to claim that "the practical nature of the method, suitable for solving complicated and elusive decision problems, had led to applications in highly diverse areas and has created a voluminous body of literature." Table 10 presents taxonomy of AHP applications. It is apparent that the AHP lends itself to a variety of decision problem topics, which occur in the manufacturing, governmental, and service sectors. The focus of this section is to describe applications of the AHP in decision problems related to economics, planning and project selection.

Table 10. Taxonomy of AHP Applications (Zahedi, 1986).

Decision Problem Topics
Economics and Planning
Energy (policies and allocations of resources)
Health
Conflict Resolution. Arms. Control. and World Influence
Material Handling and Purchasing
Flexible Manufacturing Systems
Manpower Selection and Performance
Project Selection
Marketing
Database Management System Selection
Automation of Office Systems
Microcomputer Selection
Budget Allocation
Portfolio Selection
Model Selection for Cost-Volume-Profit
Accounting and Auditing
Education
Politics
Subjective Probability Estimation and Cross Impact Analysis
Sociology
Interregional Migration Patterns
Behavior Under Competition
Environment
Architecture
Measuring the Membership Grade in Fuzzy Sets

3.3.1 Applications in Economics and Planning

Liberatore (1988) presented an application of the AHP that linked research and development (R&D) project selection with business strategy. They explained that the selection of R&D projects was concerned with the allocation of scarce resources, such as funds. manpower, and facilities. The AHP enabled the recognition and incorporation of the R&D manager's and supporting staff's expertise and knowledge. It also allowed the structuring of relationships between objectives, selection criteria, and project proposals.

Armacost, Hosseini, and Javalgi (1990) used the AHP for small business decision making. They believed the AHP provided the capability to accommodate some of the behavioral and political factors that influence the decision process. Their application involved the evaluation of alternative banks by consumers (level 1). Nine level 2 attributes were selected based on a literature review and on a two-stage focus group involving thirty randomly selected bank customers, bank managers, and administrators. The level 2 attributes were location, safety of funds, Saturday banking, paying highest interest rates on savings, overall quality of service, reputation, availability of loans, ease of qualifying for a free checking account, and low interest rates on loans. Level 3 was the decision alternatives, the three choices of banks.

Saaty's nine-point scale was used to make the pairwise comparisons of attributes with respect to the selection of a bank. A questionnaire was used to obtain the values of the pairwise comparisons for individual respondents. In completing the questionnaire, respondents indicated a reciprocal importance by using a minus sign (i.e., -7 meant 1/7). The questionnaire was sent to approximately 400 randomly chosen customers of the three alternative banks. Customers used the questionnaire to estimate the preferences of the three alternatives to the attributes. Complete responses were received from 87 customers. A microcomputer software program calculated the geometric means of the 87 individual responses and used the eigenvector method to determine the priorities of the alternatives. Consistency ratios for all comparisons in the hierarchy were less than 0.1 for the combined judgments of the 87 respondents.

Arbel and Orgler (1990) described an application of the AHP methodology to evaluate bank mergers and acquisitions (M&A) strategy. The hierarchy developed for this application included four levels with the focus, or main objective, of "increasing shareholders net worth." The second level of the hierarchy included the decision-makers. or the "actors," who were members of the board of directors. The third level included the environmental scenarios (e.g., expanding economy with little competition, expanding economy with strong competition). The forth level included the actors' objectives and concerns (e.g.. obtain core deposits that are characterized by stability and low costs compared to wholesale sources, reduce costs through economies of scale). The last level of the hierarchy represented the specific policies to be evaluated and implemented in the M&A strategy (e.g., organizational structure, type of institution, location, financial status, ownership, size compared to acquiring institution). Arbel and Orgler (1990) concluded that the application of AHP to the selection of M&A candidates, and the impression of the bankers who participated, was "that the technique provided a useful, flexible, and powerful tool for solving a large variety of complex and ill-defined bank strategic issues."

Liberatore, Monahan, and Stout (1992) used the AHP to structure a capital investment decision hierarchy. Three approaches were used to structure the AHP hierarchy including:

1. assume that business strategies do not need to be stated explicitly in order to develop a appropriate set of evaluation criteria,

2. utilize a specific planning theme or methodology in the construction of the hierarchy, and

3. develop a hierarchy based on the mission, objectives, and strategy (MOS) framework for strategic planning,

The MOS approach was recommended because it had the widest application in industry. The AHP within the MOS planning environment promoted full management participation in the decision process and improved communication at all levels of the organization. Also, the AHP within the MOS framework was found to be effective in linking capital investment decisions to strategy.

Bagchi and Rao (1992) used the AHP to rank a set of potential acquisition candidates against a multivariate set of attributes. The AHP was selected because: (1) it ensured that due consideration was given to as many relevant factors as deemed important, (2) the factors were consistently applied across all prospective merger candidates, (3) it allowed decision-makers to determine the important factors and their relative importance, (4) multiple viewpoints (stakeholders) were integrated into the decision-making process, and (5) it was easy to use. Bagchi and Rao (1992) developed a hypothetical illustration of the AHP. The goal (level 1) was to rank the merger/acquisition candidates on the basis of their potential to create value to all concerned stakeholders. Level 2 consisted of the four distinct stakeholders and included shareholders, management, employees, and creditors. Level 3 was the various criteria each stakeholder considered important in assessing the desirability of a potential merger candidate. These criteria consisted of financial characteristics, growth potential, labor environment, competitive strength, organizational fit, relative size, and industry commonality. Level 4 was the pool of candidates who were evaluated. Bagchi and Rao concluded that the AHP provides a decision framework that minimizes potential mistakes because it forces decision-makers to identify and consider all relevant factors and it provides a means for consistent application of the factors across all alternatives.

Moutinho (1993) used the AHP for corporate goal setting and goal assessment. The main objective of the hierarchy was defined as "company effectiveness." Five types of corporate goals (market share, return on investment, profit, sales volumes, and company image) defined the first level in the hierarchy. Seven types of goal-assessment/corporate control tools (management meetings, financial statements, ratio analysis, control sheets, systematic monitoring procedures, customer input data, and market analysis) were defined as the next lower level of the hierarchy. The AHP enabled the development of priorities for each management control tool used to rate the corporate goals.

Tuominen and Sierila (1993) presented a Finnish study of different strategic courses of action concerning the forest industry. AHP was applied to evaluate several strategies and to synthesize qualitative and quantitative factors used in the decision making process. The main objective in the AHP hierarchy was "the well-being of forest industries." The first level of the hierarchy was critical success factors (demand by products, raw materials, energy, technology, human resources, financial resources and development in society). The second level included critical success sub-factors for each critical success factor (e.g., domestic wood, imported wood, and other raw materials for the factor of raw materials). The lowest level of the hierarchy represented the strategy alternatives (forest profile strategy, resource strategy, paper sector strategy, and value-added strategy). The AHP enabled conclusions concerning the strategic course for the Finnish forest industry and sensitivity analyses revealed how the preferences for strategy alternatives change as the importance of the critical factors varied.

Barbarosoglu and Pinhas (1995) described an integration of the AHP with mathematical programming for a capital rationing decision. A sum of money had been given to the Istanbul Water and Sewerage Administration to allocate among several water provision and waste water projects. The AHP was used to determine the weights of all quantifiable and non-quantifiable factors, and to determine the relative priorities of the proposed projects. A mixed integer linear model was formulated to determine the multi-project schedule over a 15-year planning horizon. The model was used to determine the projects to be undertaken each year so as to maximize the total priority score of the decision-makers, subject to the financial constraints dictated by the foreign exchange credit limits and other technical constraints.

Korpela and Tuominen (1996) presented a procedure for logistic strategic management. The AHP was used as a decision support system to analyze the impact of emerging strategic issues and trends, and to determine the actions to be taken by the organization in response to the strategic issues. Three AHP hierarchies were used to analyze how the impacts of the strategic issues develop over time: one for short term (1 year), one for medium term (1 – 3 years), and one for long term (over 3 years). Priorities for the issues were based on multiple criteria related to impact and urgency. Once top priority issues were identified, the AHP was used to prioritize responses to address the issues.

Radasch and Kwak (1998) presented an integrated quantitative model for offset, industrial participation or countertrade, and planning. Countertrade is a commitment associated with a sale where the seller will provide the buyer with an offsetting agreement to purchase other products. Decision-makers applied the AHP to assess the individual preferences of the buying country's and selling company's goals. These assessments were used to formulate a goal-programming model. The AHP was used to define priorities and weights to assign to the goal programming objectives. Radasch and

Kwak (1998) integrated AHP with goal programming because it reduced the required information and ensured a feasible solution within requirements.

Israeli. Mehrez, Bochen, and Hakim (1998) used the AHP to evaluate global positioning systems technology (GPS) for the Israeli Defense Force (IDF) and proposed it as an alternative to traditional military and governmental purchasing methods. The main objective of the decision problem was to identify the best alternative for a GPS purchase decision. The first level of the hierarchy was the primary criteria for system evaluation: technical. operational, and economic criteria. The next lower level of the hierarchy was the subcriteria for each of the primary level criteria. Experts in each of the three primary criteria levels identified the subcriteria. This resulted in the identification of a third level, subcriteria for the subcriteria. Three different GPS alternative units formed the last level of the hierarchy. Israeli et. al (1998) concluded that the AHP translated a variety of user and system requirements into an effective purchasing decision.

In some cases, the AHP was used exclusively for decision processes related to planning and economics. In other cases, the AHP was used in association with other techniques. such as the MOS framework, for strategic planning or to establish the weightings for the goal programming objectives. In all of these applications. the AHP was able to incorporate qualitative and quantitative factors. and to accommodate some of the behavioral and political factors that influence the decision process. The example applications revealed that AHP is an international tool.

3.3.2 Applications in Project Selection

Muralidhar, Santhanam, and Wilson (1990) also applied the AHP to information systems project selection. They used qualitative and quantitative criteria including (1) increased accuracy in clerical operations, (2) information processing efficiency, (3) promotion of organizational learning, and (4) implementation costs. It was concluded that the AHP was easy to use, realistic, and flexible.

Brenner (1994) described an application of the AHP to prioritize proposed research and development (R&D) projects. They used the AHP to identify and build consensus around the key factors for success, communicated these factors to improve project proposals, and helped to extend limited funding to maximize project progress and completions. The proposed project's strengths and weaknesses were clearly identified by using profiles of the project rating for each factor. Only consistent sets of projects were put through the process (i.e., development projects). Projects were assigned a total score and projected staffing and costs, providing a clear picture of the priorities and resource requirements.

Alidi (1996) used the AHP to measure the initial viability of industrial projects for an Inter-Arab Gulf industrial investment company. A dialogue was developed with all groups involved in the development of industrial projects, including members of the company's board, shareholders and other governmental and public organizations. The dialogue enabled the gathering of a variety of strategic and tactical information and ensured that many points of view were considered. Significant financial and human resources were required to conduct feasibility studies. A determination of the initial viability of projects produced a ranking, which allowed for an efficient use of resources.

Raju and Pillai (1999) used five mulitcriteria decision-making methods (MCDM) to select the best reservoir configuration for the case study of Chaliyar river basin in Kerala, India. The methods included the AHP, ELECTRE-2, PROMETHEE-2, Compromise Programming (CP), and EXPROM-2. The Spearman rank correlation coefficient was used to assess the correlation among the ranks produced by each MCDM method. It was determined that the Compromise Planning was best suited for the case study based on consistency of results, robustness of results, strength of the efficient solution and confidence of results. The AHP was selected as the MCDM method most suitable for ranking the reservoirs.

Mamaghani (1999) applied the AHP for ranking alternative courses of action for information systems project evaluation and selection. He recognized the significance of the information systems planning function, stating that it is tasked with envisioning the needs of the organization and allocating resources to respond to those needs. Over time, the decisions made by the planning function reflect the organization's project portfolio. Mamaghani (1999) stated that the efficacy of the planning process determines how well the project portfolio reflects the overall corporate goals. The AHP was found to be valid, flexible, easy to apply, and did not overlook any significant evaluation factor.

As a project selection tool, the AHP provided a structure for dialogue about the project selection criteria and for building group consensus. It served as an easy to use, realistic, and flexible tool for determining project rankings in order to allocate and extend limited funding.

3.4 Knowledge Management

The quality of group organizational decisions made through techniques such as the AHP can be affected by the degree to which knowledge is managed. Davenport and Prusak (2000) believed that knowledge is not neat or simple. Their definition identifies the characteristics that make knowledge valuable and difficult to manage. Their definition of knowledge is:

> "Knowledge is a fluid mix of framed experience, values, contextual information, and expert insight that provides a framework for evaluating and incorporating new experiences and information. It originates and is applied in the minds of knowers. In organizations, it often becomes embedded not only in documents or repositories but also in organizational routines, processes, practices, and norms."

Aspects of knowledge management that are significant to AHP implementation include knowledge generation and transfer, knowledge roles and skills, and enabling technologies for knowledge management. Knowledge management is significant to the application of the AHP with a group of decision-makers because each participant in the group has a different set of knowledge about the decision. The quality of the decision may be impacted by the ability to pool the shared knowledge of all participants.

3.4.1 Knowledge Generation and Transfer

Davenport and Prusak (2000) emphasized that knowledge is as much an act or process as an artifact or thing. Knowledge generation was defined as knowledge acquired by an organization as well as that developed within the organization. They considered five modes of knowledge generation: acquisition, dedicated resources, fusion, adaptation, and knowledge networking. Knowledge acquisition can occur through buying organizations or hiring individuals that have it. An organization that acquires another firm for its knowledge is buying people because knowledge exists in people's heads. Of course, some structured knowledge may exist in document or computerized form. Knowledge through dedicated resources occurs when an organization establishes units or groups specifically for the purpose of developing new knowledge (e.g., research and development departments). Knowledge generation through fusion occurs when people with different perspectives are brought together to work on a problem or project with responsibility to develop a joint answer. Adaptation occurs when organizations have to respond to external or internal changes (e.g., new products from competitors). An organization's ability to adapt is based on whether it has existing internal resources and capabilities to digest and develop new knowledge and it is open to change. Lastly, network knowledge generation occurs when informal, self-organizing networks develop within an organization. Over time the network may become more formalized. Communities of knowers transfer knowledge by sharing expertise and solving problems together.

London (1975) investigated the effects of heterogeneous and homogenous groups in participative group decision making. The study involved examination of Wood's three stages of decision making which are generation, evaluation, and choice of alternatives (Cooper and Wood, 1974; Raben, 1973; Wood, 1970, 1972a, 1972b, 1973). Three models which involved subjects in some or all stages of decision making (participation effect) were combined with heterogeneous versus homogeneous group conditions (information effect). In the heterogeneous-information condition, each subject received information about the decision from the perspective of only one of three existing stakeholder perspectives. In the homogeneous-information condition, each subject received information about the decision from all three stakeholders' perspectives. The dependent variables of the experiment were the quantity of decision alternatives generated, the quality and uniqueness scores for the alternatives selected, the overall favorableness of group atmosphere, and peer ratings of effectiveness and influence.

The study found that the only significant factor for the standard deviations of group uniqueness scores for alternatives selected was the participation and information interaction. The main effect of level of participation had no affect on the quality and quantity of sites generated. The results showed that overall favorableness of group atmosphere and peer ratings of effectiveness and influence were greater in homogeneous groups than in heterogeneous groups. Perceptions of interpersonal influence were greater in homogeneous groups than in heterogeneous groups in the model involving the alternative generation and evaluation condition. Heterogeneous groups in the alternative generation and evaluation condition perceived the external group influence to be greater than did the homogeneous groups in the same condition. Perceptions of interpersonal relations were more favorable in the heterogeneous groups than in homogeneous groups in the generation only condition.

Stout, Cannon-Bowers, Salas, and Milanovich (1999) examined the extent to which planning behaviors in a team can foster shared mental models (SMMs). SMMs are thought to support team performance by providing team members with a common understanding of who is responsible for what task and what the information requirements are. The study findings indicated that members of teams that engaged in high-quality planning were able to: (1) form greater SMM of each team members' information requirements, (2) pass information to each other in advance of explicit requests for this information during high workload periods, and (3) make fewer errors during high workload periods.

Stasser and Titus (1987) examined the effectiveness of group discussion as a mechanism for information exchange. They made the distinction between shared information and unshared information where shared information is available to all members of a group before discussion and unshared information is available to only one member. Discussion can potentially serve an educational function when unshared information exists; members can leave a discussion with more information than they had before the discussion. However, in a previous study, Stasser and Titus (1985) found that post-discussion recall of information by group members raised doubts about whether discussion does in fact serve an educational function.

In their 1987 study, Stasser and Titus considered how the transmission of information during discussion was affected by the amount of information available for discussion and the degree to which this information was shared before discussion. They were interested in determining not only if members acquire new information through discussion, but also whether discussion tends to bias recall. Their findings showed substantial increases in the recall of unshared information only when most of the information was unshared before discussion. However, the chance of recall was small (24%) for a member who did not receive it before discussion in the low-load condition. In contrast, members in the low-load condition recalled after discussion almost half of the information that they had received before discussion. In the high-load condition, an item of unshared information had only an 8% chance of being recalled by a member who did not receive it before discussion. However, members in the high-load condition recalled after discussion one-third of the information they had received before discussion.

None of the groups appeared to have been very effective in disseminating unshared information. The recall of information also tended to be biased in favor of a group's choice. The bias was present before discussion and was exacerbated by discussion. Stasser and Titus (1987) concluded that face-to-face, unstructured discussion while trying to reach a consensus is a poor way for members to inform one another of previously unconsidered information. Much of discussion is devoted to reiterating already shared information. Information that is exchanged is biased toward confirming members' prior preferences and does not give members a more adequate and representative picture of the decision alternatives.

3.4.2 Roles and Intra-Group Relations

Lichtenstein, Alexander, Jinnett, and Ullman (1997) examined the proposition that greater diversity of team member characteristics and larger team size negatively affected members' perceptions of team integration. They recognized the importance of having a greater variety of inputs when solving organizational problems as the nature of products and services grows and becomes increasingly more complex and dependent on different technologies. They also cited findings from Kaiser and Woodman (1985) stating that in service fields, such as health care, interdisciplinary teams are perceived to be superior to individuals in assessing and solving client problems and protecting against individual errors in judgment. Their research involved 124 psychiatric units in 29 United States Department of Veteran Affairs hospitals. Data were gathered through a questionnaire. The dependent variables were related to an individual team member's perceptions about the level of integration achieved by the team on the three dimensions of role clarity on the team, participation on the team, and perception of overall team functioning. The individual level independent variables included age, gender, occupation, number of years in current position, and number of years in the Veteran Affairs system. Team-level dependent variables included the coefficient of variation of group VA tenure and position tenure.

Their findings revealed that the strongest effects of team mix were on overall team functioning. Moderate support was found for the role clarity dimension, and only limited support was observed for the individual participation dimension. They found that as teams become more diverse along most identity and organizational group characteristics, intergroup relations among team members suffer and perceived level of team integration declines. However, they indicated that it would be erroneous to conclude from their findings that teams with a more varied mix of member characteristics will be associated with lower levels of team performance. They claimed that although diverse groups may be non-cohesive, fraught with conflict, and incapable of making a decision quickly, they may create positive outcomes. They recommended varying team membership characteristics along certain key dimensions such as occupation and race, but maintaining homogeneity along dimensions such as age, tenure, or corporate division. They also suggested that steps be taken to decrease the permeability of the team's boundary by addressing two common problems in unbounded systems: (1) the dysfunctional, unconscious basic assumption made by team members about members of other organizational and identity groups, and (2) the existence of multiple personal beliefs or theories that team members use to understand and explain what occurs within the group.

Sniezek (1992) examined confidence in decisions made by groups under uncertainty. She defined confidence as "beliefs about the goodness of one's judgments or choices that can be expressed by subjective ratings or subjective probabilities about the likelihood of events." Her research addressed two features of decision-making tasks by groups. The first feature involved members of a group sharing the objective of maximizing the quality of their decision with respect to some identifiable criterion. The second feature involved groups operating under uncertainty about which alternative is superior throughout the task. She stated that disagreement within the group is often guaranteed by the deliberate creation of heterogeneous groups. Her previous research (Sniezek and Henry, 1990) showed that disagreement is greater if group members form their own judgments independently prior to the initiation of group discussion, than if they do so following some interaction. She stated that disagreement within a group provides an opportunity for enlarging the domain of information processed and has the potential to lead to information processing that reduces confidence and make the group more realistic. Her findings showed little difference between group and post-group individual judgments, suggesting that an assessment of decision quality by the group is accepted by each member at the time it is expressed. She found that insufficient information processing can create overconfidence in groups just as for individuals. Sniezek also identified social factors unique to groups such as face-to-face discussion and the objective of reaching consensus as contributors to high group confidence.

LePine, Hollenbeck, Ilgen, and Hedlund (1997) proposed that team members' general cognitive ability (*g*) and conscientiousness were key attributes for hierarchical decision-making teams with distributed expertise. They also believed that a conjunctive model where tasks depend on weakest group member was most appropriate for capturing staff members' standing on these attributes. Lastly, they believed that staff attributes interact with leader attributes to determine team performance. They also described teams in organizations today as having low vertical and horizontal substitutability. Low vertical substitutability meant that teams have a hierarchy in which status levels are distinct in terms of position power (i.e., leaders have the final say) and facilitative expertise (i.e., leaders have general knowledge about staff responsibilities). Low horizontal substitutability meant that members have differences in expertise that are not redundant or easily interchangeable. They studied 51 four-person teams performing a computerized decision-making task. Their results indicated that there were no main effects of cognitive abilities or conscientiousness on the part of the leader or the staff alone on team performance. They did find interaction effects between the leader's cognitive ability and the staff's cognitive ability on team performance. Low cognitive ability of either staff or leader neutralizes the other. The same interaction effect was found with conscientiousness. Their overall conclusion was that in hierarchical teams with distributed expertise the team is as strong as the weakest link, provided the leader is not the weakest link.

Stasser, Stewart, and Wittenbaum (1995) recognized the benefit of pooling members' unique knowledge in group decision making, but cited the finding of Stasser, Taylor, and Hanna (1989) that groups often do not benefit from the pooled knowledge because information held by only one member is omitted from discussion. They hypothesized that by assigning members expert roles, implementation of a cognitive division of labor that promotes sampling and using members' unique knowledge. Their research findings indicated that adequate collective sampling of unshared information depends on coordinated information processing, which is based on members mutually recognizing each other's responsibility for specific domains of information. They found that explicit and mutual recognition of expertise at the onset of discussion increased the amount of unshared information and increased the quality of the decision.

3.4.3 Enabling Technologies

Dixon (2000) claimed that organizations may now be addressing the issue of knowledge sharing because of their growing awareness of the importance of knowledge to organizational success or because technology has made the sharing of knowledge more feasible. She stated that one of the great promises of technology is that it can allow people to share knowledge without having to be in the same place. All of the knowledge management systems that she has studied were initially designed as technology systems, but have evolved toward being a combination of technology and face-to-face meetings. One type of knowledge that exists in organizations is "common knowledge." Dixon defined common knowledge as the knowledge that employees learn from doing the organization's tasks. Common knowledge is different from book knowledge or from lists of regulations or databases of customer information. However, she stated that the common knowledge that exists today for most organizations will not solve the problems of tomorrow. Therefore, organizations must continually reinvent and update their common knowledge. This requires them to engage in two types of knowledge activities. The first activity is to find effective ways to translate their ongoing experience into knowledge (i.e., to create common knowledge). The second activity is to transfer that knowledge across time and space (i.e., to leverage common knowledge).

Davenport and Prusak (2000) stated that technology alone will not make a person with knowledge share it with others. They claimed that technology assists in knowledge distribution, but it rarely enhances the process of knowledge use. It also is not particularly helpful in knowledge creation. However, if the organizational culture values knowledge management, technology can expand access and ease the challenge of getting the right knowledge to the right person at the right time. Davenport and Prusak (2000) believe that you may not even know how willing people are to share knowledge through technology until you expose them to the technology and see how they respond.

Nunamaker, Briggs, Mittleman, Vogel, and Balthazard (1996) defined groupware as "any technology specifically used to make groups more productive." Groupware can support knowledge management by improving information access and by changing the dynamics of group interactions through improved communication and through better-structured and focused problem solving efforts. There are many diverse technologies that fall into the definition of groupware (e.g., e-mail, electronic meeting systems, electronic voting, video teleconferencing). One type of groupware, electronic meeting systems, is a network of personal computers, usually one for each participant. Participants use the technology to support both distributed and face-to-face meetings. Distributed meetings occur when participants are geographically or temporally separated. Face-to-face meetings when participants are not geographically or temporally separated. Face-to-face meetings occur in a facility with supporting technology.

Nunamaker, Dennis, Valacich, Vogel, and George (1991) presented research aimed towards developing and using same-time/same-place and same-time/different-place electronic meeting system (EMS) technology. The development research attempted to create improved work methods using EMS technology. The empirical research attempted to evaluate and understand these methods. The research program produced software (University of Arizona GroupSystems) which was installed at EMS facilities at more than 22 universities and 12 corporations, such as BellSouth and Greyhound Financial Corporation. IBM built 36 GroupSystems facilities and had an additional 20 scheduled to be operational by January 1992. The GroupSystems software supports a variety of different tasks. Typically, the Groupware meetings begin with participants generating ideas. As they type their comments, the results are integrated and displayed on large screens at the front of the room. Everyone can see the comments of others, but without knowing who contributed them. Participants build on each others' ideas. The ideas are then organized into a list of key issues. The group can generate ideas for action plan to address the more important issues. Nunamaker et.al (1991) claimed that the result of the meeting is typically a large volume of input and ideas, and a group consensus for further action.

Kiesler and Sproull (1992) compared computer-mediated discussion to face-to-face meetings for group decision-making. They acknowledged advances in computer and telecommunications technology and noted that groups with 2 or 200 or 2000 members in the same building or across the world can "talk" at once or asynchronously. They identified the first level effects of computer technology as the planned efficiency gains or productivity gains that justify an investment in new technology. They identified second level effects as enabling new things that were impossible or infeasible without the new technology (e.g., expanding group membership). The second level effects are constructed by people as their design and use of technology interacts with and is shaped by the technological, social, and policy environment. Although electronic communication helps people get past social and psychosocial barriers, the social context cues that are present in face-to-face meetings are not available. The lack of social cues cause people to feel distant and somewhat anonymous. This can lead to self-centered and unregulated behavior. This same lack of social context cues can reduce social inhibitions in a positive way by encouraging communication across social and psychological barriers.

McLeod, Baron, Marti, and Yoon (1997) studied the impact of computer-based group decision support systems (GDSS) on minority opinions in decision-making groups. One of the benefits of GDSS is that they reduce barriers to participation in group discussion. McLeon et al. (1997) agreed that GDSS provide greater opportunity for minority opinions to be expressed; however, they disagreed with the conclusion of Rao and Jarvenpaa (1991) that GDSS will resulted in greater minority influence of existing majority opinions. They argued that expression of deviant minority opinions should be the greatest when social pressure is lowest because that is when the negative reactions of other are least likely to be felt. They believed that once minority opinions are expressed, their influence will be greatest when social pressure is highest because people pay more attention to each other under this condition.

Their research experiment involved three experimental conditions including face-to-face discussion, identified GDSS discussion, and anonymous GDSS discussion. Fifty-nine groups of four people were randomly assigned to one of the three experimental conditions. They insured someone in each group held a minority opinion for each experimental condition. They measured minority opinion expression by counting the total number of their unshared pieces of information the minorities presented and the number of times they repeated those arguments. They also measured the attention that majority group members gave to the minority members by counting the positive and negative public reactions to the minority individual's arguments. Their results found that minorities expressed their arguments most frequently and persistently when they communicated anonymously through the GDSS. However, minorities received the highest level of positive attention and had the greatest influence on the private opinions of members in the majority and on the final group decision when they communicated face-to-face. They concluded that if the presentation of key unshared information is not accompanied by group attention and acceptance, the information might have little impact on group decision quality. This conclusion directly challenges assertions that anonymous computer-linked communication systems such as GDSS result in both greater minority influence and improved group decision quality.

In summary, there are several considerations for knowledge management in AHP implementation. Homogeneous groups were perceived to be more effective and provided greater interpersonal influence than heterogeneous groups. Groups that engaged in high-quality planning formed greater shared mental models. Face-to-face, unstructured discussion was not found to be an effective way for groups to experience knowledge transfer. Diverse groups may be non-cohesive, prone to conflict, and unable to make quick decisions, but they may create positive outcomes. Disagreement within a group provides an opportunity for enlarging the domain of information processed. Social factors, such as face-to-face discussion and the objective of reaching consensus, contribute to high group confidence. Hierarchical groups with distributed expertise are as strong as the weakest link. Explicit and mutual recognition of expertise at the onset of group discussion increases the amount of unshared information and the quality of the decision. Technology may assist in knowledge distribution, but rarely enhances the process of knowledge use. Computer-based group decision support systems may reduce social inhibitions so that minority opinions get expressed; however, minority opinions receive a higher level of attention when communicated face-to-face.

3.5 Mental Workload Measurement

Eden and Ackermann (1992) define mental workload as "the degree of processing capacity that is expended during task performance." It is affected by the components of information load, namely, task domain, the number of ideas, idea diversity, and time. The amount of mental workload expended during AHP implementation is important because it may affect the quality of the decision produced. AHP implementation methodologies that minimize mental workload are of interest.

Tsang and Wilson (1997) described four common types of mental workload measurement methods: (1) subjective, (2) performance, (3) psycho-physiological, and (4) analytic. Subjective methods measure mental workload by asking operators to rate the level of mental effort they believe is required to perform a task. Performance methods use operator behavior to determine workload. Deteriorated and/or erratic performance may indicate that workload is becoming unacceptable to operators due to the limited processing capability of humans. Psychophysiological models measure changes in the operator physiology that are associated with cognitive tasks. Changes in cardiac, ocular, respiratory, and brain activity are examples of physiological measurements associated with mental workload. Analytic methods involve the use of mathematical, engineering and psychological models to represent mental workload situations.

Tsang and Wilson (1997) stated that subjective methods are the most commonly used due to ease of use. Subjective methods have other strengths, including high face validity and high operator acceptance. The two most popular subjective methods are the National Aeronautics and Space Administration Task Load Index (NASA-TLX) (Hart and Staveland, 1988) and the Subjective Workload Assessment Technique (SWAT) (Reid and Nygren, 1988).

Hart and Staveland (1988) developed the NASA-TLX as a subjective, multidimensional rating technique by which specific sources of workload relevant to a given task can be identified and considered in computing a global workload rating. The NASA-TLX is the result of a three-year research program to identify the factors associated with variations in subjective workload within and between different types of tasks. Hart and Staveland (1988) believed that subjective ratings come closest to tapping the essence of mental workload and provide the most "generally valid and sensitive indicator." The NASA-TLX ranks workload on a given scale for each of six workload related factors. The six factors fall within three categories: (1) task-related scales, (2) behavior-related scales, and (3) subject-related scales. Table 11 provides a definition of the six factors. Two types of information are collected on each factor from the perspective of the rater: (1) its subjective importance as a source of loading for that type of task (its weight), and (2) its magnitude in a particular example of the task (the numerical value of a rating). The average of the six ratings, weighted to reflect the relative contribution of each factor to the workload of a specific task, is the integrated measure of overall workload.

Table 11. NASA-TLX Factors (Hart and Staveland, 1988).

Scale	Definition
Behavior-Related Scales	
Mental Demand	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Demand	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous?
Task-Related Scales	
Temporal Demand	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Subject-Related Scales	
Performance	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration Level	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Hart and Staveland (1988) made several comparisons of the NASA-TLX to SWAT. SWAT requires the performance of a preliminary card-sort by each subject to rank-order 27 combinations of three levels (low, medium, high) of the three factors (time load, psychological stress, and mental effort) with respect to the importance they place on them in their personal definition of workload. Conjoint analysis techniques are used to produce an interval scale of overall workload based on individual differences in workload definition. Subjects rate tasks as low, medium, or high on the three factors of time load, psychological stress, and mental effort. A single rating of overall workload is determined by identifying the position on the interval scale for the combination of values for the three factors. Hart and Staveland (1988) did not believe the key assumption of conjoint analysis (i.e., statistical independence among components) was supported by the data from their experiments. They found that the ratings of Time Pressure, Mental Effort, and Stress were highly correlated; not independent. They also believed that the three factors used in SWAT were not adequate to represent the factors associated with workload for a broad range of tasks. Another criticism of SWAT was its lack of sensitivity in measuring the workload of a specific task, due to the use of the *a priori* biases of subjects about workload to weight scale ratings into a single workload value.

The NASA-TLX workload measurement technique has been used in several areas to provide a subjective assessment of task difficulty. McCann, Royle, Andre, and Battiste (1996) use the NASA-TLX to evaluate electronic navigation aids used by pilots. The pilots rated the six constructs (mental demand, physical demand, temporal demand, performance, effort, and frustration) on a 12 point Likert scale. This measurement showed that the navigation aids significantly reduced workload for the pilots.

3.6 Questionnaire Design

Questionnaire design is significant to this research because some of the data will be collected through questionnaires. Charlton (1993) identified five principles that were adopted as standards for the development of United States Air Force Operational Test and Evaluation (USAF OT&E) questionnaires. The five principles were:

1. An adequate sample size must be employed. Based on a desired sampling error of 10% at 80% confidence, and for a generic population size of 1,000, the recommended sample size is 40 or more ratings or subjects per evaluation area.

2. A parametric rating scale/descriptor set should be used. That is, a balanced, equal-interval scale with normative values should be used so that the data produced will approximate interval as opposed to ordinal data.

3. Questions should be based on narrowly focused evaluation areas. In order to provide good agreement and reliable data, the questions should reflect specific, well-defined tasks or attributes, not broad areas of system performance.

4. A well-defined threshold of acceptance must be identified in advance. The criterion for a positive evaluation should be described in terms of the minimally acceptable distribution of questionnaire responses (e.g., a criterion based on a median score of 5 and 80% of the ratings greater than or equal to 4 on 6-poin effectiveness scale) prior to data collection.

5. Questionnaires should be associated with objective performance measures where feasible. Questionnaire data should not be used as a principal or single method of evaluation without first exhausting other efforts to obtain objective measures and requirements.

Charleton (1996) offered several recommendations for questionnaire techniques for test and evaluation. He outlined a five-step process for creating a questionnaire, which includes these steps and guidelines:

1. Select a questionnaire type from among rating scale, hierarchical, semantic differential, multiple choice, and open-ended questionnaires.

2. Select the response scale and descriptor set which defines the distribution of responses by providing the type and number of allowable answers to

questions. Balanced scales are preferred because they tend to produce distributions that are nearly normal.

3. Word the questions by following rules regarding vocabulary, negatives, double-barreled questions, leading/loaded questions, emotionality, brevity, and relevance.

4. Assemble the questionnaire elements in a complete package to include clear instructions, consistent format, brevity, and appropriate materials such as a cover sheet. Questions should flow from the most general to the rare and unusual. If it takes more than 15 minutes to answer all the questions, consider dividing the questions among two or more separate questionnaires to be administered at different times during the test.

5. Review or pretest the questionnaire by examining question relevance, question wording, and questionnaire format.

A recommendation for summarizing questionnaire data was to use the mode or median versus the average. This is because questionnaire data represents an ordinal or interval measurement scale.

CHAPTER 4

METHODOLOGY

This research evaluated two strategies for knowledge management in AHP implementation. The knowledge management strategies focused on two of the enhancement areas from the literature review: consensus building and integration with electronic meeting technology. The research methodology involved two components. The first component involved an experimental process to collect performance data for three AHP model alternatives. The second component involved the development of an AHP model selection methodology, which made use of the performance data collected through the experimental process. An experimental model was developed to guide the research process.

The experimental model evaluated the effectiveness of using knowledge self-assessment and electronic meeting technology with the AHP to determine if decision-maker judgement quality can be improved without compromising mental workload. Individual and group activities were included in the experimental process. Individual activities were conducted through the use of questionnaires to gather participant demographic data, pairwise comparison judgments, and information regarding the participants' perceived knowledge of the decision problem's hierarchical elements. Group activities were performed using face-to-face communication, facilitated by electronic meeting technology.

The AHP model selection methodology development involved the application of data collected through the experimental process. An AHP model selection decision hierarchy was developed using the cost and quality attributes and sub-attributes that were measured in the experiment. The performance of the AHP model alternatives with respect to cost and quality sub-attributes defined the alternative priority weightings for the sub-attributes in the AHP model selection decision hierarchy.

This chapter describes the methodology that was followed in the assessment and details the participant demographic characteristics, the independent and dependent variables, and the measurement techniques used in the experimental process.

4.1 Overview of Experimental Research Model

The experiment examined several additions to the traditional AHP implementation. These implementations introduced knowledge management strategies to aid in the AHP process, as well as to examine the refinements to decision variables that directly influence a user's choice of the most appropriate AHP model. Figure 3 contrasts the traditional AHP methodology with the methodology used in this experiment. The additions are indicated by the shaded boxes. Five additions were examined including: (1) knowledge management strategies, (2) assessment of consensus as a quality measure, (3) assessment of the quality of the decision based on consistency and consensus, (4) measurement of the cost of the AHP implementation, and (5) introduction of a proposed model to select the AHP model most appropriate for making capital investment decisions considering quality and cost attributes and their sub-attributes.

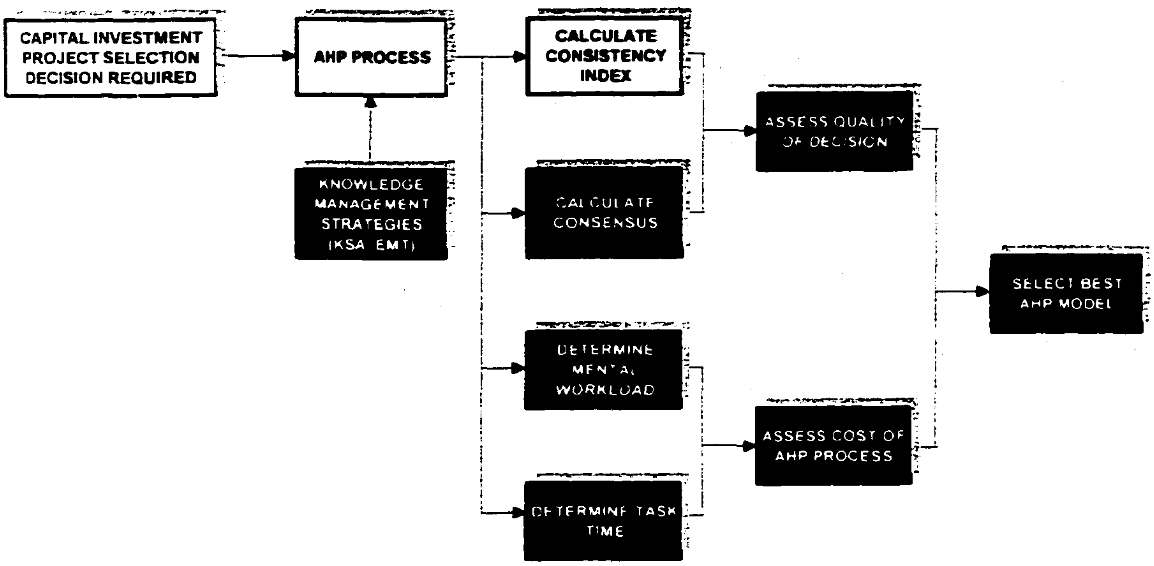


Figure 3. Experimental Research Model.

This research method used the traditional AHP process, referred to as the baseline model, as the control model in the experiment. The knowledge self-assessment and electronic meeting technology models, produced through the introduction of knowledge management strategies, were compared to the baseline in terms of various performance measures. Measures other than group consistency, which is the traditional AHP measurement, were introduced. Group consensus in combination with group consistency was used to assess the quality of the decision. Mental workload and task completion time were used to assess the cost of the AHP implementation model.

The data gathered through the experimental component of this research were applied to the construction of a decision hierarchy for selecting the most appropriate AHP model given specified priority weightings for cost versus quality, mental workload versus task completion time, and group consensus versus group consistency. The evaluation of

AHP group decision models is a unique concept. Previous research related to the implementation of AHP for group decisions has been limited to the measurement of some aspects of AHP performance for a specific AHP methodology. This research compared and contrasted three AHP group decision implementation methodologies with respect to the cost and quality measures. The AHP decision hierarchy objective used in the experiment, a capital allocation problem, is one that organizations are challenged with on a frequent basis. The participants involved in the experimental process are actual managers within a healthcare system and with a healthcare perspective. The research goes a step further by defining a methodology and decision tree for selecting the most appropriate AHP model for prioritizing capital investments, given an organization's specific cost and quality attribute and sub-attribute priority weightings.

4.2 Experimental Variables

Experimental variables included independent and dependent variables. The independent variables were AHP model type, group size, level of responsibility, and decision hierarchy attributes. There was an interest in determining if these independent variables influenced decision quality. AHP model types included baseline, knowledge self-assessment, and electronic meeting technology. Group sizes of five and seven were examined. Levels of responsibility included Vice President and Non-Vice President. The dependent variables were the aggregate group consistency index, pairwise comparison variances, mental workload, decision hierarchy factor weightings, and task completion time. The aggregate group consistency index and pairwise comparison variances were used to measure decision quality. The aggregate group consistency index is the primary measure of AHP decision quality and incorporates the concept of making logical decisions. The pairwise comparison variance measures group agreement. Mental workload and task completion time were use to measure resource cost. Mental workload measured the mental effort. Task completion time measured staff time consumed. AHP attribute weighting variance measured group agreement, but differs from pairwise comparison variances in that it represents the result of the interaction between pairwise comparison judgments for all AHP matrices. Information contained in Table 12 summarizes the independent and dependent variables and describes why each variable is significant to the experimental process.

4.3 Experimental Design

The second important consideration in the research project was the scope of the AHP to include in the experimental process. In order to ensure consistency with the experimental method, the steps falling immediately after the creation of the decision problem hierarchy were included. This required a predefined decision hierarchy. The hierarchy for the decision problem is presented in Figure 4. This hierarchy reflects the criteria specified in the INTEGRIS Health E-Business Value Matrix Project Assessment Questionnaire provided in Appendix B. The hierarchy requires the development of five pairwise comparison matrices. Matrix A was developed for the attributes (i.e., internal business processes, learning and growth, customer, finance and value identify the most successful capital investment projects). Matrices B through E were developed for the sets of sub-attributes comprising each attribute. For example, the attributes of finance and

Table 12. Independent and Dependent Variables.

Variable	Definition	Significance to Experimental Process
Independent Variables:		
AHP Model Type	Variations in approaches to implementing the AHP	Approaches offer potential to improve AHP decision quality as measured by the Aggregate Group Consistency Index and the Pairwise Comparison Variances
Group Size	Number of participants in AHP process	Group size has potential to influence the AHP decision quality
Level of Responsibility	Vice President and Non Vice President	Level of responsibility and associated knowledge has potential to influence the AHP decision quality
Dependent Variables:		
Aggregate Group Consistency Index	Measure of consistency of pairwise comparison judgments	The primary measure of AHP decision quality; incorporates concept of being able to make logical decisions
Pairwise Comparison Variances	Measure of dispersion of pairwise comparison judgments	A measure of group agreement; could reflect degree of buy-in for AHP decisions
Mental Workload	The amount of mental effort required to perform baseline, knowledge self-assessment, and electronic meeting technology tasks	The workload should be considered when evaluating the AHP methods.
Decision Hierarchy Attribute Weighting Variances	Variances of the principal vector computed for primary and secondary factors; the weightings reflect the importance of the primary and secondary factors	A measure of group agreement; could reflect degree of buy-in for AHP decisions; differs from Pairwise Comparison Variances in that it represents the result of computing the eigenvector for the matrix of pairwise comparisons
Task Completion Times	Time to complete baseline, knowledge self-assessment, and electronic meeting technology tasks	Represents staff resource consumption which may vary among AHP models

value is associated with the sub-attributes of cost savings potential, startup costs, ongoing cost, and revenue source potential.

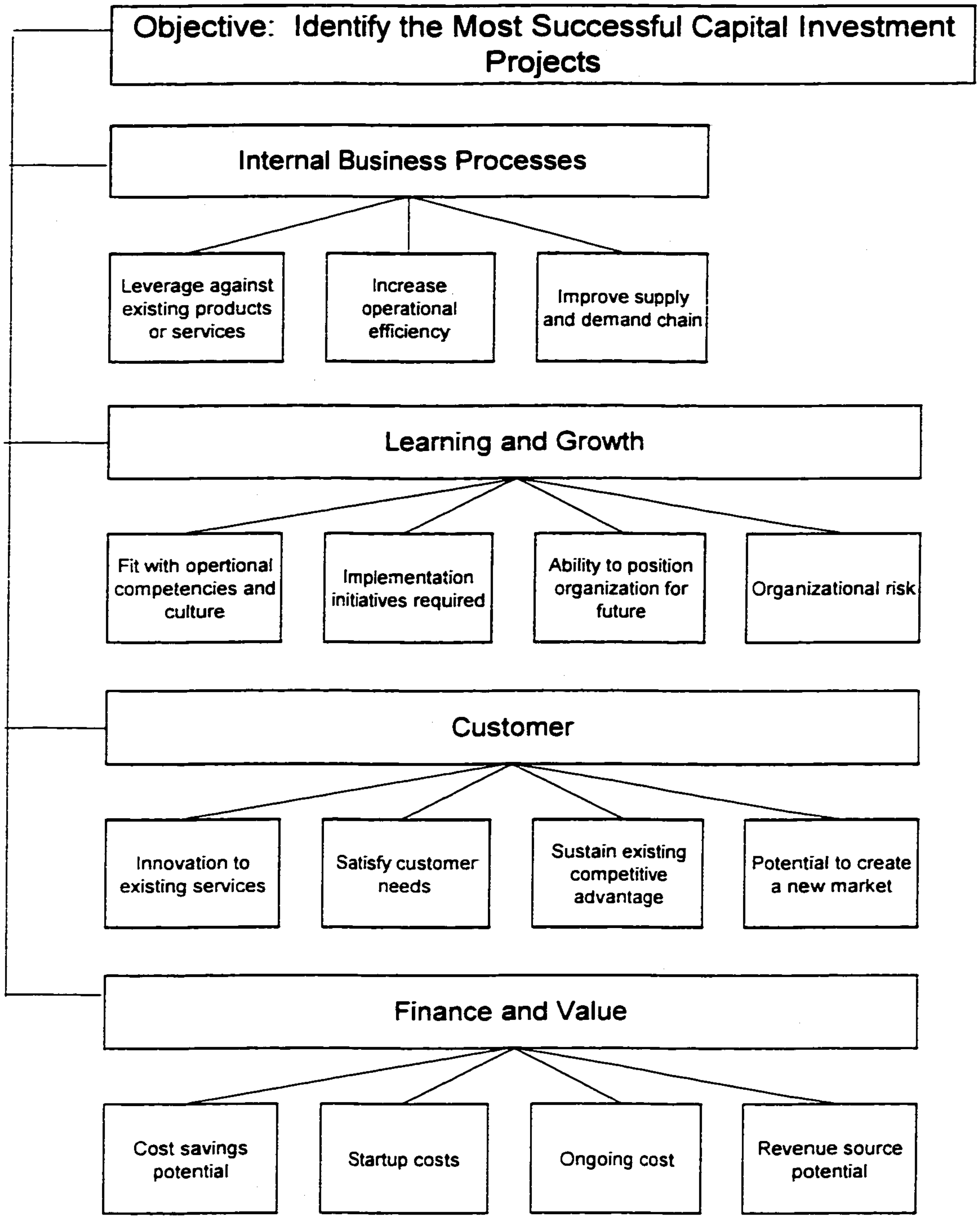


Figure 4. Capital Investment Project Selection Decision Hierarchy.

The experimental methodology used in this research examined group rather than individual decision-making. Thus, the third consideration was the number of participants in an experimental group (i.e., group size). Two different group sizes of five and seven were used. The selection of the two group sizes was based on "guidelines for the effective committees" recommended by Szilagyi (1981). Szilagyi stated that it is important to "keep the number of members at a manageable size, usually five to seven." Scholtes (1988) stated that "typically, teams should have no more than five members in addition to the team leader and quality advisor." In addition, thought was given to the minimum number of roles within a typical organization that would be involved in the decision problem. For most organizations, a minimum of five individuals of senior management, including the Chief Operating Officer, Chief Information Officer, Chief Financial Officer, Vice President of Human Resources, and Vice President of Marketing would be involved in capital investment decisions. Some organizational structures, such as healthcare, have additional positions in senior management roles including Vice Presidents of Legal and Nursing. The last consideration in the experimental design was the number of experimental replications required to produce valid conclusions. Four replications for a group size of five and for a group size of seven were used.

Three different models were used to conduct the AHP in this research as shown in Figure 5. Aggregate group consistency indices were computed for each group for each model. The baseline model involved gathering the pairwise comparisons of the hierarchical elements by individual through the use of a questionnaire. Pairwise comparison matrices were constructed using the geometric means of the participants' individual pairwise comparisons as the matrix elements. The geometric mean was

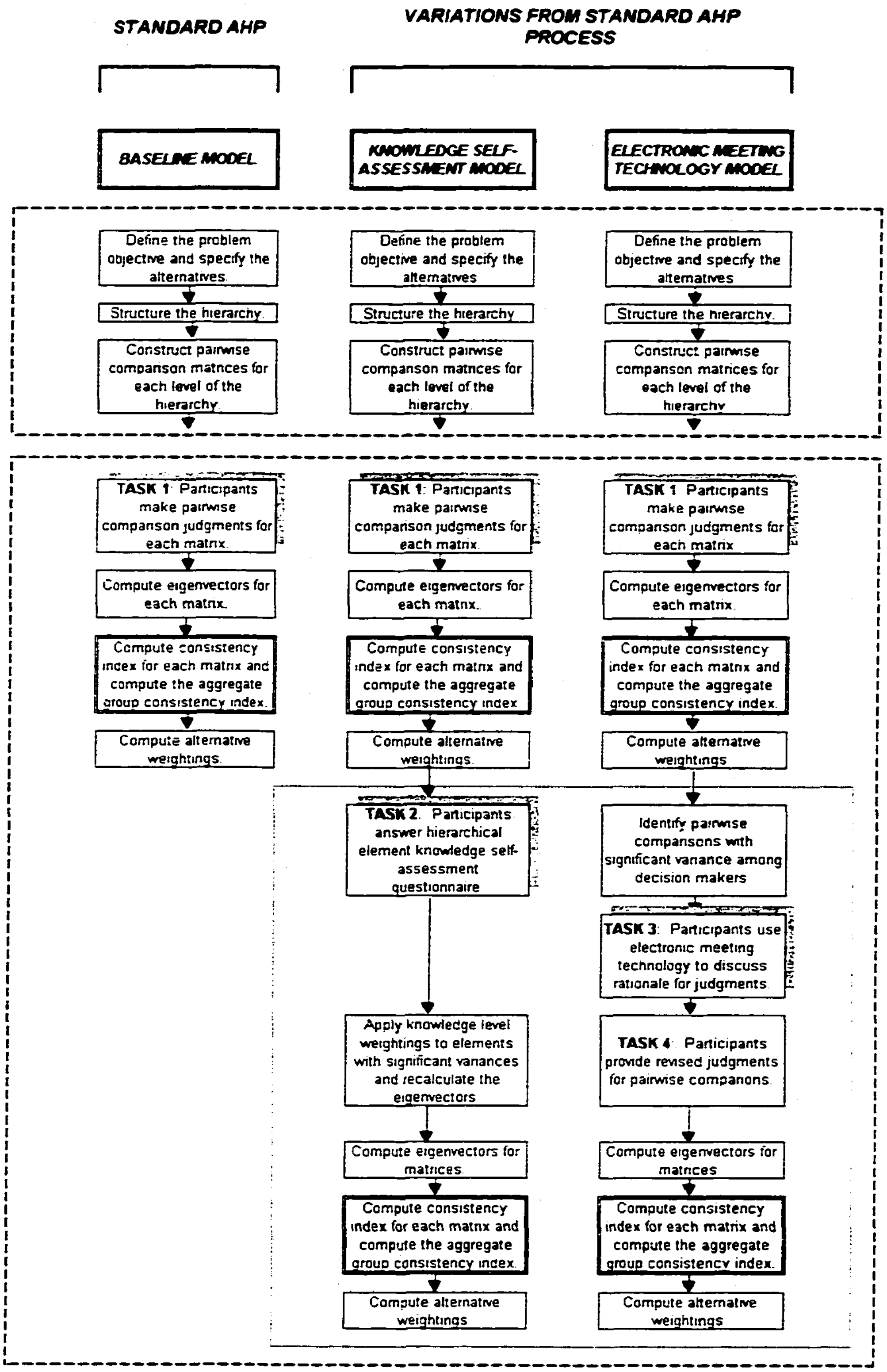


Figure 5. AHP Models.

selected because it is the recommended statistic for averaging ratio quantities (Fruend and Perles. 1974).

The knowledge self-assessment model involved the use of a knowledge self-assessment questionnaire to obtain each participant's perceived knowledge of each pairwise comparison. Pairwise comparison matrices were constructed using the weighted geometric mean of the participants' indvidual pairwise comparisons as the matrix elements.

The electronic meeting technology model used electronic meeting software and a multi-media meeting facility designed for group interaction. In this model, the participants used electronic meeting technology to discuss the individual pairwise comparison judgments they made in the baseline model. The participants provided individual revised pairwise comparison judgments of primary and secondary factors after the electronic meeting discussion. Group pairwise comparison matrices were constructed using the revised geometric mean of the group's pairwise comparisons as the matrix elements.

4.4 Participants

The participants were forty-eight individuals employed by INTEGRIS Health with responsibilities for financial, clinical, operations, human resources, strategic planning, information technology, and other functions. INTEGRIS Health is the second largest non-profit business in the state of Oklahoma. It is a multi-facility health care system comprised of two hospitals located in metropolitan Oklahoma City, eleven hospitals located in rural Oklahoma towns, home health, hospice, physician clinics, and rehabilitation services. The decision to use subjects from INTEGRIS Health was driven by two parameters:

1. these individuals have knowledge of the healthcare industry. which was important for the decision problem, and
2. access to the experimental premises and to the electronic meeting technology was easier for employees of the organization. versus individuals who were not employed by INTEGRIS Health.

The forty-eight individuals were assigned to one of the four groups of five or one of the four groups of seven. The participants areas of responsibility fell into one of six general areas of responsibility, including financial, clinical, operations, human resources, marketing, information technology, and other. Their areas of responsibility were either Vice President level or Non-Vice President level. Twenty-four of the participants were female and twenty-four were male. Participants' ages varied from less than 30 years of age to less than 60 years of age with the majority of the participants falling in the age range of 41 to 50. The participant average years of healthcare experience was 17.2 years. The average computer skill rating for all participants was determined through self-assessment. The average skill rating was 1.67, which fell between very good and somewhat good on a 5-point scale (1 = very good, 2 = somewhat good, 3 = neutral, 4 = somewhat limited, and 5 = very limited). The participant demographic characteristics, including area of responsibility, level of responsibility, gender, age, number of years experience in healthcare, and computer skill level are summarized in Table 13. All participants signed the Informed Consent Form provided in Appendix C.

The potential participants were selected by reviewing the INTEGRIS Health organization chart to develop categories of responsibility, and then by reviewing the on-line organizational telephone directory to develop a listing of potential participants within each category of responsibility. The listing identified 75 potential participants. The letter provided in Appendix D was sent by electronic mail to each individual in the listing. The

Table 13. Participant Demographics.

Demographic Characteristics		Participant Count
Area of Responsibility	Financial	11
	Clinical	12
	Operations	6
	Human Resources	2
	Strategic Planning	2
	Information Technology	8
	Other	7
Level of Responsibility	Non-VP	40
	VP	8
Gender	Female	24
	Male	24
Age Range	< 30	1
	30 to 40	16
	41 to 50	21
	51 to 60	10
	> 60	0
Average Years Experience in Healthcare		17.2
Average Computer Skill Level Rating		1.67

individuals were asked to respond by electronic mail if they were interested in participating. The letter suggested that the incentive for participating was the opportunity to influence factors to be considered in the evaluation of new capital investment projects. Fifty-two individuals were recruited to participate, with four of these individuals identified as back-up participants. Four individuals cancelled their participation on or before the date of the actual experiment due to scheduling conflicts and were replaced with the four back-up participants.

A broad representation of perspectives within each group was desired to enlarge the domain of information processed and produce a higher quality decision (Sniezek and Henry, 1990). The goal was to form groups of size five with a maximum of one individual from each organizational area of responsibility and to form groups of size seven with no more than two individuals from any one organizational area of responsibility. Limitations in scheduling flexibility prevented this from happening for every group. Table 14 presents the composition for each of the eight groups.

Table 14. Experimental Group Composition.

Identification	Size	Composition
A	Five	Human Resources (1), Information Technology (2), Financial (1), Operations (1); 1 VP (Finance)
B	Seven	Human Resources (1), Information Technology (1), Financial (1), Clinical (2), Operations (2)
C	Five	Information Technology (2), Financial (1), Operations (1), Other (1)
D	Five	Financial (2), Clinical (3)
E	Five	Information Technology (1), Clinical (1), Other (3)
F	Five	Financial (1), Information Technology (2), Clinical (1), Marketing (1), Other (2)
G	Seven	Financial (1), Clinical (4), Operations (2)); 1 VP (Finance), 2 VP (Clincial), 1 VP (Operations)
H	Seven	Financial (4), Clinical (1), Marketing (1), Other (1); 2 VP (Finance)

4.5 Electronic Meeting Software

Groupware Workgroup Edition 2.1 software, Ventana GroupSystems ©(1989-1999 Ventana Corp.) was selected for use in the experimental process because it is the electronic meeting technology used by INTEGRIS Health. Groupware offers a collection of tools to support group activities including tools to support brainstorming, list building, information gathering, voting, organizing, prioritizing, and consensus building. One of these tools, the Topic Commenter, provides the capability for discussing specific topics.

In the Topic Commenter, each participant is given the electronic equivalent of lined sheets of paper labeled with topics. The topics can be entered or imported prior to starting the Topic Commenter activity. The participants can comment on the topics in any order they choose. In this experiment, the researcher designated the pairwise comparisons as the topics prior to starting the activity. Figure 6 shows the screen that participants viewed as they commented on the pairwise judgments.

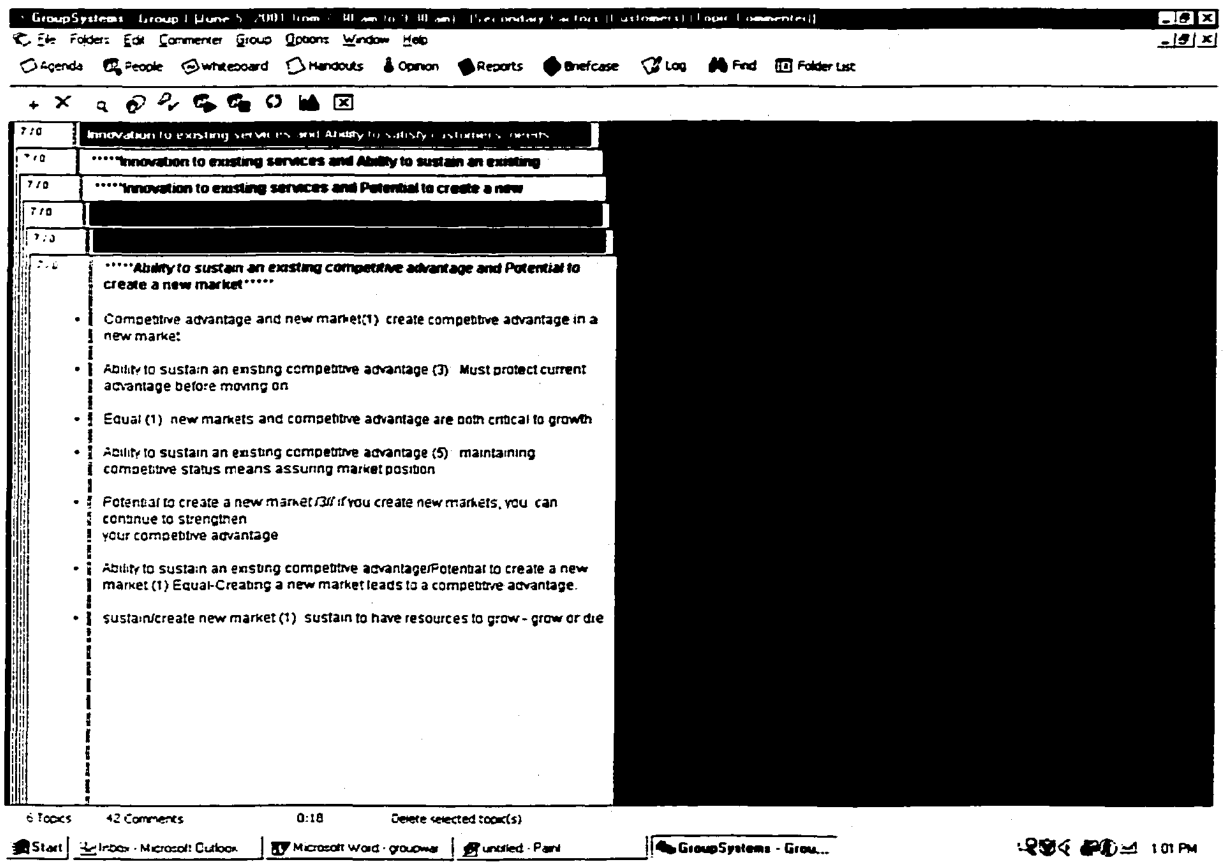
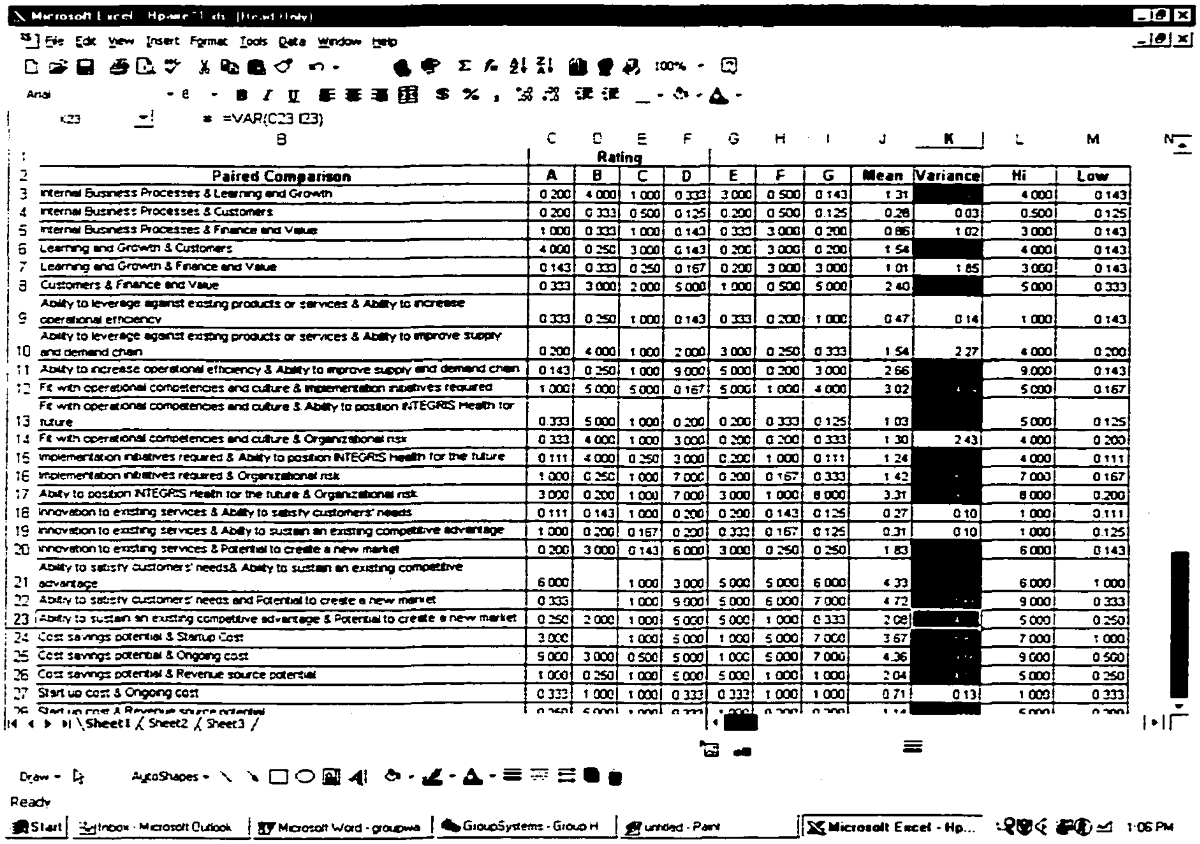


Figure 6. Groupware Topic Commenter Screen.

Another function of the Groupware software is the capability for including electronic handouts in the meeting process. The group variances for each pairwise comparison were calculated in advance of the group meeting and were included as an electronic meeting handout. Figure 7 shows the format in which the pairwise comparison variances were presented to participants. The pairwise comparisons with the highest variances were highlighted by using a black cell background in combination with bolded white font in the handout. They were highlighted in the Topic Commenter by using leading and lagging asterisks in the topic titles.



	Paired Comparison	A	B	C	D	E	F	G	Mean	Variance	Hi	Low
3	Internal Business Processes & Learning and Growth	0.200	4.000	1.000	0.333	3.000	0.500	0.143	1.31	[illegible]	4.000	0.143
4	Internal Business Processes & Customers	0.200	0.333	0.500	0.125	0.200	0.500	0.125	0.28	0.03	0.500	0.125
5	Internal Business Processes & Finance and Value	1.000	0.333	1.000	0.143	0.333	3.000	0.200	0.86	1.02	3.000	0.143
6	Learning and Growth & Customers	4.000	0.250	3.000	0.143	0.200	3.000	0.200	1.54	[illegible]	4.000	0.143
7	Learning and Growth & Finance and Value	0.143	0.333	0.250	0.167	0.200	3.000	3.000	1.01	1.85	3.000	0.143
8	Customers & Finance and Value	0.333	3.000	2.000	5.000	1.000	0.500	5.000	2.40	[illegible]	5.000	0.333
9	Ability to leverage against existing products or services & Ability to increase operational efficiency	0.333	0.250	1.000	0.143	0.333	0.200	1.000	0.47	0.14	1.000	0.143
10	Ability to leverage against existing products or services & Ability to improve supply and demand chain	0.200	4.000	1.000	2.000	3.000	0.250	0.333	1.54	2.27	4.000	0.200
11	Ability to increase operational efficiency & Ability to improve supply and demand chain	0.143	0.250	1.000	9.000	5.000	0.200	3.000	2.66	[illegible]	9.000	0.143
12	Fit with operational competencies and culture & Implementation initiatives required	1.000	5.000	5.000	0.167	5.000	1.000	4.000	3.02	[illegible]	5.000	0.167
13	Fit with operational competencies and culture & Ability to position INTEGRIS Health for future	0.333	5.000	1.000	0.200	0.200	0.333	0.125	1.03	[illegible]	5.000	0.125
14	Fit with operational competencies and culture & Organizational risk	0.333	4.000	1.000	3.000	0.200	0.200	0.333	1.30	2.43	4.000	0.200
15	Implementation initiatives required & Ability to position INTEGRIS Health for the future	0.111	4.000	0.250	3.000	0.200	1.000	0.111	1.24	[illegible]	4.000	0.111
16	Implementation initiatives required & Organizational risk	1.000	0.250	1.000	7.000	0.200	0.167	0.333	1.42	[illegible]	7.000	0.167
17	Ability to position INTEGRIS Health for the future & Organizational risk	3.000	0.200	1.000	7.000	3.000	1.000	8.000	3.31	[illegible]	8.000	0.200
18	Innovation to existing services & Ability to satisfy customers' needs	0.111	0.143	1.000	0.200	0.200	0.143	0.125	0.27	0.10	1.000	0.111
19	Innovation to existing services & Ability to sustain an existing competitive advantage	1.000	0.200	0.167	0.200	0.333	0.167	0.125	0.31	0.10	1.000	0.125
20	Innovation to existing services & Potential to create a new market	0.200	3.000	0.143	6.000	3.000	0.250	0.250	1.83	[illegible]	6.000	0.143
21	Ability to satisfy customers' needs& Ability to sustain an existing competitive advantage	6.000		1.000	3.000	5.000	5.000	6.000	4.33	[illegible]	6.000	1.000
22	Ability to satisfy customers' needs and Potential to create a new market	0.333		1.000	9.000	5.000	6.000	7.000	4.72	[illegible]	9.000	0.333
23	Ability to sustain an existing competitive advantage & Potential to create a new market	0.250	2.000	1.000	5.000	5.000	1.000	0.333	2.08	[illegible]	5.000	0.250
24	Cost savings potential & Startup Cost	3.000		1.000	5.000	1.000	5.000	7.000	3.67	[illegible]	7.000	1.000
25	Cost savings potential & Ongoing cost	9.000	3.000	0.500	5.000	1.000	5.000	7.000	4.36	[illegible]	9.000	0.500
26	Cost savings potential & Revenue source potential	1.000	0.250	1.000	5.000	5.000	1.000	1.000	2.04	[illegible]	5.000	0.250
27	Start up cost & Ongoing cost	0.333	1.000	1.000	0.333	0.333	1.000	1.000	0.71	0.13	1.000	0.333
28	Start up cost & Revenue source potential	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Figure 7. Group Pairwise Comparison Variance Report.

4.6 Facilities

A conference room, know as the INTEGRIS Health Newly Emerging Strategic Technology (NEST) conference was utilized to bring subjects together in face-to-face interaction using the Groupware software. The NEST is located in Oklahoma City, Oklahoma in a building that houses the INTEGRIS Health data center and other information technology functions. The NEST is furnished with a custom-built 12' 6" conference table that accommodates up to twelve personal computers. A picture of the NEST is provided in Appendix E.

4.7 Equipment

Equipment in the NEST includes personal computers networked through a local area network to enable participants to access the Groupware software. The computers were IBM Thinkpads with 600 Mhz processors with 128 megabytes of Random Access Memory. The personal computers are networked to a 600 Mhz workstation, located in the NEST.

Additional equipment located in the NEST includes a Sharp Notevision Model MT1045, 1024 x 768, 2000 ANSI lumen, LCD projector which enabled the display of the real time, interactive communication screen. A Lexmark Optra 45 N printer located in the NEST enabled real-time printing of standardized reports offered through the Groupware software.

Participants were provided the packet of information contained in Appendix F to guide them in the completion of various data collection forms required for each of these models. Data collection forms were color coded to assist the participants in the completion of their tasks.

4.8 Experimental Procedure

Figure 8 presents a flowchart of the experimental research process. The gray-shaded area reflects the tasks associated with the knowledge self-assessment and electronic meeting technology models. Participants were scheduled into one of the electronic meeting dates and times. Several days in advance of their scheduled meeting date, participant packets were delivered to each participant. The packet instructed them to:

1. Read and sign the informed consent form.
2. Complete the demographic questionnaire.
3. Complete the baseline pairwise comparison data collection form (Appendix G).
4. Complete the NASA-TLX mental workload data collection form for the baseline pairwise comparison data collection activity (Appendix H).
5. Complete the knowledge self-assessment data collection form (Appendix I).
6. Complete the NASA-TLX mental workload data collection form for the knowledge self-assessment data collection activity (Appendix H).

Participants performed these activities individually in their work environment or at home. The researcher obtained completed packets from each participant in advance of their scheduled meeting. The baseline pairwise comparison judgments for participants within each group were summarized and included as handouts in the Groupware agendas for each group.

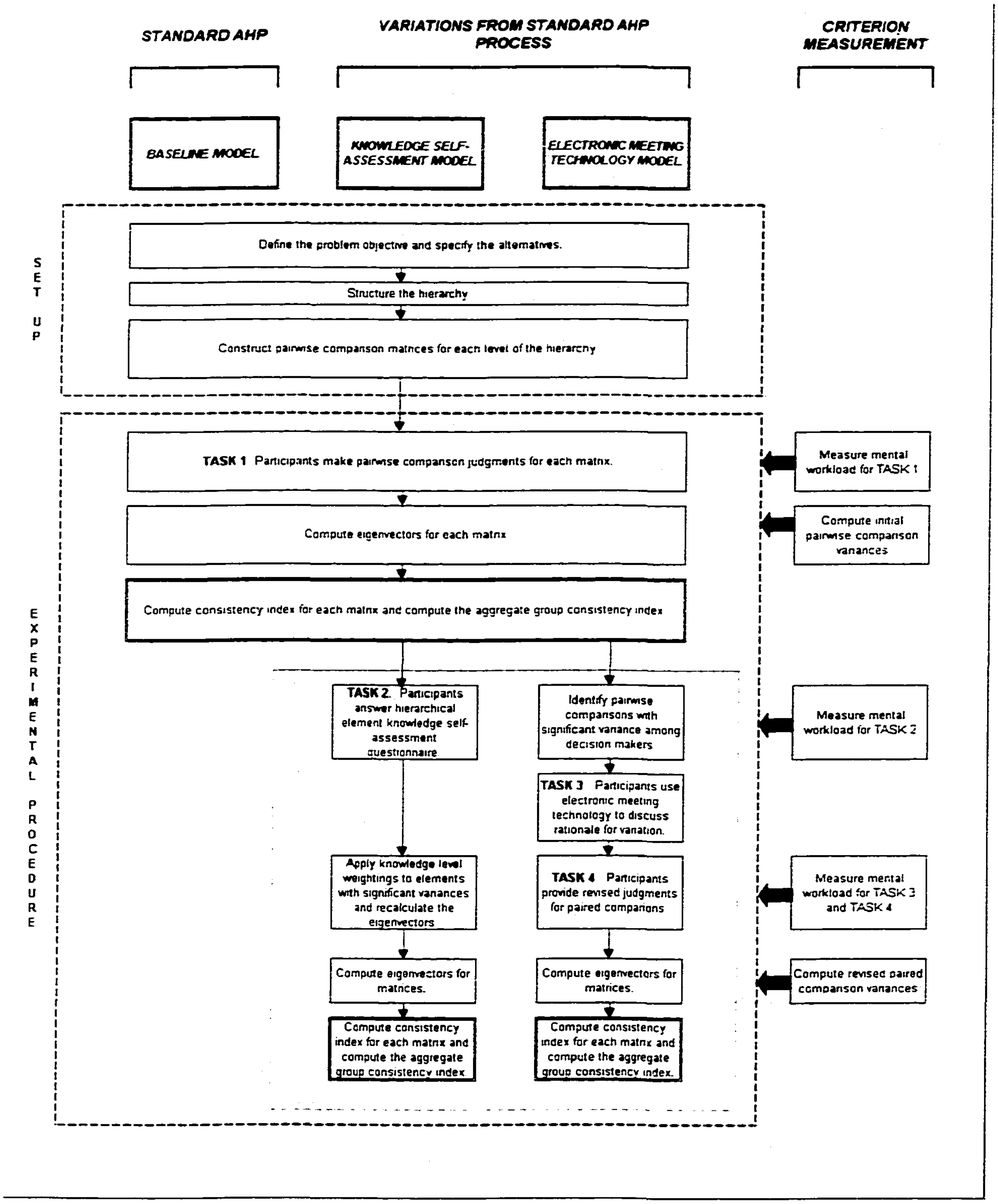


Figure 8. Experimental Procedure.

Participants convened in the NEST to participate in the electronic meeting to discuss their pairwise comparison judgments. The Topic Commenter Groupware activity was used to interactively generate a comprehensive accumulation of ideas regarding the rationale for the pairwise comparison judgments. In essence, this provided the opportunity for knowledge transfer among subjects regarding each of the AHP pairwise comparisons. The participants were provided with their baseline data collection form and were asked to refer to their baseline judgments as they entered the following comments into the Topic Commenter: (1) the pairwise attribute they believed was most important when evaluating proposed capital investment projects, (2) the rationale for their decision, and (3) their rating of the most important attribute within a pairwise comparison set relative to the least important attribute within the pairwise comparison set. They were asked to pay particular attention to those pairwise comparisons that had the most variation within their group. As mentioned earlier, these pairwise comparison attributes were flagged with asterisks within the Topic Commenter activity. The participants completed their data entry for each matrix using the Topic Commenter activity and were asked to make revised pairwise comparison judgments on a new data collection form. This data collection form is provided in Appendix J. Each matrix was introduced to participants one at a time to minimize information overload (Grise and Gallupe, 1999). At the conclusion of each Topic Commenter activity for a matrix, the experimenter produced a report that documented all preceding discussion and displayed it on the screen. An example of this report is provided in Appendix K.

The researcher ensured the participants had adequate time to input their information through the Topic Commenter activity, but timed the process so it was limited to approximately 90 minutes for each group to ensure the experimental methodology was similar among groups. At the conclusion of the meeting, participants were asked to complete the Post Electronic Meeting Survey contained in Appendix L.

4.9 Pilot Experiment

A pilot experiment was conducted using all three models with a control group of four individuals who are staff in the INTEGRIS Health Decision Support department. The participants were also asked to complete an evaluation of the experimental process and communication materials using the Dissertation Pilot Evaluation Questionnaire provided in Appendix M. Tables 15 and 16 present the results of the pilot evaluation questionnaire. Table 15 presents participants' agreement to statements about the experimental tasks using a five point scale (SD = strongly disagree, D = disagree, N = neutral, A = agree, and SA = strongly agree). Table 16 presents participants' agreement to statements about the communication material using the same five-point scale. Data in Tables 15 and 16 show the participants opinions generally ranged from neutral to strongly agree, indicating that they found the data collection forms easy to use, the experimental tasks flowed smoothly, the software and NEST equipment were easy to use, and written instructions were easy to understand.

In addition to the questionnaire, participants were asked these specific questions at the conclusion of the experiment:

1. Should the order of topics on the Topic Commenter activity be consistent with the order in which the attributes are presented on the paired comparison tool or should they be ordered according to the rating variance (high to low)?
2. Would it be helpful to provide space for documenting the rationale for your rating on the paired comparison tool?

Table 15. Summary of Pilot Evaluation (Experimental Tasks).

Question	Agreement Scale Average Score					Comments
EXPERIMENTAL TASKS	SD	D	N	A	SA	
1. The paired comparison data collection form was easy to use.			2	2		• Having more of a description of what the paired comparisons mean would help: writing the reasoning behind the choice would have been easier at the time of rating. • An explanation of the attributes would be helpful. Adding a rationale section would be nice as well. • Once I figured out how to fill it out, it was easy to use. All the different definitions a person can give to the attributes, however, probably caused some difficulty.
2. The knowledge self-assessment tool was easy to use.			1	2	1	
3. The NASA-TLX workload measurement tool was easy to use.		1	1	1	1	• Having to compare items such as performance versus effort did not make sense. For example, the temporal demand (time pressure) caused the frustration level to increase. How do you choose between the two? • Some of the category descriptions are confusing (e.g., performance versus others). All should be on a similar scale. Performance seems to be high/low instead of low/high.
4. The experimental tasks flowed together smoothly.				3	1	• I got more comfortable after the first section.
5. The Groupware software was easy to use.				2	2	• In listing Attribute A and Attribute B, would it be possible to have a simple definition of each? • The software was very user friendly.
6. The NEST equipment was easy to use.				3	1	• The mouse made it easier for me.
7. The Groupware activity provided an opportunity for knowledge transfer.				1	3	• Caused me to want to discuss a little more before rating on the second rating. • It was easy to read other individuals' opinions. Not allowing for oral discussion of the various opinions sped up the process.
8. I considered the opinions of others when I completed my revised pairwise comparison tool.				2	2	• In some instances, I realized that I had not chosen the appropriate ranking to go with my reasoning. Discussing the reasoning at the time of the ranking would probably help. • I did change some of my answers afterwards. • I considered all opinions, but in many instances my original opinion was not altered much, if at all.

3. Did the Topic Commenter activity get easier with more practice?

4. Did you get less conscientious in your participation as the experiment progressed?

Table 17 provides a listing of issues and resolutions for improvement from the dissertation pilot evaluation questionnaire, the discussion associated with the four questions posed to the participants at the conclusion of the experiment, and from the general observations by the experimenter. The issues were defined more by the comments than the ratings in Tables 15 and 16. A resolution was identified for all known issues.

Table 16. Summary of Pilot Evaluation (Communication Tasks).

COMMUNICATION MATERIAL	SD	D	N	A	SA	
1. The instructions were easy to understand.			2	2		• Can you make them even more simple? I found when writing my reasoning. I had selected the incorrect ranking. • The instructions had to be read slowly two times; and I still felt a bit unclear as to what I was to do. Probably a more basic level of explanation would be helpful for individuals who are unfamiliar with the techniques used. A oral briefing many have been helpful at the start.
2. The instructions were helpful.			1	2	1	• The examples were a good resource.
3. The letter describing the experimental tasks increased my understanding of the experimental objective and related tasks.			1	2	1	• A more detail description of the attributes would help participants.
4. The Informed Consent Form was easy to understand.				1	2	Note: 1 participant failed to provide a rating for this question.
Other Comments	Non Applicable					• I am not sure my understanding of the various attributes was complete to when I started trying to justify, I ran into problems remembering why I chose what I chose. I found mistakes between my reasoning and rankings. • My biggest problem /challenge was use of the laptop; everything else flowed well. • When filling out the forms at our desks in our own offices, there was a lot less time pressure, and therefore, less frustration. The instructions gave a suggestion of how long the task should take, which added minimal time pressure. In the NEST, however, the time pressure was greatly elevated.

Table 17. Pilot Study Issues and Resolutions.

Issue	Resolution
Attributes lack a standard definition.	Defined attributes and provided this to participants on the paired comparison tool.
Time pressure in session two of the experimental process created frustration.	Reduced the number of attributes included in the experiment.
Participants had some difficulty remembering the rationale for their original pairwise comparison ratings.	Provided space for participants to think about and document the rationale for their initial pairwise comparison ratings on the paired comparison tool.
Participants had some difficulty with the NASA-TLX factors and scales. In some cases, the factors influenced each other.	Clarified the distinction between factors. Ensured the scales for each factor were in the proper order (e.g. high/low versus low/high). Provided instruction on how to deal with the influence of one factor with another factor.
Participants were not clear on how to perform the paired comparison ratings.	Simplified and clarified the pairwise comparison instructions. Included the scale for the ratings. Included encouragement for back-and-forth communication to answer questions about a participant's rationale.
Laptop eraser mouse was difficult for some participants to use.	Provided the option for participants to use an external mouse versus the eraser mouse.
Had to write the specific task for the Topic Commenter on the flip chart pad.	Added instructions to the Topic Commenter task in the Groupware software.
Had to request the participants focus on the topics with the most variance.	Listed the topics in descending order of rating variance within the Groupware software.
There was no rationale for the order of the secondary tasks. The secondary task with the largest number of attributes was last in the agenda.	Structured the order of the sub-attribute groupings strategically with the secondary groups with the smaller number of attributes first to give participants an opportunity to gain confidence early. Sequenced the secondary group with the largest number of attributes in the middle. Sequenced an attribute with a small number of sub-attributes at the end.

4.10 Experimental Analyses

Five analyses were conducted in this research. The independent variables for each analysis were the AHP model, group size, level of responsibility, and/or decision hierarchy attributes. A definition of each hypothesis, including a description of the dependent variables, follows.

4.10.1 Analysis One

Hypothesis A: The electronic meeting technology model will produce greater consistency compared to the baseline and knowledge self-assessment models.

Hypothesis B: The smaller group size will produce greater consistency compared to the larger group size.

Hypothesis C: The electronic meeting technology model in combination with a smaller group size will produce greater consistency compared to the baseline and knowledge self-assessment models with either group size.

These hypotheses evaluated the quality of the decision by examining consistency in pairwise comparisons for each group. As previously defined, consistency in the AHP represents the transitivity of preference in the pairwise comparison matrices (e.g., if A=3B and B=6C, then A=18C). AHP consistency is a measure of the degree to which transitivity was maintained in the pairwise comparison judgments. The independent variables for these hypotheses were model type and group size. The electronic meeting technology model was hypothesized to produce greater consistency than the other models because it provides an opportunity for participants to communicate their judgments in an autonomous manner. Opinions from non-dominant and dominant views were shared equally. This equal sharing also provides an opportunity for knowledge to be transferred due to a broader sharing of opinions. The smaller group size was hypothesized to produce greater consistency because a smaller group size may promote greater intimacy and there is less information for participants to consider when making their pairwise comparison judgments.

The dependent variable in these hypotheses was the aggregate group consistency index for the entire hierarchy. A group consistency index was calculated for each of the five sub-attribute matrices for each model. The aggregate group consistency index for the entire hierarchy was calculated based on the sub-attribute matrix consistency indices and the attribute principal vectors as described in Section 3.2.2.

4.10.2 Analysis Two

> *Hypothesis A:* The electronic meeting technology model will produce lower pairwise comparison variances compared to the baseline model.
>
> *Hypothesis B:* The smaller group size will produce lower pairwise comparison variances compared to the baseline model.
>
> *Hypothesis C:* The electronic meeting technology model in combination with the smaller group size will produce lower pairwise comparison variances compared to the baseline model in combination with either group size.

These hypotheses evaluated the quality of the decision by assessing individual consensus on the pairwise comparisons. The independent variables were model type and group size. The electronic meeting technology model was hypothesized to produce greater individual consensus than the baseline model because participants were informed of areas where the variance in participant judgment consistency was highest. The electronic meeting technology model also afforded an opportunity for dominant and non-dominant opinions and their rationale to be expressed, increasing knowledge transfer. The smaller group size was hypothesized to produce greater individual consensus because a smaller group may promote increased group intimacy.

The dependent variable was the group mean pairwise comparison variance for all participants for the baseline and electronic meeting technology models. A comparison was made between the variance of the initial average pairwise comparisons and the revised average pairwise comparisons to determine if the variances decreased through the knowledge transfer opportunity of the electronic meeting discussion. The variances of means for each of the twenty-seven pairwise comparisons were calculated for each model for each group.

4.10.3 Analysis Three

> *Hypothesis A:* The Vice President level of responsibility will produce a lower pairwise comparison variance in the baseline model compared to the Non-Vice President level of responsibility.

This hypothesis evaluated whether or not the participants at the Vice President level of responsibility had more consensus than the Non-Vice President level of responsibility in their initial pairwise comparisons. The independent variable was the level of responsibility. The Vice President level of responsibility was hypothesized to have greater consensus than the Non-Vice President level of responsibility because the participants in the Vice President level of responsibility were perceived to have a broader and similar range of experience. The baseline model versus the comparison of the baseline models to other models was of interest in this analysis. The interest in this analysis was strictly to examine individual consensus within a group that is homogeneous with respect to level of responsibility. The dependent variable was the pairwise comparison variances.

4.10.4 Analysis Four

> *Hypothesis A:* The electronic meeting technology model will produce a lower mental workload compared to the baseline model and the knowledge self-assessment models.
>
> *Hypothesis B:* The smaller group size will produce a lower mental workload compared to the larger group size.

Hypothesis C: The electronic meeting technology model in combination with the smaller group size will produce a lower mental workload compared to the baseline model or the knowledge self-assessment model with either group size.

These hypotheses evaluated the mental workload required for tasks associated with each model to determine if the additional activities of the knowledge self-assessment and electronic meeting technology models significantly increased mental workload compared to the baseline model. The independent variables were model type and group size. The electronic meeting technology was hypothesized to produce a lower group mental workload compared to the other models because it provided an opportunity for knowledge transfer among participants. Participants who might lack knowledge about specific pairwise comparisons could rely upon the knowledge of other participants, thus, decreasing their mental work effort. The smaller group size was hypothesized to produce a lower mental workload because the amount of information produced and to be considered was lower than the amount produced by a larger quantity of participants.

The dependent variable was the group mean NASA-TLX mental workload score for each group for each of the tasks involved in all models. Mental workload scores were obtained for each of the following tasks:

Task 1 (Baseline): Participants made initial individual pairwise comparison judgments for each matrix.

Task 2 (Knowledge Self-Assessment): Participants individually answered hierarchical knowledge self-assessment questionnaire.

Task 3 : Participating in a face-to-face meeting using Groupware electronic meeting technology to discuss outlier pairwise judgments through the Topic Commenter task; and

Task 4: Completing the revised AHP pairwise comparison judgment task. pairwise comparisons and made revised pairwise comparison judgments for each matrix.

4.10.5 Analysis Five

Hypothesis A: The priority weighting variances for attributes and sub-attributes will differ significantly among attributes and sub-attributes.

Hypothesis B: The electronic meeting technology will produce lower attribute and sub-attribute priority weighting variances than the baseline or knowledge self-assessment models.

These hypotheses evaluated whether or not the group consensus on attribute and sub-attribute priority weightings varied significantly. The independent variables were attributes and sub-attributes, group, model type, and group size. The attribute and sub-attribute priority weightings produced by the electronic meeting technology were hypothesized to have greater consensus among groups due to the knowledge transfer opportunity this model provided. The smaller group size was hypothesized to produce greater individual consensus because a smaller group may promote increased group intimacy, and because there is less information to consider when participants made their pairwise comparisons. The dependent variable was the attribute and sub-attribute priority weighting.

CHAPTER 5

EXPERIMENTAL RESULTS AND ANALYSIS

This chapter describes the computational procedures that were used to analyze the hypotheses generated for the experimental component of this research. The general procedures and methods for measuring the dependent variables are defined. The statistical methods used to analyze the five hypotheses are discussed and the results of the analyses are presented.

5.1 General Computational Procedure

All data were configured in Microsoft Excel© (1995-1997 Microsoft, Inc.) spreadsheets and analyzed either using Microsoft Excel or SAS© (1999 SAS). The data sets were developed from the demographic questionnaires, baseline and electronic meeting technology pairwise comparison judgments of participants, knowledge self-assessment questionnaires, NASA-TLX mental workload data collection forms, and the post electronic meeting surveys.

Microsoft Excel workbooks were created to develop the complete AHP matrices for the attribute and sub-attributes using the pairwise comparison values for each participant for each group. Formulas were developed to calculate the eigenvectors for the attribute matrix (Matrix A) and each of the four sub-attribute matrices (Matrix B through Matrix E), and to compute the consistency indices for each matrix and the aggregate group consistency index for each group.

5.2 Results and Analysis

Statistical tests were performed to determine the impact of augmenting the AHP implementation with knowledge self-assessment weightings and electronic meeting technology. The tests evaluated whether there was improvement in decision-maker judgement consistency and consensus, and if so, the level of improvement. The tests also evaluated the level of mental effort required to perform tasks associated with the knowledge self-assessment and electronic meeting technology models in comparison with the baseline model. A description of the five analyses of variance that were performed is provided in Table 18. The design, dependent and independent variables, and the associated model for each analysis are defined.

The use of ANOVA requires specific assumptions to be satisfied. The assumptions for the analysis of variance are that the observations are adequately described by the model:

$$y_{ij} = \mu + \tau_i + \varepsilon_{ij} \text{ or } y_{ij} = \mu + \tau_i + \beta_j + \varepsilon_{ijk}$$

and that the errors are normally and independently distributed with mean zero and constant but unknown variance (Montgomery, 1991). Model adequacy checking is a procedure used to test for violations of these assumptions and is based on an examination of the errors or residuals. "If the model is adequate, the residuals should be structureless;

Table 18. Summary of Analyses.

ANALYSIS ONE

A. The electronic meeting technology model will produce greater consistency compared to the baseline and knowledge self-assessment models.
B. The smaller group size will produce greater consistency compared to the larger group size.
C. The electronic meeting technology model in combination with a smaller group size will produce greater consistency compared to the baseline and knowledge self-assessment models with either group size.

Design	Dependent Variable	Independent Variables	Model for Analyses
3 x 2 Factorial ANOVA	Aggregate Group Consistency Index	(1) AHP Model Type (α_i) (2) Group Size (β_j)	$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk}$

ANALYSIS TWO

A. The electronic meeting technology model will produce lower pairwise comparison variances compared to the baseline model.
B. The smaller group size will produce lower pairwise comparison variances compared to the larger group size.
C. The electronic meeting technology model in combination with the smaller group size will produce lower pairwise comparison variances compared to the baseline model with either group size.

Design	Dependent Variable	Independent Variables	Model for Analysis
2 x 2 Factorial ANOVA	Group Pairwise Comparison Variances	(1) AHP Model Type (α_i) (2) Group Size (β_j)	$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk}$

ANALYSIS THREE

A. The Vice President level of responsibility will produce a lower pairwise comparison variance in the baseline model compared to the Non-Vice President level of responsibility.

Design	Dependent Variable	Independent Variables	Model for Analyses
Single Factor ANOVA	Individual Pairwise Comparison Means	(1) Organizational Role (α_i)	$Y_{ijk} = \mu + \alpha_i + \varepsilon_{ijk}$

ANALYSIS FOUR

A. The electronic meeting technology model will produce a lower mental workload compared to the baseline and knowledge self-assessment models.
B. The smaller group size will produce a lower mental workload compared to the larger group size.
C. The electronic meeting technology model in combination with the smaller group size will produce a lower mental workload than the baseline and knowledge self-assessment models with either group size.

Design	Dependent Variable	Independent Variables	Model for Analysis
3 x 2 Factorial ANOVA	Group Mental Workload Mean	(1) AHP Model Type (α_i) (2) Group Size (β_j)	$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk}$

ANALYSIS FIVE

A. The priority weighting variances for attributes and sub-attributes will differ significantly across attributes and sub-attributes.
B. The electronic meeting technology model will produce lower attribute and sub-attribute weighting variances than the baseline or knowledge self-assessment models.

Design	Dependent Variable	Independent Variables	Model for Analyses
19 X 3 Factorial ANOVA	Attribute and Sub-attribute Priority Weighting	(1) Attribute and Sub-attribute priority weighting (α_i) (2) AHP Model Type (β_i)	$Y_{ijk} = \mu + \alpha_i + \beta_j + \varepsilon_{ijk}$

they should contain no obvious patterns," (Montgomery, 1991). The residual for observation j in treatment i is:

$$e_{ij} = y_{ij} - \hat{y}_{ij}$$

where $\hat{y}_{ij}$ is the corresponding treatment average.

The normality assumption requires that a normal probability plot of the residuals resembles a straight line. The independence assumption requires that a plot of the residuals in a time-ordered sequence does not show positive correlation. The constant variance assumption is verified when a plot of the residuals versus the experimental factors appears patternless. Model adequacy testing was performed by examining the residuals for the data used in analyses one through five. The residual analyses for each dependent variable will be described within the discussion of each individual analysis.

5.2.1 Analysis One: Aggregate Consistency Index (Model, Group Size)

The participants used the pairwise comparison data collection forms to define their pairwise comparison judgments for attribute and sub-attributes in the baseline and electronic meeting technology models (Appendices G and J, respectively). Each model required fifty-four comparisons. However, the participants were required to rate only the pairwise comparisons in the upper half of each attribute and sub-attribute matrix, yielding twenty-seven judgments. The pairwise comparisons for the lower half of each primary and secondary matrix were derived by taking the mathematical inverse of the corresponding pairwise comparisons in the upper half of each matrix.

Knowledge self-assessment weightings were computed for each individual for each pairwise comparison based on the individual's knowledge rating using the five-point Likert scale provided in Table 19. The individual ratings for each pairwise comparison were summed within each of the eight participant groups to obtain a total pairwise comparison score. The weights for each comparison were calculated by dividing the individual ratings by the group's total pairwise comparison score, such that the summation of the individual weights across each pairwise comparison was equal to 1.00.

Table 19. Knowledge Self-Assessment Likert Scale.

Level of Knowledge	Score
Very unknowledgeable	1
Somewhat unknowledgeable	2
Neutral	3
Somewhat knowledgeable	4
Very knowledgeable	5

Two types of geometric means were used to aggregate the subjects' fifty-four pairwise comparison judgments. The geometric mean is the n^{th} root of the product of n numbers (Freund and Perles, 1974) and is used to average ratios or rates of change. A geometric mean was computed to aggregate individual participant pairwise judgments in the baseline and electronic meeting technology models and a weighted geometric mean was computed to aggregate individual participant judgments in the knowledge self-assessment model. The formulas that were used to calculate the means are:

$$\text{Geometric Mean: } J_g(k,l) = \prod_{i=1}^{n} J_i(k,l)$$

$$\text{Weighted Geometric Mean: } J_g(k,l) = \prod_{i=1}^{n} J_i(k,l)^{w_i} \quad \text{where}$$

$J_g(k,l)$ = the group judgment of the relative importance of attributes k and l.

$J_i(k,l)$ = the i^{th} individual's judgment of the relative importance of attributes k and l,

w_i = the weight of the i^{th} individual, based on the knowledge self-assessment weightings,
and subject to the constraint

$$\sum_{i=1}^{n} w_i = 1.$$

The eigenvector method was used to obtain "priority vectors" for each matrix. The priority vector represents the relative importance of each attribute within the AHP matrix. The priority vector was calculated by dividing each element of the matrix by the sum of its respective column, then averaging the row elements (Canada, et. al. 1996). The result is a priority vector with elements that sum to 1.00. Priority vectors were calculated for each of the five matrices (A through E) using the geometric means of the pairwise comparison judgments as the matrix elements for the baseline and electronic meeting technology models. The weighted geometric means were used as the matrix elements for the knowledge self-assessment model.

The aggregate group consistency index which is computed based on the geometric means of the pairwise comparisons was used to determine the group consistency. Recall that the smaller the index, the more consistent the judgments. Yeh et. al (1999) suggested that a consistency index of less than 0.10 implies consistency among judgments. The steps used to calculate the consistency index for each of the five matrices were:

Step 1: Convert the pairwise comparisons to decimal equivalents creating a matrix.

Step 2: Divide each cell in the matrix by the sum of the associated column in the matrix creating a new matrix.

Step 3: Average the rows in the new matrix to produce the principal vector.

Step 4: Multiply the principle vector by the first matrix to create another new matrix.

Step 5: Compute the average for each row in the new matrix generated from Step 4.

Step 6: Compute the average of the average rows in the new matrix generated from Step 4 to produce the maximum eigenvector (λ_{max}).

Step 7: The consistency index is then calculated as:

$$\text{CI} = \frac{\lambda_{max} - N}{N - 1}$$

where N = the number of attributes in the matrix of pairwise comparisons.

An aggregate group consistency index was calculated for the aggregate of all five matrices for each participant group. As discussed in section 3.2.2, the calculation of the aggregate group consistency index (M) for the entire hierarchy requires the calculation of cluster consistency indices (i.e., the sub-attribute consistency indices). The formula for calculating M for lower level clusters and for the aggregate consistency index is:

$$\text{M} = n\text{-level Consistency Index} + (\text{vector of } n\text{-level priority weights}) \times (\text{vector of } n+1\text{- level Consistency Indices})$$

In order to test the ANOVA assumptions, the Aggregate Group Consistency Index residuals were calculated using SAS. The SAS Univariate procedure was used to test the normality assumption. The normal probability and stem leaf plots did not reveal any abnormality. The Shapiro-Wilkerson statistic for residuals was 0.9857, indicating a high probability of normality. These tests validated the normality assumption. The randomness assumption was tested by plotting the residuals versus the factor values (model type and group size). Visual examination of the residuals plotted against the levels of the experimental factors did not reveal any non-constant variances or obvious patterns, which satisfied the constant variance assumption. The independence assumption could not be tested because the time order of data collection was not relevant to the experimental method. However, the data were collected in random order to minimize bias due to sequential observations. Such randomization typically ensures satisfaction of the independence assumption.

A summary of the aggregate group consistency indices by group size and AHP model for each of the eight participant groups is provided in Table 20. The results show that the direction of change in the aggregate group consistency index between the baseline and electronic meeting technology models is somewhat random. However, the aggregate group consistency index for the knowledge self-assessment model is consistently improved, compared to both the baseline and electronic meeting technology models. According to Figure 9, the knowledge self-assessment model appears to produce more consistent judgements, as does a group size of seven. According to Figure 10, there does not appear to be an interaction effect between the baseline model type and group size because the aggregate group consistency indexes for the two group sizes are very similar.

Table 20. Summary of the Aggregate Group Consistency Indices by Model Type and Group Size.

	AHP Model Type				
	Baseline	KSA	EMT	Average	Variance
Group Size = 5	0.211	0.296	0.092		
	0.157	0.097	0.192		
	0.102	0.165	0.170		
	0.193	0.196	0.148		
Average	**0.166**	**0.188**	**0.151**	**0.168**	**0.003**
Group Size =7	0.095	0.129	0.197		
	0.065	0.050	0.046		
	0.077	0.081	0.102		
	0.032	0.063	0.123		
Average	**0.067**	**0.081**	**0.117**	**0.088**	**0.002**
Average	**0.117**	**0.134**	**0.134**		
Variance	**0.003**	**0.007**	**0.003**		

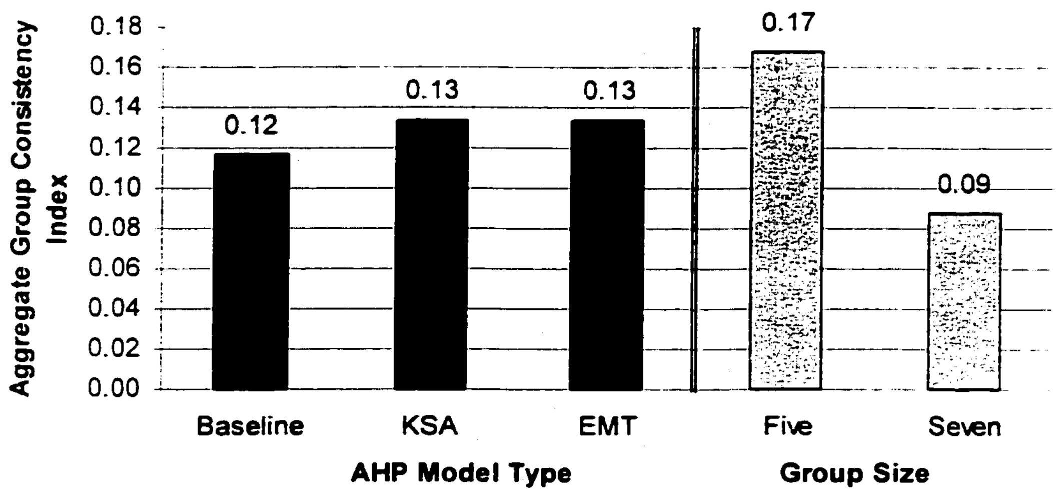


Figure 9. Model and Group Size Main Effects by Aggregate Group Consistency Index.

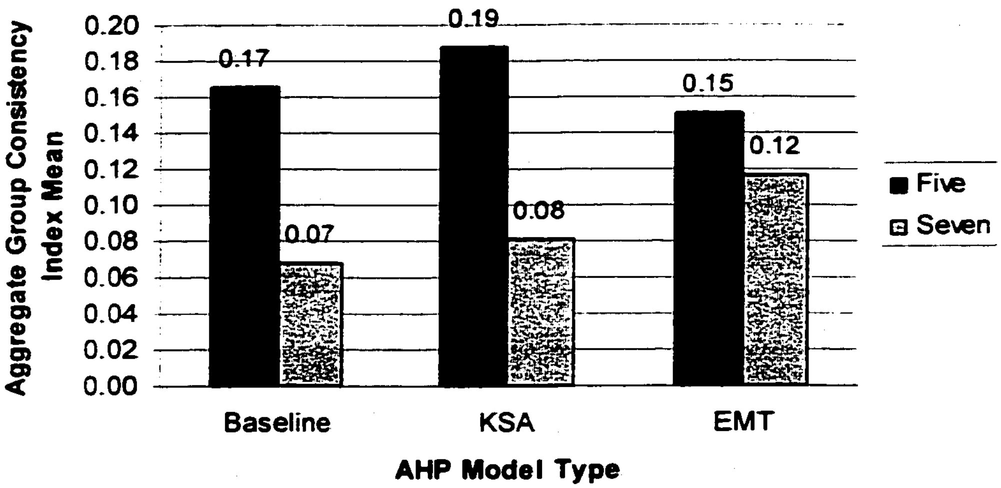


Figure 10. Model and Group Size Interaction by Aggregate Group Consistency Index.

A 3 × 2 ANOVA was used to assess the variation in the aggregate group consistency index among the three AHP models (baseline, knowledge self-assessment, and electronic meeting technology) and the two different group sizes (five and seven). Hypothesis A examined the equality effect of AHP models on the aggregate group consistency index using the following hypothesis statement:

$H_o : \tau_1 = \tau_2 = \tau_3 = 0$

H_1 : at least one $\tau_i \neq 0$

where τ_i is the effect of the ith level of the AHP model factor.

Hypothesis B examined the effect of group size on the aggregate group consistency index using the following hypothesis statement:

$H_o : \beta_1 = \beta_2 = 0$

H_1 : at least one $\beta_j \neq 0$

where β_j is the effect of the jth level of the group size factor.

Hypothesis C examined the interaction between AHP model and group size on the aggregate group consistency index using the following hypothesis statement:

H_o : $(\tau\beta)_{ij} = 0$

H_1 : at least one $(\tau\beta)_{ij} \neq 0$

where $(\tau\beta)_{ij}$ is the effect of the interaction between τ_i (AHP model) and β_j (group size).

The ANOVA summary for this analysis is provided in Table 21. The ANOVA revealed that there were significant main effects for group size (F = 13.79, p = 0.0016), but not for model type (F = 10.29, p = 0.7494). There was no significant interaction between model type and group size.

Table 21. ANOVA Summary for Aggregate Group Consistency Index (Model and Group Size).

Source	DF	Mean Square	F Value	Pr>F
AHP Model Type	2	0.0008	0.2900	0.7494
Group Size	1	0.0384	13.7900	0.0016
Interaction	2	0.0047	1.1700	0.3341

The ANOVA results do not support Hypothesis A because the electronic meeting technology used as a knowledge management tool for the AHP decision processes did not produce more consistency than either the baseline or knowledge self-assessment models. Instead, the baseline model produced greater group consistency than the other two models. The ANOVA results also do not support Hypothesis B, that a smaller group size produces greater consistency than a larger group size. Instead, the group size of seven was significantly more consistent than the group size of five. Again, the ANOVA results do not support Hypothesis C, that the combination of the electronic meeting technology model and a smaller group size would produce greater consistency. Instead, the interaction between AHP model type and group size was not significant.

In an effort to understand why consistency did not improve overall, but did improve for some groups, variables that could potentially influence group consistency were identified. These variables and their definitions are provided in Table 22.

Table 22. Potential Influential Variables for the Aggregate Group Consistency Index.

Variable	Definition
Group Mix	The quantity of perspectives represented in the group. Data was provided through demographic questionnaire. Perspectives defined by participants' areas of responsibility include: financial, clinical, operations, human resources, marketing, information technology, and other.
Group Size	The size of the group in the electronic meeting technology model.
Average Years Experience in Healthcare	The group average years of experience in healthcare. Data provided through demographic questionnaire.
Group Influence Rating	The group average rating of the post electronic meeting survey question: "To what degree did the discussion contribute to the revision of your pairwise comparison ratings?"

The line graphs in Figure 11 were constructed to gain insight on whether or not these variables influenced the change in the aggregate group consistency index from the baseline model to the electronic meeting technology model. The data points are ordered by group sequence, which is the order in which the experiments were conducted. Group size appears to have the strongest influence on the aggregate group consistency index because the aggregate group consistency data points and the group size data points have somewhat of an inverse linear relationship to each other. The other variables do not seem to have any relationship to the change in the aggregate group consistency index from the baseline model to the electronic technology meeting model.

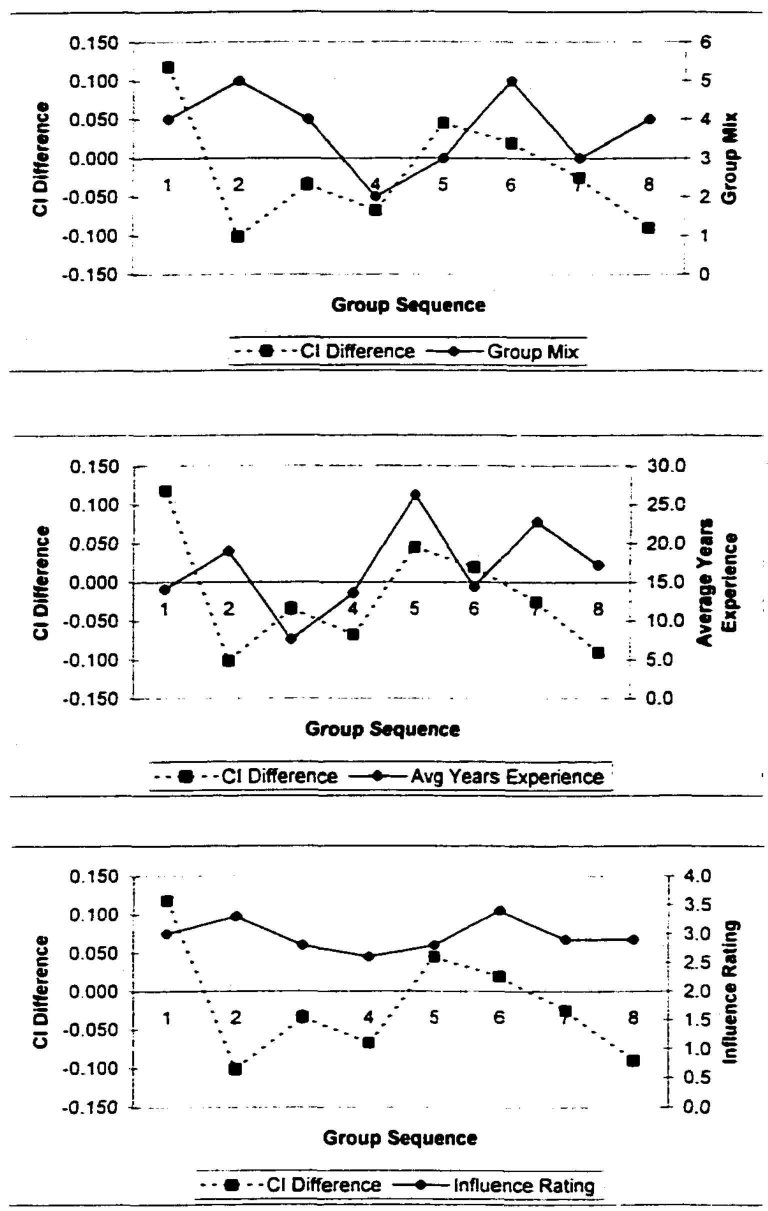


Figure 11. Group-Based Variables Plotted Against Aggregate Group Consistency Index.

5.2.2 Analysis Two: Pairwise Comparison Variances (Model, Group Size)

The pairwise comparison variance is a measure of the dispersion of individual participant opinions. This measure represents group consensus regarding the relative importance of the decision hierarchy attributes. Consensus differs from the aggregate group consistency index. The aggregate group consistency index incorporates the concept of being able to make logical deductions from raw data (e.g., A = 3 B and B = 4C, then A = 12 C). Consensus, on the other hand, defines group agreement and is measured as the variance among judgments and does not represent relations between attributes. Pairwise comparison variances were computed for each of the twenty-seven pairwise comparisons made by individuals within a group using the formula:

$$s^2 = \sum \frac{(x_i - \bar{x})^2}{n-1}$$

where x_i represents a paired comparison rating for participant i, and n is the number of participants.

In order to test the ANOVA assumptions, the Aggregate Group Consistency Index residuals were calculated using SAS. The SAS Univariate procedure was used to test the normality assumption. The normal probability and stem leaf plots did not reveal any abnormality. The Shapiro-Wilkerson statistic for residuals was 0.843, indicating a somewhat high probability of normality. These tests validated the normality assumption. The randomness assumption was tested by plotting the residuals versus the factor values (model type and group size). Visual examination of the residuals plotted against the levels of the experimental factors revealed some degree of non-constant variances. Variance-stablilizing was performed by a log transformation of the data. This transformation weakened the normality in the data set and did not change the ANOVA.

Therefore, the original data set was used in the analysis. A time-sequenced randomization of tasks was not possible with the methodology used so the independence assumption was not tested

A summary of pairwise comparison variances by AHP model type and group size is provided in Table 23 and illustrated in Figure 12. The electronic meeting technology model appears to produce a slightly lower pairwise comparison variance for both group sizes. Similarily, the group size of seven appears to produce a lower pairwise comparison variance than a group size of five.

Table 23. Summary of Pairwise Comparison Variances for Model Type and Group Size.

	Group Size		
Model	Five	Seven	Average
Baseline	12.908	10.086	**11.497**
EMT	10.503	9.643	**10.073**
Average	**11.705**	**9.864**	

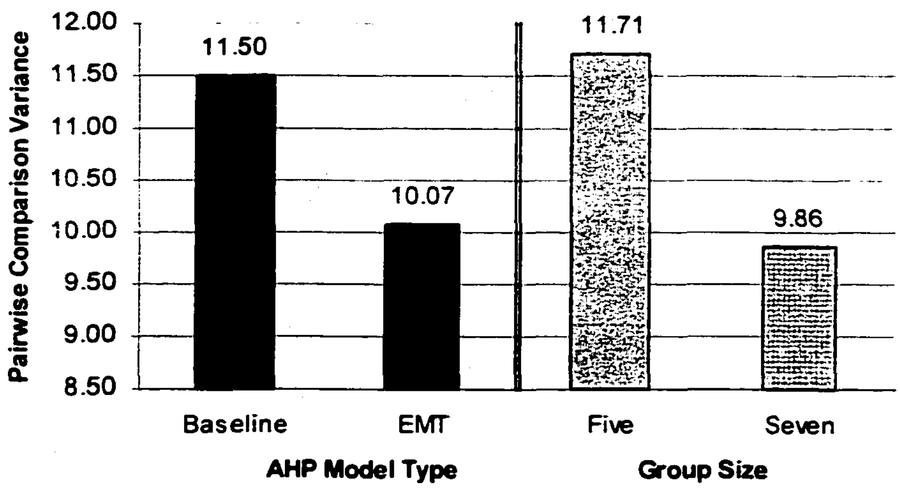


Figure 12. Model and Group Size Effects by Pairwise Comparison Variance.

Figure 13 shows a graph of the interaction between model and group size. There does not appear to be any interaction effects because the pairwise comparison variances for both group sizes are very similar for both model types.

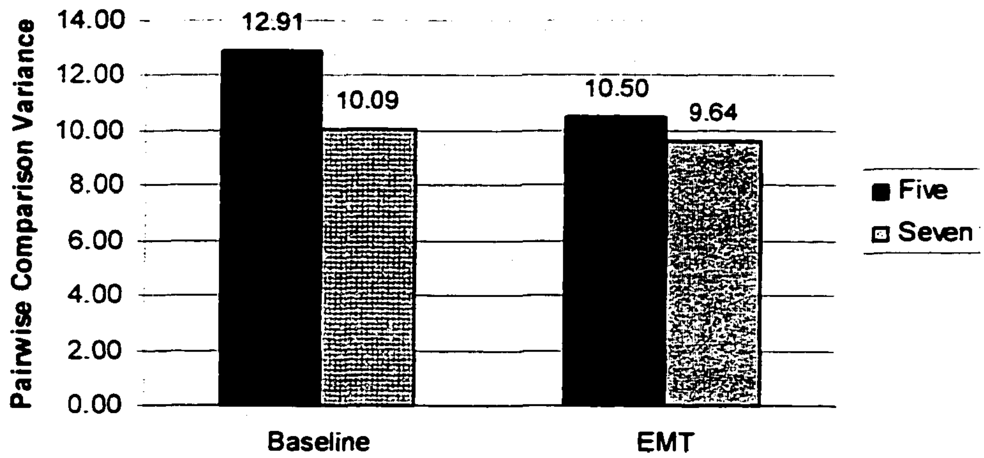


Figure 13. Model and Group Size Interaction by Pairwise Comparison Variance.

A 2×2 ANOVA was used to compare pairwise comparison variances for the two AHP models (baseline and electronic meeting technology) and the two group sizes (five and seven). Hypothesis A examined the equality of AHP models using the following hypothesis statement:

$H_o : \tau_1 = \tau_2 = 0$

$H_1 :$ at least one $\tau_i \neq 0$

where τ_i is the effect of the i^th level of the AHP model factor.

Hypothesis B examined the equality of group size using the following hypothesis statement:

$H_o : \beta_1 = \beta_2 = 0$

H_1 : at least one $\beta_j \neq 0$

where β_j is the effect of the jth level of the group size factor.

Hypothesis C examined the interaction between AHP model type and group size using the following hypothesis statement:

H_o : $(\tau\beta)_{ij} = 0$

H_1 : at least one $(\tau\beta)_{ij} \neq 0$

where $(\tau\beta)_{ij}$ is the effect of the interaction between AHP model (τ_i) and group size (β_j).

The ANOVA summary for this analysis is provided in Table 24. The ANOVA reveals that model type is not significant (F = 0.51, p = 0.4757). There are also no significant effects for group size (F = 0.86, p = 0.3569) or for the interaction between model and group size. None of the hypotheses were supported in this analysis and none of the effects under examination were found to influence the pairwise comparison variances.

Table 24. ANOVA Summary for Pairwise Comparison Variance (Model and Group Size).

Source	DF	Mean Square	F Value	Pr>F
AHP Model Type	1	54.7649	0.51	0.4757
Group Size	1	91.5253	0.86	0.3569
Interaction	1	25.9756	0.24	0.6231

5.2.3 Analysis Three: Pairwise Comparison Variances (Level of Responsibility)

The assumption behind analysis 3 was that participants at the Vice President level of responsibility will produce more agreement with respect to the pairwise comparison variances because they share a more similar mental model of the relative importance of attributes and sub-attributes to capital investment decisions.

In order to test the ANOVA assumptions, the Aggregate Group Consistency Index residuals were calculated using SAS. The SAS Univariate procedure was used to test the normality assumption. The normal probability and stem leaf plots did not reveal any abnormality. The Shapiro-Wilkerson statistic for residuals was 0.9815, indicating a high probability of normality, validating the normality assumption. The randomness assumption was tested by plotting the residuals versus the factor values (model type and group size). Visual examination of the residuals plotted against the levels of the experimental factors revealed some degree of non-constant variances. Variance-stablilizing was performed by a log transformation of the data. This transformation weakened the normality in the data set and did not change the ANOVA. Therefore, the original data set was used in the analysis. A time-sequenced randomization of tasks was not possible with the methodology used so the independence assumption was not tested.

A summary of the pairwise comparison variances by level of responsibility is provided in Table 25 and shown in Figure 14. The results indicated that the Non-VP level of responsibility produced a lower pairwise comparison variance than the VP level of responsibility.

Table 25. Summary of Pairwise Comparison Variances by Level of Responsibility.

	Level of Responsibility	
Model	**Vice President**	**Non-Vice President**
Baseline	5.322	4.077

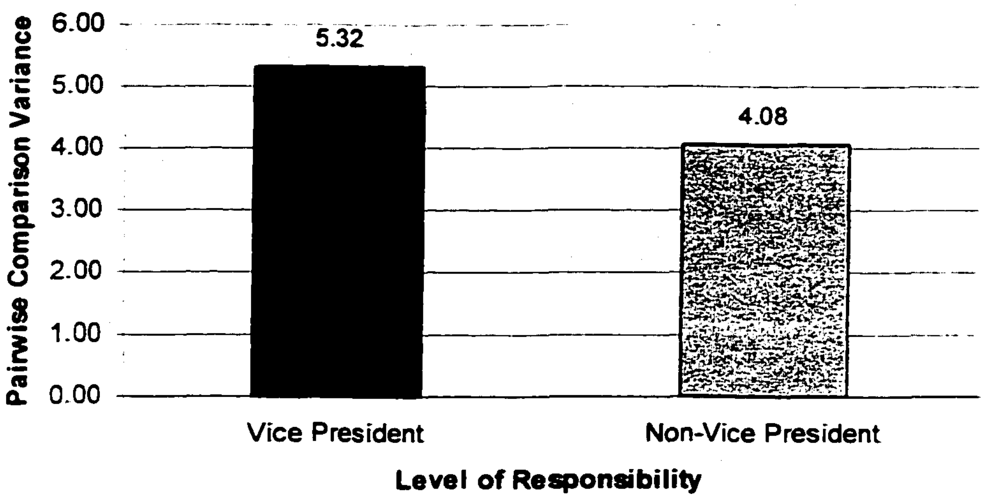


Figure 14. Level of Responsibility Main Effect by Pairwise Comparison Variance.

A single factor ANOVA was used to test the hypothesis. Hypothesis A examined the equality of group consensus using the following hypothesis statement:

$H_o : \mu_1 = \mu_2$

$H_1 : \mu_1 < \mu_2$

where μ_i is the effect of the i^{th} level of responsibility.

The ANOVA summary for this analysis is provided in Table 26. The main effect of Level of Responsibility was not significant ($F = 2.63$, $p = 0.1109$). This analysis does not support Hypothesis A because the pairwise comparison variance for the Vice President level of responsibility was not significantly lower than the Non-Vice President level of responsibility.

Table 26. ANOVA Summary for Pairwise Comparison Variance (Level of Responsibility).

Source	DF	Mean Square	F Value	Pr>F
Level of Responsibility	1	18.709	2.631	0.1109

5.2.4 Analysis Four: Mental Workload (Model, Group Size)

The NASA-TLX (Hart and Staveland, 1988) was used as a subjective measure of mental workload. The NASA-TLX measured six factors related to mental workload (mental demand, physical demand, temporal demand, performance, effort, and frustration) using a Likert scale. The participants were asked to rate the following tasks using the NASA-TLX data collection form and instructions provided in Appendix M:

Task 1: Completing the initial AHP pairwise comparison judgment task;

Task 2: Completing the Hierarchical Element Knowledge Self-Assessment Questionnaire;

Task 3 : Participating in a face-to-face meeting using Groupware electronic meeting technology to discuss outlier pairwise judgments through the Topic Commenter task; and

Task 4: Completing the revised AHP pairwise comparison judgment task.

Following the completion of each task, the participants were asked to circle the member of each pair of mental workload factors that provided the most significant source of workload in the task. A count of the number of times each factor was circled was tabulated. This count was divided by the total count to determine a weighting for each factor. The participants were also asked to rate the task's workload with respect to each NASA-TLX factor by marking a location along a 10-point Likert scale, with 1 indicating low workload and 10 indicating high workload. The mental workload of each participant was calculated by multiplying each NASA-TLX factor weighting by the task rating and summing these values for all NASA-TLX factors. The mental workload value for each task was determined by averaging across the participant mental workload values to produce an average group mental workload.

The NASA-TLX measurement for Task 1 was used as a baseline mental workload measure since this activity is the core component of the AHP process. The modifications to AHP implementation used in this experiment required the performance of additional tasks. The intent was to measure the degree to which these modifications affect mental workload as compared to the baseline AHP process.

A summary of the mental workload index by group size and AHP model for each of the eight participant groups is provided in Table 27. Figure 15 presents the average mental workload for model type and group size. The baseline model appears to produce a higher mental workload. The mental workload for the group size of five was very similar to the group size of seven.

Table 27. Summary of NASA-TLX Mental Workload Ratings by Model Type and Group Size.

	AHP Model Type				
	Baseline	KSA	EMT	Average	Variance
Group Size = 5	6.600	6.933	5.350		
	6.760	4.960	5.880		
	6.475	6.167	5.375		
	7.550	6.600	4.500		
Average	**6.846**	**6.165**	**5.276**	**6.096**	**0.807**
Group Size = 7	6.680	3.383	5.125		
	6.420	5.520	6.586		
	6.500	6.933	5.914		
	6.471	6.014	6.400		
Average	**6.518**	**5.463**	**6.006**	**5.996**	**0.940**
Average	**6.682**	**5.814**	**5.641**		
Variance	**0.136**	**1.430**	**0.475**		

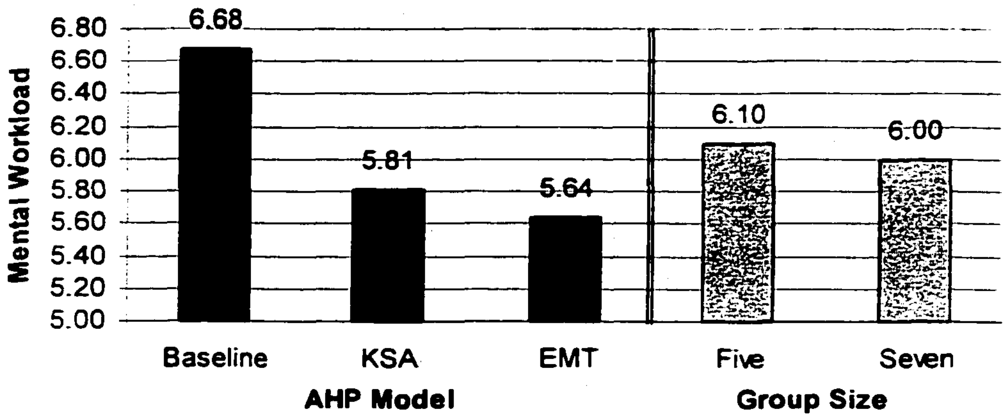


Figure 15. Model and Group Size Main Effects by Mental Workload Rating.

Figure 16 presents the interaction between model and group size. There does not appear to be an interaction between model and group size that affects mental workload.

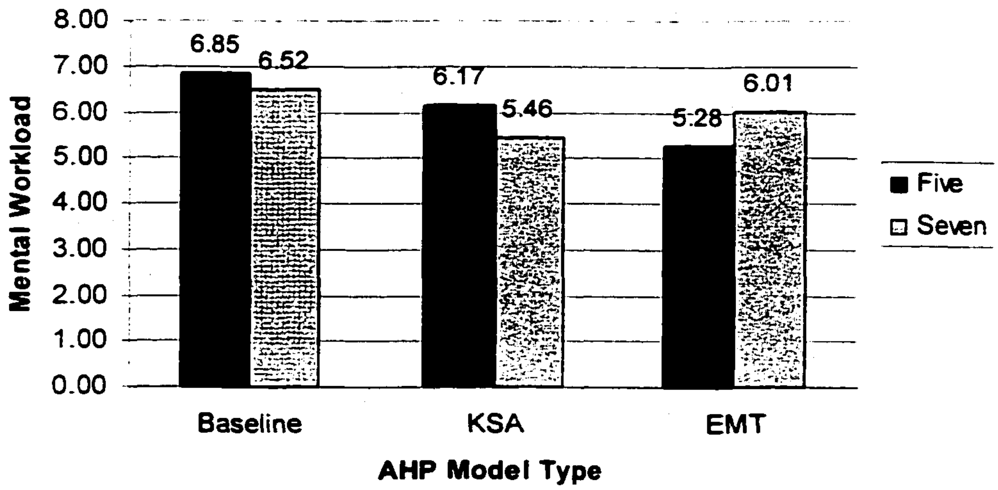


Figure 16. Model and Group Size Interaction by Mental Workload Rating.

A 3×2 ANOVA was used to compare mental workload measures for the three AHP models (baseline and electronic meeting technology) and the two group sizes (five and seven). Hypothesis A examined the effect of AHP model type on mental workload using the following hypothesis statement:

$H_o : \tau_1 = \tau_2 = \tau_3 = 0$

H_1 : at least one $\tau_i \neq 0$

where τ_i is the effect of the ith level of the AHP model type factor.

Hypothesis B examined the effect of group size on mental workload using the following hypothesis statement:

$H_o : \beta_1 = \beta_2 = 0$

H_1 : at least one $\beta_j \neq 0$

where β_j is the effect of the jth level of the group size factor.

Hypothesis C examined the interaction between AHP model type and group size using the following hypothesis statement:

$H_o : (\tau\beta)_{ij} = 0$

H_1 : at least one $(\tau\beta)_{ij} \neq 0$

where $(\tau\beta)_{ij}$ is the effect of the interaction between τ_i (AHP model) and β_j (group size).

The ANOVA for this analysis is summarized in Table 28. The ANOVA reveals that there are significant main affects for AHP model type ($F = 3.73$, $p = 0.0442$). However, the main effect of group size was not significant ($F = 0.09$, $p = 0.0442$), as was the interaction between model type and group size.

Table 28. ANOVA Summary for Mental Workload Rating (Model and Group Size).

Source	DF	MS	F	Pr > F
Group Size	1	0.0220	0.04	0.8462
AHP Model Type	2	2.3880	4.21	0.0316
Interaction	2	0.9698	1.71	0.2091

A Tukey's Studentized Range (HSD) Test was performed to identify which models are significantly different. The critical value for AHP model type was computed as 0.961. As shown in Figure 17, significant differences were found between the baseline and the electronic meeting technology models. The absolute value of the difference in mental workload between the baseline and the electronic meeting technology AHP models (1.041) exceed the critical value of 0.9611. The conclusion of the Tukey test is that the baseline AHP model differed significantly compared to the electronic meeting technology AHP model, and that there is no significant difference between the knowledge self-assessment and electronic meeting technology or the baseline and knowledge self-assessment AHP models. The electronic meeting technology model produced a lower mental workload in comparison to the baseline; however, the Tukey test indicated that the knowledge self-assessment and the electronic meeting technology models are similar; thus, Hypothesis A is not supported. The results do not support Hypothesis B because mental workload for the smaller group size was not significantly different than the larger group size. The results also do not support Hypothesis C because there was not a significant interaction between model and group size.

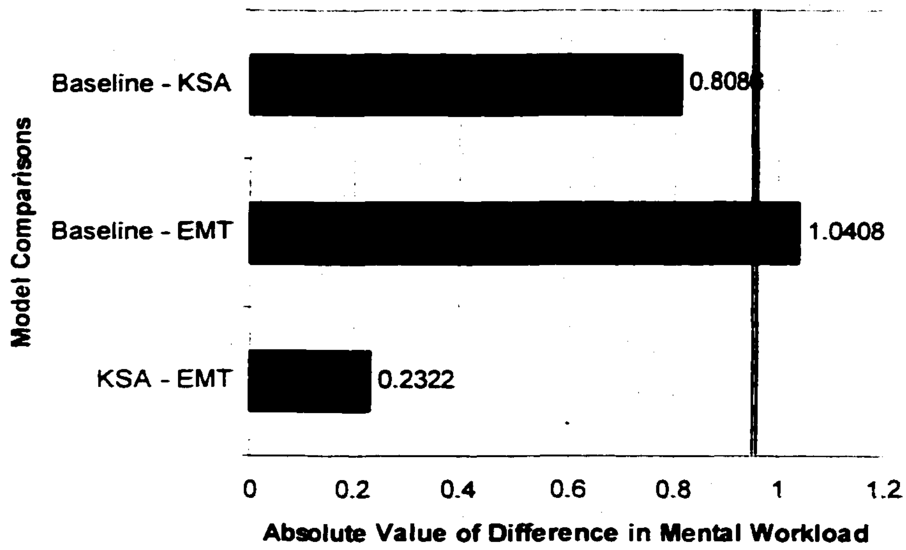


Figure 17. Tukey's Studentized Range Test (HSD) for Model Types by Mental Workload.

5.2.5 Analysis Five: Attribute Weighting Variance (Attribute and Sub-attribute, Model)

The variance of the decision hierarchy attribute weightings was calculated by computing the weightings for each attribute and for each group for each AHP model type. The variance between attributes and sub-attributes within a group was computed as:

$$s^2 = \sum \frac{(x_i - \bar{x})^2}{n-1}$$

where x_i represents an attribute or sub-attribute weighting for decision hierarchy attribute I (i.e., 4 for attribute A, 3 for sub-attribute B, 4 for sub-attribute C, 4 for sub-attribute D, and 4 for sub-attribute E), and

n is the number of decision hierarchy attributes.

A summary of the attribute weightings for each of the eight groups, (Group A through Group H), categorized for each group size, and for each AHP model is provided in Figure 18. A summary of the attribute and sub-attribute weighting variances by model type is provided in Table 29. According to Figure 19, the greatest variance in weighting

Objective: Identify the most successful capital investment projects.

Matrix A Attribute Weightings

Group	A1: Internal Business Processes			A2: Learning and Growth			A3: Customer			A4: Finance and Value		
	Baseline	KSA	EMT	Baseline	KSA	EMT	Baseline	KSA	EMT	Baseline	KSA	EMT
Group Size = 5												
A	0.143	0.132	0.156	0.164	0.118	0.106	0.419	0.445	0.467	0.274	0.305	0.272
C	0.189	0.147	0.186	0.099	0.093	0.085	0.484	0.585	0.537	0.215	0.174	0.191
D	0.229	0.212	0.218	0.094	0.095	0.082	0.364	0.414	0.358	0.313	0.279	0.342
E	0.152	0.154	0.130	0.097	0.138	0.118	0.555	0.503	0.587	0.196	0.205	0.165
Group Size = 7												
B	0.160	0.142	0.165	0.079	0.077	0.051	0.483	0.477	0.467	0.278	0.304	0.317
F	0.120	0.094	0.106	0.186	0.198	0.153	0.401	0.472	0.408	0.293	0.236	0.333
G	0.238	0.233	0.176	0.064	0.067	0.054	0.397	0.391	0.46	0.301	0.308	0.311
H	0.165	0.168	0.197	0.139	0.158	0.125	0.435	0.395	0.415	0.262	0.279	0.263
Average	**0.175**	**0.160**	**0.167**	**0.115**	**0.118**	**0.097**	**0.442**	**0.460**	**0.462**	**0.267**	**0.261**	**0.274**
Variance	**0.002**	**0.002**	**0.001**	**0.002**	**0.002**	**0.001**	**0.004**	**0.004**	**0.005**	**0.002**	**0.003**	**0.004**

A1: Internal Business Processes (Matrix B Sub-attribute Weightings)

Group	B1: Leverage against existing products or services			B2: Increase operational efficiency			B3: Improve supply and demand chain		
	Baseline	KSA	EMT	Baseline	KSA	EMT	Baseline	KSA	EMT
Group Size = 5									
A	0.148	0.128	0.141	0.510	0.455	0.691	0.342	0.416	0.168
C	0.170	0.249	0.200	0.360	0.332	0.409	0.375	0.419	0.390
D	0.113	0.183	0.173	0.421	0.463	0.547	0.381	0.354	0.280
E	0.057	0.306	0.250	0.443	0.437	0.508	0.259	0.257	0.242
Group Size = 7									
B	0.114	0.125	0.101	0.450	0.549	0.556	0.425	0.327	0.340
F	0.201	0.171	0.198	0.444	0.597	0.424	0.335	0.232	0.378
G	0.296	0.191	0.268	0.504	0.511	0.438	0.286	0.298	0.293
H	0.249	0.226	0.241	0.553	0.565	0.563	0.237	0.209	0.196
Average	**0.169**	**0.197**	**0.197**	**0.461**	**0.489**	**0.517**	**0.330**	**0.314**	**0.286**
Variance	**0.006**	**0.004**	**0.003**	**0.004**	**0.007**	**0.009**	**0.004**	**0.006**	**0.007**

A2: Learning and Growth (Matrix C Sub-attribute Weightings)

Group	C1: Fit with operational competencies and culture			C2: Implementation initiatives required			C3: Ability to position organization for future			C4: Organizational risk		
	Baseline	KSA	EMT	Baseline	KSA	EMT	Baseline	KSA	EMT	Baseline	KSA	EMT
Group Size = 5												
A	0.228	0.142	0.231	0.165	0.077	0.200	0.409	0.477	0.376	0.198	0.304	0.191
C	0.174	0.144	0.202	0.116	0.107	0.099	0.465	0.563	0.468	0.245	0.186	0.232
D	0.113	0.116	0.132	0.092	0.087	0.071	0.484	0.519	0.497	0.311	0.278	0.299
E	0.057	0.073	0.073	0.129	0.148	0.113	0.409	0.384	0.377	0.405	0.396	0.437
Group Size = 7												
B	0.114	0.105	0.100	0.119	0.102	0.109	0.569	0.605	0.629	0.198	0.187	0.162
F	0.201	0.125	0.209	0.147	0.205	0.187	0.402	0.460	0.289	0.250	0.209	0.334
G	0.296	0.402	0.323	0.096	0.089	0.100	0.455	0.352	0.443	0.153	0.158	0.133
H	0.249	0.273	0.261	0.128	0.139	0.121	0.332	0.246	0.360	0.290	0.342	0.259
Average	**0.179**	**0.173**	**0.191**	**0.124**	**0.119**	**0.125**	**0.441**	**0.451**	**0.430**	**0.256**	**0.258**	**0.256**
Variance	**0.006**	**0.012**	**0.007**	**0.001**	**0.002**	**0.002**	**0.005**	**0.014**	**0.011**	**0.006**	**0.007**	**0.010**

A3: Customer (Matrix D Sub-attribute Weightings)

Group	D1: Innovation to existing services			D2: Satisfy customer needs			D3: Sustain existing competitive advantage			D4: Potential to create a new market		
	Baseline	KSA	EMT	Baseline	KSA	EMT	Baseline	KSA	EMT	Baseline	KSA	EMT
Group Size = 5												
A	0.248	0.274	0.203	0.326	0.318	0.380	0.163	0.167	0.167	0.243	0.242	0.249
C	0.122	0.101	0.091	0.390	0.370	0.379	0.200	0.209	0.167	0.323	0.320	0.343
D	0.137	0.149	0.101	0.512	0.525	0.556	0.134	0.126	0.137	0.217	0.197	0.204
E	0.115	0.119	0.097	0.414	0.406	0.435	0.273	0.274	0.204	0.198	0.202	0.264
Group Size = 7												
B	0.133	0.103	0.149	0.543	0.525	0.596	0.199	0.259	0.170	0.125	0.112	0.065
F	0.088	0.083	0.091	0.548	0.611	0.595	0.216	0.220	0.186	0.148	0.086	0.128
G	0.162	0.180	0.117	0.420	0.423	0.429	0.213	0.211	0.268	0.205	0.166	0.186
H	0.197	0.224	0.214	0.373	0.354	0.373	0.239	0.213	0.257	0.191	0.209	0.163
Average	**0.150**	**0.154**	**0.133**	**0.441**	**0.442**	**0.468**	**0.207**	**0.210**	**0.197**	**0.206**	**0.194**	**0.203**
Variance	**0.003**	**0.005**	**0.003**	**0.007**	**0.010**	**0.010**	**0.002**	**0.002**	**0.002**	**0.004**	**0.005**	**0.007**

A4: Finance and Value (Matrix E Sub-attribute Weightings)

Group	E1: Cost savings potential			E2: Startup cost			E3: Ongoing cost			E4: Revenue source potential		
	Baseline	KSA	EMT	Baseline	KSA	EMT	Baseline	KSA	EMT	Baseline	KSA	EMT
Group Size = 5												
A	0.370	0.396	0.331	0.130	0.129	0.086	0.201	0.198	0.166	0.299	0.277	0.417
C	0.304	0.323	0.335	0.095	0.104	0.181	0.200	0.181	0.174	0.401	0.392	0.408
D	0.326	0.327	0.391	0.098	0.082	0.086	0.236	0.245	0.200	0.340	0.345	0.323
E	0.343	0.359	0.319	0.149	0.151	0.168	0.293	0.324	0.320	0.215	0.165	0.194
Group Size = 7												
B	0.194	0.162	0.319	0.075	0.059	0.094	0.300	0.258	0.333	0.431	0.521	0.254
F	0.403	0.491	0.342	0.142	0.089	0.193	0.175	0.114	0.245	0.279	0.306	0.220
G	0.285	0.277	0.253	0.120	0.107	0.086	0.199	0.164	0.207	0.396	0.452	0.454
H	0.246	0.257	0.344	0.156	0.154	0.089	0.271	0.231	0.282	0.328	0.358	0.286
Average	**0.309**	**0.324**	**0.329**	**0.121**	**0.109**	**0.123**	**0.234**	**0.214**	**0.241**	**0.336**	**0.352**	**0.320**
Variance	**0.005**	**0.010**	**0.001**	**0.001**	**0.001**	**0.002**	**0.002**	**0.004**	**0.004**	**0.005**	**0.012**	**0.010**

Figure 18. Attribute and Sub-attribute Weightings.

among groups occurs (in descending order) with the attributes and sub-attributes:

- ability to position organization for the future (C3),
- ability to satisfy customer needs (D2),
- revenue source potential (E4),
- fit with operational competencies and culture (C1), and
- organizational risk (C4).

The least variance in weighting is produced by the knowledge self-assessment model, followed by the baseline model, as shown in Figure 20.

Table 29. Summary of Attribute and Sub-attribute Priority Weighting Variances by Model.

	Average Priority Weighting Variance			
Attributes and Sub-attributes	**Baseline**	**KSA**	**EMT**	**Average**
A1: Internal Business Processes	0.0017	0.0020	0.0013	**0.0017**
A2: Learning and Growth	0.0019	0.0020	0.0013	**0.0017**
A3: Customer	0.0039	0.0042	0.0053	**0.0045**
A4: Finance and Value	0.0017	0.0025	0.0043	**0.0028**
B1: Leverage against existing products or services	0.0032	0.0037	0.0032	**0.0034**
B2: Increase operational efficiency	0.0036	0.0072	0.0088	**0.0065**
B3: Improve supply and demand chain	0.0042	0.0064	0.0066	**0.0057**
C1: Fit with operational competencies and culture	0.0064	0.0120	0.0071	**0.0085**
C2: Implementation initiatives required	0.0006	0.0018	0.0017	**0.0014**
C3: Ability to position organization for the future	0.0049	0.0140	0.0121	**0.0103**
C4: Organizational risk	0.0062	0.0073	0.0099	**0.0078**
D1: Innovation to existing services	0.0026	0.0045	0.0025	**0.0032**
D2: Satisfy customer needs	0.0069	0.0105	0.0099	**0.0091**
D3: Sustain existing competitive advantage	0.0016	0.0022	0.0020	**0.0020**
D4: Potential to create a new market	0.0026	0.0053	0.0067	**0.0049**
E1: Cost savings potential	0.0045	0.0096	0.0015	**0.0052**
E2: Startup cost	0.0008	0.0011	0.0019	**0.0013**
E3: Ongoing cost	0.0023	0.0042	0.0042	**0.0036**
E4: Revenue source potential	0.0052	0.0119	0.0095	**0.0089**
Average	**0.0034**	**0.0059**	**0.0053**	

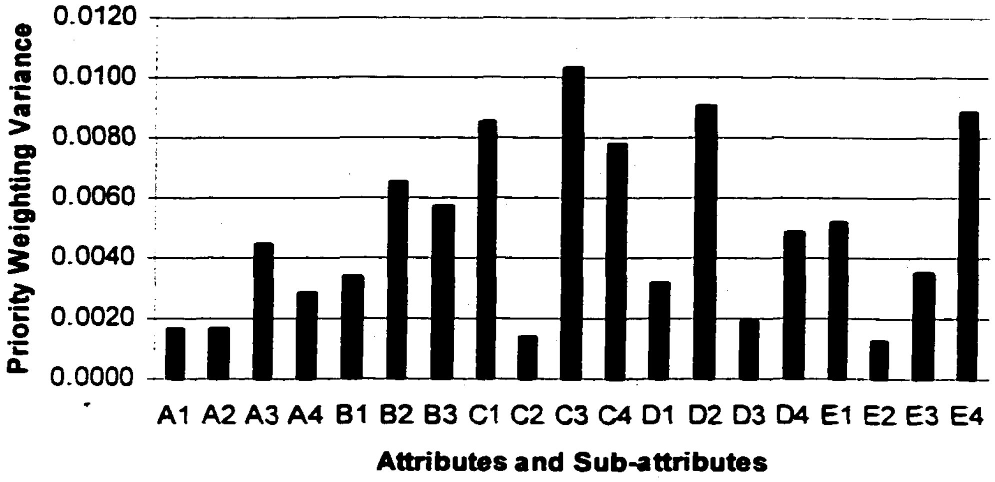


Figure 19. Attribute and Sub-attribute Main Effects by Priority Weighting Variance.

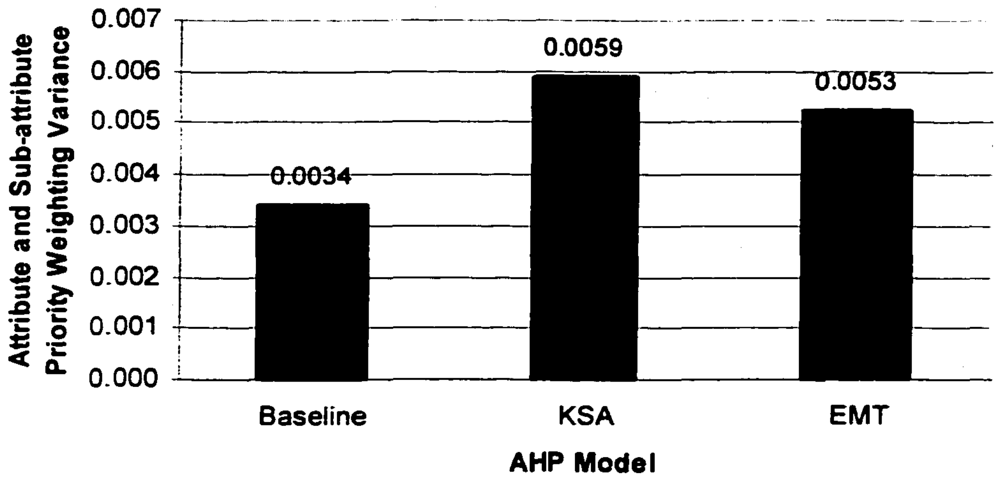


Figure 20. Model Main Effect by Priority Weighting Variance.

A 19 $\times 3$ factor ANOVA was used to test Hypothesis A about the attribute and sub-attribute priority weighting variances. The theory was that participants in the electronic meeting technology model would produce more agreement with respect to the attribute weightings. Hypothesis A examined the effect of attributes and sub-attributes on priority weighting variances using the following hypothesis statement:

$$H_o : \tau_1 = ... = \tau_{19} = 0$$

$$H_1 : \text{at least one } \tau_i \neq 0$$

where τ_i is the effect of the i^{th} level of the attribute.

Hypothesis B examined the effect of AHP model type on priority weighting variances using the following hypothesis statement:

$$H_o : \beta_1 = \beta_2 = 0$$

$$H_1 : \text{at least one } \beta_j \neq 0$$

where β_j is the effect of the j^{th} level of the AHP model type.

The ANOVA summary for this analysis is provided in Table 30. The ANOVA reveals that there are significant main effects due to attributes and sub-attributes (F = 9.08, $p \leq 0.0001$), and for model type (F = 10.51, p = 0.0003).

Table 30. ANOVA Summary for Priority Weighting Variances (Attributes and Sub-attributes and Model).

Source	DF	Mean Square	F Value	Pr>F
Attributes and Sub-attributes	18	<0.0001	9.08	< 0.0001
Model Type	2	< 0.0001	10.51	0.0003

A Tukey's Studentized Range (HSD) Test was performed to identify which models are significantly different. The critical value for AHP model type was computed as 0.0013. As shown in Figure 21, significant differences were found for the baseline model. The absolute value of the difference in attribute and sub-attribute priority weighting variances between the baseline and the knowledge self-assessment model

(0.0024) and the baseline and electronic technology model (0.0017) exceed the critical value of 0.0013. The conclusion of the Tukey test is that the baseline model differed significantly compared to the knowledge self-assessment and electronic meeting technology models.

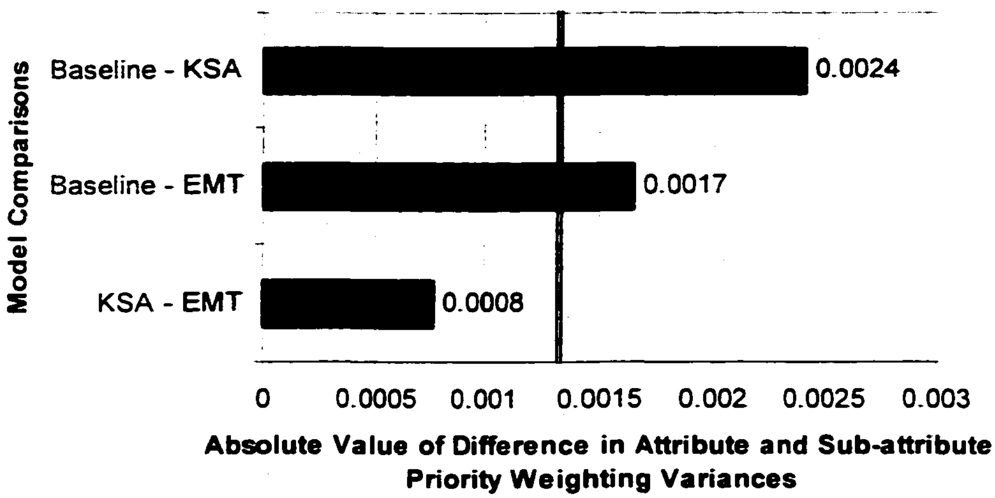


Figure 21. Tukey's Studentized Range Test (HSD) for Model Type by Attribute and Sub-attribute Priority Weighting Variance.

These results support Hypothesis A because there are significant differences in attribute and sub-attribute priority weighting variances. The results also support Hypothesis B because the model that produced the lowest attribute weighting variance was the knowledge self-assessment model, not the electronic meeting technology model. The results do not support Hypothesis C because the combination of electronic meeting technology and all attributes did not produce a lower attribute weighting variance compared to either of the other models and all attributes.

5.3 Task Completion Time

The time to perform the activities required for each model was measured by the mean task completion time as documented on associated data collection forms and is provided in Table 31. The times in Table 31 represent the amount of time, measured in minutes, for the completion of each individual task. The times for Tasks 1 and 2 were measured by each participant as the time to complete the initial pairwise comparisons and the knowledge self-assessment data collection forms, respectively. The time for Tasks 3 and 4 was measured as the total time required to participate in the electronic meeting. This time was a control variable, common to all groups, and was fixed at approximately 1.5 hours.

The time to complete the baseline model was the time to complete Task 1, which was 29.3 minutes (group size of five) and 32.8 minutes (group size of seven). The time to complete the knowledge self-assessment model was the combined time of Tasks 1 and 2, which was 37.0 minutes (group size of five) and 40.3 minutes (group size of seven). The time to complete the electronic meeting technology model was the combined time of Tasks 1 and 3 & 4, which was 127.8 minutes (for a group size of five) and 129.1 minutes (group size of seven).

Table 31. Task Completion Time.

Task #	Task Description	Average Task Time (minutes)	
		Group Size = Five	Group Size = Seven
1	Complete baseline initial pairwise comparisons	29.3	32.8
2	Complete knowledge self-assessment questionnaire	7.7	7.5
3 & 4	Participate in electronic meeting	98.5	96.3

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

This chapter discusses the conclusions that can be made from the experimental results and the contributions they have made to research. Future research opportunities to further scientific knowledge are also identified.

6.1 Summary of Experimental Results

This section summarizes the results for the five analyses. The degree to which the data collected through the research process supports hypotheses is discussed.

6.1.1 Analysis One Summary

Analysis One evaluated the effects of AHP model type and group size on the group consistency. Group consistency was measured by the aggregate group consistency index which is an indicator of the degree to which logic (i.e.. transitivity) in judgment was maintained (i.e. if A = 3B and B = 4C, then A = 12 C). There were significant main effects for group size, but not for AHP model type. A group size of seven produced more group consistency than a group size of five. Three other group variables were investigated to determine if they impacted the change in the aggregate group consistency index for a participant group from the baseline to the electronic meeting technology models. These group variables included group mix (i.e., the number of areas of responsibility represented by the participants), average years of experience, and average influence rating (i.e., the participant rating of how much the opinions of others in the group influenced their judgment). None of these variables appeared to influence group consistency.

In terms of practical application, the three AHP models produced similar aggregate group consistency indexes. Therefore, the level of decision quality, as measured by the transitivity logic of the group, is similar. A group size of seven would be more logical than a group size of five; thus, produces a higher decision quality. Therefore, decision quality is only influenced by group size regardless of the AHP model used.

6.1.2 Analysis Two Summary

Analysis Two evaluated the effects of AHP model type and group size on individual consensus. Individual consensus was measured by the variance in participants' pairwise comparisons and indicates the degree of agreement among participants. Neither AHP model type or group size affected pairwise comparison variances. The methodology provided participants with data regarding baseline pairwise comparison judgment statistics, including the mean and variances for the group, at the beginning of the electronic meeting. However, the post electronic meeting survey results indicated that participants, on average, felt only weakly influenced by the opinions of other participants. Analysis Two results do not support the theory of improving group consensus through the use of electronic meeting technology or through the use of a smaller group size.

The quality implication to consider for practical application is that decision quality as measured by group consensus would be similar for each of the three AHP models. Consensus is an important factor in attaining group buy-in for decision implementation. These findings indicate that group consensus in AHP decisions will not be improved through knowledge management strategies.

6.1.3. Analysis Three Summary

Analysis Three evaluated the effects of level of management responsibility on pairwise comparison variances. Level of responsibility was not significant. Although the differences in the pairwise comparison variances between the Vice President and Non-Vice President levels of responsibility were not significant, it is interesting that the pairwise comparison variance for the Non-Vice President level of responsibility was lower compared to the Vice President level of responsibility. This could be due to the smaller sample size of participants in the Vice President level of responsibility (8) versus the sample size of participants in the Non-Vice President level of responsibility (40). It could also be explained by the variation in area of responsibility of the Vice Presidents. The mix of Vice Presidents included four responsible for financial, three responsible for clinical, and one responsible for operational areas. The mix of Non-Vice President responsibilities included two for human resources, eight for information technology, seven for financial, nine for clinical, two for marketing, five for operations, and seven for other. The variation in their responsibilities could have introduced significant differences in their perspective on the attributes and sub-attributes (i.e., their pairwise comparison judgments). Their differences, in terms of responsibility, could have been more pronounced than their similarities in terms of organizational role. Analysis Three results do not support the theory that there is less variation in individual consensus among participants who share a more global or corporate perspective.

These findings suggest that a grouping of individuals who are homogenous with respect to their level of responsibility, but heterogeneous with respect to their area of responsibility, do not have a higher level of consensus. Therefore, groups comprised of individuals with similar levels of responsibility will not necessarily produce a higher quality of decision as measured by group consensus, and decision implementation buy-in will not be positively influenced.

6.1.4. Analysis Four Summary

Analysis Four evaluated the effects of AHP model type and group size on mental workload. There was a significant main effect for AHP model type, but not for group size. The electronic meeting technology model produced a lower mental workload compared to the baseline model. The sequence with which the participants performed their tasks was: (1) initial baseline pairwise comparison judgments, (2) knowledge self-assessment ratings, and (3) revised electronic meeting technology pairwise comparison judgments. The difference in mental workload between the initial and revised pairwise comparison tasks could be explained by the fact that the participants experienced a learning curve for the task of making pairwise comparison judgments. The task became easier with repetitive performance from the baseline task to the electronic meeting technology task.

The mental workload for the electronic meeting technology was lower, but not significantly lower, than the mental workload for the knowledge self-assessment model.

One explanation could be that the task of completing the knowledge self-assessment ratings was not as difficult as the task of performing the initial pairwise comparison judgments, but that it was slightly more difficult than the task of performing the revised pairwise comparison judgments.

Analysis Four results supported the theory that the tasks involved in using the electronic meeting technology model do not increase the mental workload of the participants. However, the results did not support the theory that the group size of five resulted in lower mental workload than the group size of seven or that the combination of a smaller group size with the electronic meeting technology model resulted in a lower mental workload. As previously mentioned, the task of making revised pairwise comparison judgments during the electronic meeting was somewhat repetitious of the task of making the initial pairwise comparison judgments for the baseline model. This may explain why the mental workload for the electronic meeting technology model was lower than baseline. Other possible explanations are that the Groupware software was easy to use, and the meeting organization, including the agenda and instructions, was clear and easy to follow.

These findings suggest that the electronic meeting technology model will produce a lower cost, as measured by mental workload, than the baseline model. Individuals in this experiment did not experience additional mental workload stress interfacing with the Groupware electronic meeting technology.

6.1.5 Analysis Five Summary

Analysis Five evaluated the effects of attributes and sub-attributes and AHP model type on group consensus. Group consensus was measured by the attribute and sub-attribute priority weighting variances. There were main effects for both attributes and sub-attributes and AHP model type. Significant differences in attribute and sub-attribute priority weighting variances could be explained by the differences in the collective knowledge level, experience and perspective represented by the each group. The attributes and sub-attributes with the greatest priority weighting variance are candidates for further discussion to increase the knowledge transfer among participants.

Analysis Five results did not support the theory that the electronic meeting technology model decreases variation in judgment because the group consensus was significantly lower for the baseline model compared to the other models. The use of knowledge management strategies actually hurt group consensus since both the knowledge self-assessment and electronic meeting technology models produced significantly lower group consensus with respect to attribute and sub-attribute priority weighting variance.

These findings suggest that the baseline will perform at a higher quality level than the other AHP models in terms of producing more consensus across groups with respect to the attribute and sub-attribute priority weightings. The practical implication is that the baseline model is a superior model in terms of producing similar levels of importance for the attributes and sub-attributes considered in AHP decisions.

6.1.6 Summary of Analyses

Table 32 presents a summary of the experimental results for all of the five hypotheses. A "Yes" indicates that the factor or interaction of factors was found to significantly affect the dependent variable in the analysis. The superior factor level that produced the most desirable dependent variable measurement is noted in parenthesis. A "No" indicates the factor or interaction of factors did not significantly affect the dependent variable.

Table 32. Summary of Significant Experimental Results.

Analysis	Dependent Variable	Significance of Factors (Superior Factor)				
		Group Size	AHP Model Type	Level of Responsibility	Attribute and Sub-attribute Priority Weightings	Interaction
One: Group Consistency	Aggregate Group Consistency Index	Yes (7)	No			No
Two: Individual Consensus	Pairwise Comparison Variances	No	No			No
Three: Individual Consensus	Pairwise Comparison Variances			No		
Four: Mental Workload	NASA-TLX Score	No	Yes (no dominant model per Tukey test)			No
Five: Group Consensus	Attribute and Sub-attribute Priority Weightings		Yes (Baseline)		Used for Blocking	

6.2 Conclusions and Practical Applications

Factors in this experimental research had differential effects on decision-making. These differential effects are important considerations when evaluating potential outcomes of group decisions. This research involved the use of the AHP to establish priority weightings for a decision hierarchy to be used for capital investment project selection decisions. Conclusions that can be made with respect to this specific AHP decision process are:

- a group size of seven versus five increases group consistency,
- the use of knowledge management strategy tasks did not increase mental workload, and

The practical application of these conclusions involves the development of decision hierarchy for selecting the AHP model (baseline, knowledge self-assessment, or electronic meeting technology) for use in making capital investment decisions. The data supporting these research conclusions can be used to select the AHP model which best meets an organization's cost and quality parameters.

Organizations make many group decisions on a daily basis. The decisions may involve determining the best approach to solving a problem or whether or not to pursue initiatives that will introduce anticipated costs and benefits. The quality of these decisions can have significant short term and long term financial, operational, and, in the case of healthcare, clinical affects on the organization. This research examined two sub-attributes that contribute to the cost of making group decisions about proposed capital investments: (1) mental workload and (2) decision task completion time requirements. These two cost components were selected based on the experience of the researcher. This experience has revealed that the effort of decision-makers to understand decision attributes from all perspectives (i.e., mental workload) is a significant cost factor. Decision-maker time availability (i.e., task completion time) is another significant factor in the cost of decision making. Figure 22 provides a two-level hierarchy that can be used in the decision to select the most appropriate AHP model. The attributes are cost and quality. The sub-attributes for cost are mental workload and task completion time. The

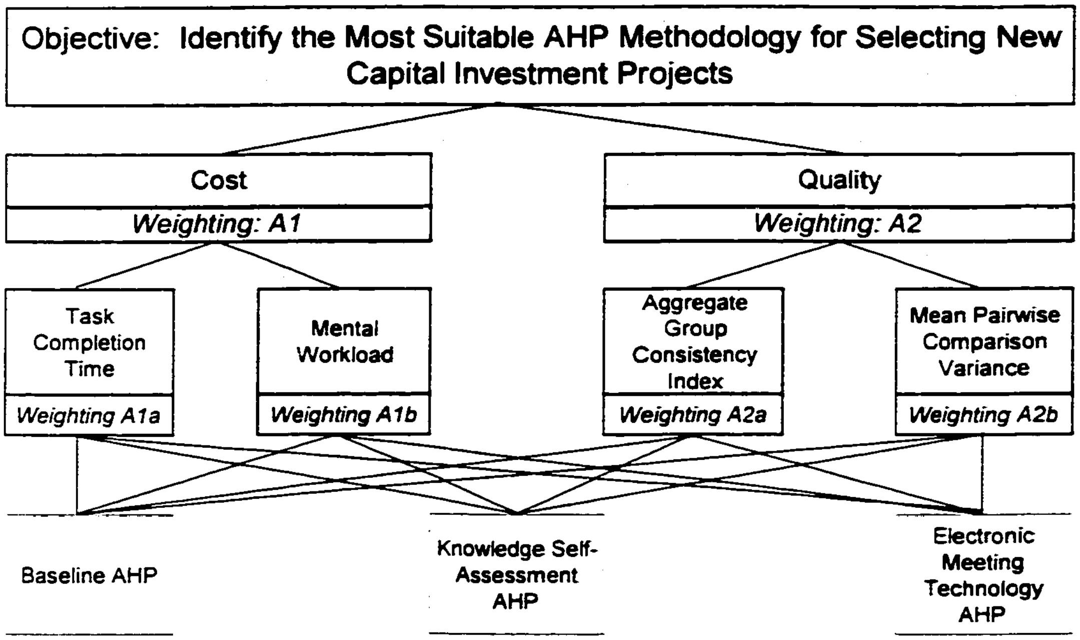


Figure 22. AHP Model Selection Hierarchy.

sub-attributes for quality are the aggregate group consistency index and the mean pairwise comparison variance. In this experiment, the mental workload cost for each AHP model was measured by the NASA-TLX score. Task completion time was measured as the time for an individual participant to complete the baseline and knowledge self-assessment model tasks.

An organization can use the AHP process to establish relative weightings for the attributes and sub-attributes for use in selecting the appropriate AHP model. The pairwise comparisons for each of the three alternative models can be determined by using data produced through this experimental process and shown as "actual" in Table 33. The data reflects the relative performance of each AHP model in terms of the cost and quality

Table 33. **Cost and Quality Sub-attribute Performance Data.**

Group Size	Sub-attribute	Baseline		KSA		EMT	
		Actual	Transformed	Actual	Transformed	Actual	Transformed
Five	Task Time (minutes) multiplied by 5	146.5	9.00	185.0	8.59	639.0	3.80
	Mental Workload (NASA-TLX Score)	6.85	1.00	6.71	1.74	5.64	7.19
	Pairwise Comparison Variance	12.91	1.00	12.91	1.00	10.50	6.90
	Aggregate Group Consistency Index	0.17	2.33	0.19	1.00	0.15	3.67
Seven	Task Time (minutes) multiplied by 7	229.6	8.12	282.1	7.57	903.0	1.00
	Mental Workload (NASA-TLX Score)	6.52	2.69	6.39	3.36	6.14	4.64
	Pairwise Comparison Variance	10.09	7.90	10.09	7.90	9.64	9.00
	Aggregate Group Consistency Index	0.07	9.00	0.08	8.33	0.12	5.67

sub-attributes. For example, a group size of seven is superior to a group size of five with respect to the aggregate group consistency index; however, the electronic meeting technology model is superior to the other models with respect to mental workload and pairwise comparison values.

Since it is desirable for each of the attributes to have low values, and all variables were measured using a different scale, a regression equation was used transform the actual values for the AHP models for each of the sub-attributes in Table 33 to a common scale. The association of measurement scales with pairwise comparison judgments using Saaty's scale was recommended by Watson and Freeling (1982). A linear regression model was used to transform the actual sub-attribute performance data. Table 34 provides the regression variables that were calculated based on the low and high values of the sub-attribute performance, the slope, and intercept. This recommended approach has

Table 34. Sub-attribute Data Transformation.

Regression Variables		Task Completion Time		Mental Workload		Aggregate Group Consistency Index		Pairwise Comparison Variance	
		actual (y)	converted (x)	actual (y)	converted (x)	actual (y)	converted (x)	actual (y)	converted (x)
Low Value		29.300	9.000	5.280	9.000	0.070	9.000	9.640	9.000
High Value		98.500	1.000	6.850	1.000	0.190	1.000	12.910	1.000
Slope		-0.116		-5.096		-66.667		-2.446	
Intercept		12.387		35.904		13.667		32.584	
		Actual	Transformed	Actual	Transformed	Actual	Transformed	Actual	Transformed
Group Size = 5	Baseline	29.30	9.00	6.85	1.00	0.17	2.33	12.91	1.00
	KSA	37.00	8.11	6.17	4.46	0.19	1.00	12.91	1.00
	EMT	98.50	1.00	5.28	9.00	0.15	3.67	10.50	6.90
Group Size =7	Baseline	32.80	8.60	6.52	2.68	0.07	9.00	10.09	7.90
	KSA	40.30	7.73	5.46	8.08	0.08	8.33	10.09	7.90
	EMT	96.30	1.25	6.01	5.28	0.12	5.67	9.64	9.00

been applied and is reflected in the "transformed" sub-attribute performance presented in Table 33.

The weightings for each alternative can be calculated as shown in Table 35. An application of the AHP decision hierarchy using the transformed data values for a group size of seven is provided Table 36. The approach taken in this example transformed data values to a common scale of 1 to 9, where 1 represents poor performance and 9 represents good performance. The attribute and sub-attribute weightings relative to each other would be established by an organization through an AHP process. For this example, the relative weightings for the attributes have been assigned as:

Cost (Weighting A1): 0.40
Quality (Weighting A2): 0.60

The relative weightings for the sub-attributes have been assigned as:

Task Completion Time (Weighting A1a): 0.50
Mental Workload (Weighting A1b): 0.50

Aggregate Group Consistency Index (Weighting A2a): 0.60
Mean Pairwise Comparison Variance (Weighting A2b): 0.40

Table 35. AHP Model Weighting Calculations.

Baseline AHP Model Weighting:

$$(CostWeighting)\times(TaskCompletionTimeWeighting)\times(BaselineTaskCompletionTimeRating)+$$
$$(CostWeighting)\times(MentalWorkloadWeighting)\times(BaselineMentalWorkloadRating)+$$
$$(QualityWeighting)\times(AggregateGroupInconsistencyIndexWeighting)\times(BaselineAggregateGroupInconsistencyIndexRating)+$$
$$(QualityWeighting)\times(MeanPairedComparisonVarianceWeighting)\times(BaselineMeanPairedComparisonVarianceRating)$$

Knowledge Self-Assessment AHP Model Weighting:

$$(CostWeighting)\times(TaskCompletionTimeWeighting)\times(KSATaskCompletionTimeRating)+$$
$$(CostWeighting)\times(MentalWorkloadWeighting)\times(KSAMentalWorkloadRating)+$$
$$(QualityWeighting)\times(AggregateGroupInconsistencyIndexWeighting)\times(KSAAggregateGroupInconsistencyIndexRating)+$$
$$(QualityWeighting)\times(MeanPairedComparisonVarianceWeighting)\times(KSAMeanPairedComparisonVarianceRating)$$

Electronic Meeting Technology AHP Model Weighting:

$$(CostWeighting)\times(TaskCompletionTimeWeighting)\times(EMTTaskCompletionTimeRating)+$$
$$(CostWeighting)\times(MentalWorkloadWeighting)\times(EMTMentalWorkloadRating)+$$
$$(QualityWeighting)\times(AggregateGroupInconsistencyIndexWeighting)\times(EMTAggregateGroupInconsistencyIndexRating)+$$
$$(QualityWeighting)\times(MeanPairedComparisonVarianceWeighting)\times(EMTMeanPairedComparisonVarianceRating)$$

Table 36. Example of AHP Model Evaluation Calculations.

AHP Model Alternative	Score Calculation	Score
Baseline AHP Model Weighting:		
(CostWeighting)(TaskCompletionTimeWeighting)(BaselineTaskCompletionTimeTransformedScore) +	(0.40)(0.50)(8.60) +	1.720
(CostWeighting)(MentalWorkloadWeighting)(BaselineMentalWorkloadTransformedScore) +	(0.40)(0.50)(2.68) +	0.536
(QualityWeighting)(AggregateGroupConsistencyIndex)(BaselineAggregateGroupConsistencyIndexTransformedScore) +	(0.60)(0.40)(9.00) +	2.160
QualityWeighting)(MeanPairwiseComparisonVarianceWeighting)(BaselineMeanPairwiseComparisonVarianceTransformedScore) +	(0.60)(0.60)(7.90)	2.844
	Total	**7.260**
Knowledge Self-Assessment Weighting:		
(CostWeighting)(TaskCompletionTimeWeighting)(KSATaskCompletionTimeTransformedScore) +	(0.40)(0.50)(7.73) +	1.546
(CostWeighting)(MentalWorkloadWeighting)(KSAMentalWorkloadTransformedScore) +	(0.40)(0.50)(8.08) +	1.616
(QualityWeighting)(AggregateGroupConsistencyIndex)(KSAAggregateGroupConsistencyIndexTransformedScore) +	(0.60)(0.40)(8.33) +	1.999
QualityWeighting)(MeanPairwiseComparisonVarianceWeighting)(KSAMeanPairwiseComparisonVarianceTransformedScore) +	(0.60)(0.60)(7.90)	2.844
	Total	**8.005**
Electronic Meeting Technology Weighting:		
(CostWeighting)(TaskCompletionTimeWeighting)(EMTTaskCompletionTimeTransformedScore) +	(0.40)(0.05)(1.25) +	0.250
(CostWeighting)(MentalWorkloadWeighting)(EMTMentalWorkloadTransformedScore) +	(0.40)(0.95)(5.28) +	1.056
(QualityWeighting)(AggregateGroupConsistencyIndex)(EMTAggregateGroupConsistencyIndexTransformedScore) +	(0.60)(0.40)(5.67) +	1.361
QualityWeighting)(MeanPairwiseComparisonVarianceWeighting)(EMTMeanPairwiseComparisonVarianceTransformedScore) +	(0.60)(0.60)(9.00)	3.240
	Total	**5.907**

The knowledge self-assessment alternative had the highest score (8.005) as calculated in Table 36. The alternative scores are dependent on the relative importance an organization establishes for the attributes (i.e., cost and quality) and their corresponding sub-attributes. A sensitivity analysis, using AHP alternative transformed ratings for both group sizes was performed to demonstrate the effect of various attribute and sub-attribute priority weightings. Table 37 shows the conditions that were used in the sensitivity analysis. A greater quantity and range of weighting combinations was used in the analysis for the attributes of cost and quality (seven increments from 90/10 to 10/90) compared to the cost and quality sub-attributes (three increments including 70/30, 50/50, and 30/70).

Table 37. Sensitivity Analysis Conditions.

Priority Weighting Combinations	Cost versus Quality	Cost	Quality
		Task Time (TT) versus Mental Workload (MW)	Consistency (CI) versus Individual Consensus (Con)
90/10	Yes	No	No
80/20	Yes	No	No
70/30	No	Yes	Yes
60/40	Yes	No	No
50/50	Yes	Yes	Yes
40/60	Yes	No	No
20/80	Yes	No	No
10/90	Yes	Yes	Yes

The sensitivity analysis results are contained in Appendix N and are summarized in Table 38. Table 38 shows scenarios, which represent different attribute weighting combinations. The conclusion column defines the AHP model that is dominant (i.e., scores the highest) for the scenario. Exceptions are noted when different AHP models dominate dependent on the weighting combinations of the sub-attributes. The sub-

Table 38. Summary Sensitivity Analysis for AHP Model Alternative Selection.

		Dominant AHP Model			
		Group Size = 5		Group Size = 7	
Scenario	Attribute Weighting	Conclusion	Comments	Conclusion	Comments
Very High Cost/Very Low Quality	90/10	EMT except when TT/MW = 70/30 => use Baseline	Baseline preferred when task time is dominant to Mental Workload	KSA except when TT/MW = 70/30 => use Baseline	KSA preferred when cost is very high compared to quality; however, Baseline preferred when task time is high compared to mental workload
High Cost/Low Quality	80/20	EMT except when TT/MW = 70/30 => use Baseline	Baseline preferred when task time is dominant to Mental Workload	KSA except when TT/MW = 70/30 => use Baseline	KSA preferred when cost is very high compared to quality; however, Baseline preferred when task time is high compared to mental workload
Moderately High Cost/Moderately Low Quality	60/40	EMT	EMT preferred when cost is moderately high to very low compared to quality	Baseline except when TT/MW = 30/70 and CI/Con = 30/70 or 50/50 => use KSA	Baseline preferred when cost is high compared to quality; however, KSA preferred when task time is low compared to mental workload and consistency index is low compared to consensus
Equal Cost and Quality	50/50	EMT		Baseline except when TT/MW = 30/70 and CI/Con = 30/70 => use KSA	Baseline preferred when cost is equal to quality; however, KSA preferred when consistency index is low compared to consensus
Moderately Low Cost/Moderately High Quality	40/60	EMT		Baseline except when TT/MW = 30/70 and CI/Con = 30/70 => use either Baseline or KSA	Baseline preferred when cost is moderately low compared to quality; however KSA equally preferred when task time is high compared to mental workload
Low Cost/High Quality	20/80	EMT		Baseline	Baseline preferred when cost is low to very low compared to quality
Very Low Cost/Very High Quality	10/90	EMT		Baseline	

attributes are designated as: task time (TT), mental workload (MW), consistency (CI), individual consensus (Con).

Due to the dynamics created by the relationships of multiple attributes and sub-attributes, it is not possible to establish specific recommendations global to all applications. However, some general application recommendations are:

For a Group Size of Five

- Use the EMT model. The exception to this is when the priority weighting of cost is highly (80/20) or very highly (90/10) more important than quality and task time is more important than mental workload (70/30). For this exception, the baseline model is recommended.

Referencing Table 34, this can be explained by the fact that the EMT model out performs the other models in mental workload and individual consensus measures, and is similar to the other models with respect to the consistency index measure. However, the EMT model is inferior to the other models with respect to task completion time. Therefore, when cost is weighted highly or very highly more important than quality and task time is weighted more important than mental workload, the EMT model suffers and the baseline model prevails.

For a Group Size of Seven

- Use the baseline model when the priority weighting for cost is moderately high (60/40) to very low (10/90) compared to quality. The exception to this is when the task time priority weighting is low compared to mental workload (20/80) and the consistency index priority weighting is low compared to consensus (20/80). For this exception, the KSA model is recommended.

  Referencing Table 34, this can be explained by the fact that the baseline model slightly out performs the other models in task completion time and consistency index. However, the baseline model is inferior to the other models with respect to mental workload. Therefore, when the task completion time is weighted low compared to mental workload and the consistency index is also weighted low compared to consensus, the KSA model prevails.

- Use the KSA model when cost is high (80/20) to very high (90/10) compared to quality. The exception is when cost is task time is high (80/20) compared to mental workload. For this exception, the baseline model is recommended.

  Referencing Table 34, this can be explained by the fact that the KSA and baseline models differ only slightly with respect to both cost sub-attributes (task completion time and mental workload). The baseline is slightly more predominant than the KSA model with respect to mental workload and slightly less predominant to the KSA model with respect to task completion time. Therefore, when cost is weighted high to very high compared to quality, the KSA mode prevails. However, when task time is high compared to mental workload, the baseline model prevails.

These general recommendations have been incorporated into the AHP model selection decision tree provided in Figure 23. The decision tree nodes represent the attribute or sub-attribute weightings that are most relevant to the AHP model selection. These nodes include: cost attribute and task time and consistency index sub-attributes.

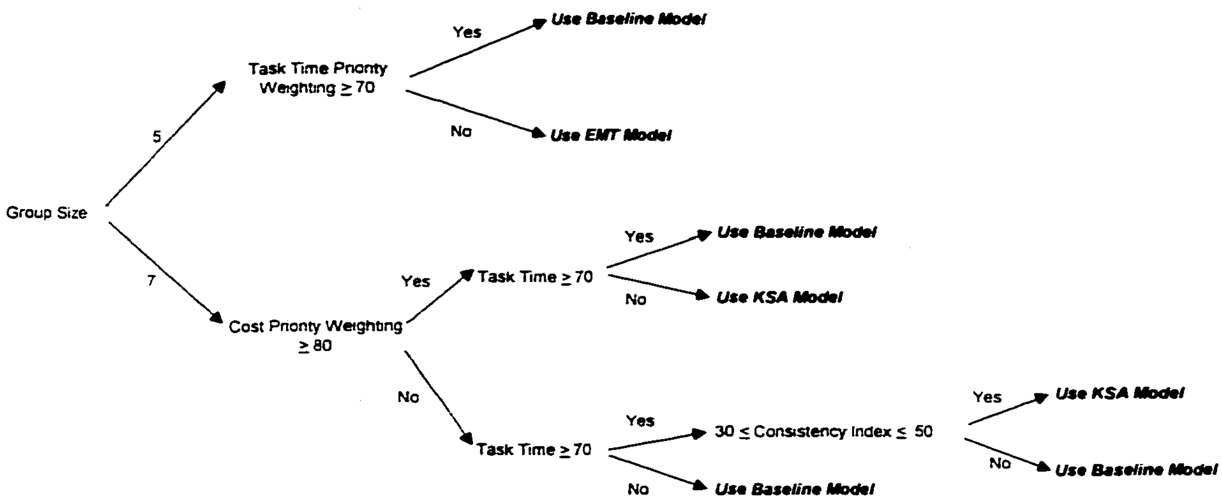


Figure 23. AHP Model Selection Decision Tree.

6.3 Contributions to Research

The goals of this dissertation were to evaluate the impact of knowledge management strategies on AHP decision cost and quality outcomes and to develop an AHP model selection methodology. Two knowledge management strategies were used: knowledge self-assessment and electronic meeting technology. The research contributions achieved are:

This dissertation research made contributions in two categories: (1) analysis of AHP decision cost and quality, and (2) AHP model development. The specific contributions within each category are:

Analysis of AHP Decision Cost and Quality

Based on the relative importance of cost and quality, recommendations are made for the use of knowledge management strategies and group size.

- The use of knowledge management strategies did not significantly improve decision quality with respect to group consistency, individual consensus or group consensus.

- The use of knowledge management strategies did not significantly increase mental workload; tasks performed using electronic meeting technology resulted in significantly lower mental workload.

- A group size of seven versus a group size of five significantly improved decision quality with respect to group consistency.

AHP Model Development

Two AHP hierarchies were developed to advance knowledge with respect to AHP applications.

- A decision hierarchy comprised of four attributes and fifteen sub-attributes was developed and can be used by organizations to assess capital investment projects.

- The application of the capital investment decision hierarchy produced cost and quality measures that can be used to evaluate AHP model alternatives.

- An AHP model selection decision hierarchy comprised of cost and quality attributes and sub-attributes was developed. The model can be used to select the most appropriate AHP model from the three used in this experimental process. AHP model alternative priority weightings with respect to sub-attributes were established through AHP implementation cost and decision quality data obtained through this experimental research.

- An AHP model selection decision tree was developed to determine the most appropriate AHP model based on cost and quality attribute and sub-attribute priority weightings.

This research model represents advancement to the state of the art and advances the body of knowledge with respect to measuring the impact of knowledge management strategies on AHP implementation. Both the practical and scientific contributions provide knowledge to enhance the effectiveness of the AHP as a multi-attribute decision technique.

6.4 Limitations of Research

Limitations in the results of this research fall into the categories of: (1) AHP scope, (2) participant representation and type of organization, (3) computer skill level of participants, and (4) type of electronic meeting technology used. Only a portion of the AHP implementation was incorporated into the research. A prescribed hierarchy was necessary to ensure task completion time and mental workload for each group was based on a consistent set of information and breadth of tasks. The scope did not include evaluation of capital investment projects because the intent was to measure cost and quality for specific AHP steps.

It was a significant accomplishment to obtain the participation of forty-eight INTEGRIS Health employees and their commitment to each devote approximately 2.5 hours of their time to this study. However, this number of participants was assembled into four groups of each of the two group sizes, allowing only four replications for each group. This quantity of replications is rather small. In addition, the study findings with respect to aggregate group consistency, as well as individual and group consensus may be impacted by the culture of INTEGRIS Health and the knowledge base of the participants. Study findings with respect to task completion time and mental workload, on the other hand, may be used to represent groups of decision-makers outside the boundaries of INTEGRIS Health. Since INTEGRIS Health is a service organization, and more specifically a healthcare organization, the priority weightings established for the capital investment decision hierarchy may be limited to the perspectives of INTEGRIS Health and/or of healthcare organizations and may not be transferable to non-health care organizations.

and/or of healthcare organizations and may not be transferable to non-health care organizations.

The average computer skill level of the forty-eight participants was 1.67, which fell between very good and somewhat good on a 5-point scale (1 = very good, 2 = somewhat good, 3 = neutral, 4 = somewhat limited, and 5 = very limited). The results with respect to mental workload and task time may have been different if participants had a different average computer skill level.

Conclusions made regarding the comparison of the three models, and the electronic meeting technology, in particular, are specific to the Groupware software that was used to conduct the electronic meeting. Although the functionality of different types of electronic meeting technologies is similar, their interfaces will vary. Other types of electronic meeting technology might produce different results.

6.5 Recommendations for Future Research

The effects of knowledge self-assessment and electronic meeting technology offer many opportunities for improving knowledge management in AHP implementation. There are several areas recommended for future research. In regard to knowledge self-assessment, additional research could be performed to refine the knowledge self-assessment questionnaire by defining knowledge attributes associated with specific attributes and sub-attributes. For example, knowledge about the attribute "sustain an existing competitive edge" might be measured by asking participants to rate themselves on more specific criteria such as their knowledge about the environmental attributes required to sustaining a competitive edge, or their knowledge of the organization's current market share for specific services. The knowledge self-assessment weighting could be computed based on an aggregation of the criteria knowledge ratings. This research could define knowledge competencies about attributes involving capital investment decisions. It could also determine the effect of knowledge competencies on the aggregate group consistency index.

Further research could be performed in the area of electronic meeting technology. Since group size affected group consistency, it would be beneficial to examine a broader range of group sizes. Research could be conducted on additional group sizes and compositions and the effect these have on the aggregate group consistency index, as well as the pairwise comparison variances. The research could identify the optimum range of group size for specific types of decisions. It could also identify the affects of homogenous and heterogenous group composition on group consistency and consensus in AHP implementation.

Another potential area for future research would be to further discuss through the electronic meeting technology the pairwise comparisons that have high variances and/or are contributing to inconsistent judgments. It would be beneficial to study the impact of providing feedback on pairwise comparison judgments that contribute most to inconsistency to determine the affect this information has on increasing group consistency. This would be similar in concept to the provision of statistics regarding individual consensus, which was part of this experimental method. The effect of providing and discussing this information on the aggregate group consistency index and pairwise comparison variance could be evaluated. The groups could be given a decision quality objective such as reaching a specified aggregate group consistency index. Data could be collected on the time required for groups to reach their objective. The relationship between the amount of time and other attributes such as overall group competency as measured by knowledge of attributes, and group mix could be examined.

Another interesting area to explore would be to assign expert roles within groups based on attribute knowledge competencies for participants. The affects of informing and not informing the groups about the roles could be investigated. Variations in group consistency and individual and group consensus, as well as individual confidence in the group decision could be measured.

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APPENDIX A

AHP WEIGHTING CALCULATION

STEP 3: OBTAIN PAIRWISE COMPARISON JUDGMENTS (ATTRIBUTES)

Attributes	A	B	C	D	Decimal Equivalents A	B	C	D	Normalized Matrix A	B	C	D	Row Sum	Average
A. Market	1	1/3	5	2	1.000	0.333	5.000	2.000	0.213	0.205	0.294	0.179	0.891	0.223
B. Financial	3	1	6	8	3.000	1.000	6.000	8.000	0.638	0.615	0.353	0.714	2.321	0.580
C. Core Learning & Growth	1/5	1/6	1	1/5	0.200	0.167	1.000	0.200	0.043	0.103	0.059	0.018	0.222	0.055
D. Stakeholder	1/2	1/8	5	1	0.500	0.125	5.000	1.000	0.106	0.077	0.294	0.089	0.567	0.142
					4.700	1.625	17.000	11.200						1.000

STEP 4: DETERMINING PRIORITY WEIGHTINGS (ATTRIBUTES)

Priority Weights for Attributes	
A. Market	0.223
B. Financial	0.580
C. Core Learning & Growth	0.055
D. Stakeholder	0.142

STEP 5: COMPUTE LOCAL CONSISTENCY INDEX (ATTRIBUTES)

A	B	C	D	Row Total	Entity	
0.223	0.193	0.277	0.283	0.977	4.3865954	
0.668	0.580	0.333	1.133	2.714	4.6779604	
0.045	0.097	0.055	0.028	0.225	4.0580838	
0.111	0.073	0.277	0.142	0.603	4.2545694	
			Lambda Max =		4.3443023	
			Consistency Index =		0.1147674	
			Consistency Ratio =		0.1275194	> 0.10

STEP 3: OBTAIN PAIRWISE COMPARISON JUDGMENTS (SUB-ATTRIBUTES A - D)

Subattributes	A1	A2	Decimal Equivalents A1	A2	Normalized Matrix A1	A2	Row Sum	Average
A1. Market Share	1	1	1.000	1.000	0.500	0.500	1.000	0.500
A2. Customer Acquisition	1	1	1.000	1.000	0.500	0.500	1.000	0.500
			2.000	2.000				1.000

Subattributes	B1	B2	Decimal Equivalents B1	B2	Normalized Matrix B1	B2	Row Sum	Average
B1. Cost	1	1/2	1.000	0.500	0.333	0.333	0.667	0.333
B2. Profitability	2	1	2.000	1.000	0.667	0.667	1.333	0.667
			3.000	1.500				1.000

Subattributes	C1	C2	Decimal Equivalents C1	C2	Normalized Matrix C1	C2	Row Sum	Average
C1. Employee Satisfaction	1	1/5	1.000	0.200	0.167	0.167	0.333	0.167
C2. Employee Productivity	5	1	5.000	1.000	0.833	0.833	1.667	0.833
			6.000	1.200				1.000

Subattributes	D1	D2	Decimal Equivalents D1	D2	Normalized Matrix D1	D2	Row Sum	Average
D1. Payor Satisfaction	1	1/6	1.000	0.167	0.143	0.143	0.286	0.143
D2. Physician Satisfaction	6	1	6.000	1.000	0.857	0.857	1.714	0.857
			7.000	1.167				1.000

STEP 5: COMPUTE LOCAL CONSISTENCY INDEX (SUB-ATTRIBUTES)

A1	A2	Row Total	Entity
0.500	0.500	1.000	2.0000
0.500	0.500	1.000	2.0000
	Lambda Max =		2.0000
	Consistency Index =		0.5000
	Consistency Ratio =		N/A

B1	B2	Row Total	Entity
0.333	0.333	0.667	2.0000
0.667	0.667	1.333	2.0000
	Lambda Max =		2.0000
	Consistency Index =		0.5000
	Consistency Ratio =		N/A

C1	C2	Row Total	Entity
0.167	0.167	0.333	2.0000
0.833	0.833	1.667	2.0000
	Lambda Max =		2.0000
	Consistency Index =		0.5000
	Consistency Ratio =		N/A

D1	D2	Row Total	Entity
0.143	0.143	0.286	2.0000
0.857	0.857	1.714	2.0000
	Lambda Max =		2.0000
	Consistency Index =		0.5000
	Consistency Ratio =		N/A

STEP 3: OBTAIN PAIRWISE COMPARISON JUDGMENTS (ALTERNATIVES)

		P-1	P-2	P-3	Decimal Equivalents P-1	P-2	P-3	Normalized Matrix P-1	P-2	P-3	Row Sum	Average
A1. Market Share	P-1	1	1/5	1/8	1.000	0.200	0.125	0.071	0.048	0.086	0.205	0.068
	P-2	5	1	1/3	5.000	1.000	0.333	0.357	0.238	0.229	0.824	0.275
	P-3	8	3	1	8.000	3.000	1.000	0.571	0.714	0.686	1.971	0.657
					14.000	4.200	1.458					1.000

		P-1	P-2	P-3	Decimal Equivalents P-1	P-2	P-3	Normalized Matrix P-1	P-2	P-3	Row Sum	Average
A2. Customer Acquisition	P-1	1	1/4	1/9	1.000	0.250	0.111	0.071	0.040	0.085	0.196	0.065
	P-2	4	1	1/5	4.000	1.000	0.200	0.286	0.160	0.153	0.598	0.199
	P-3	9	5	1	9.000	5.000	1.000	0.643	0.800	0.763	2.206	0.735
					14.000	6.250	1.311					1.000

STEP 5: COMPUTE LOCAL CONSISTENCY INDEX (SUB-ATTRIBUTES)

P-1	P-2	P-3	Row Total	Entity
0.068	0.055	0.082	0.205	3.008
0.341	0.275	0.219	0.835	3.040
0.546	0.824	0.657	2.027	3.085
		Lambda Max =		3.044
		Consistency Index =		0.0221905
		Consistency Ratio =		0.0382595

P-1	P-2	P-3	Row Total	Entity
0.065	0.050	0.082	0.197	3.012
0.262	0.199	0.147	0.608	3.049
0.589	0.997	0.735	2.321	3.157
		Lambda Max =		3.072

		Consistency Index =	0.036
		Consistency Ratio =	0.062

B1: Cost		P-1	P-2	P-3	Decimal Equivalents P-1	P-2	P-3	Normalized Matrix P-1	P-2	P-3	Row Sum	Average
	P-1	1	4	9	1.000	4.000	9.000	0.735	0.750	0.692	2.177	0.726
	P-2	1/4	1	3	0.250	1.000	3.000	0.184	0.188	0.231	0.602	0.201
	P-3	1/9	1/3	1	0.111	0.333	1.000	0.082	0.063	0.077	0.221	0.074
					1.361	5.333	13.000					1.000

P-1	P-2	P-3	Row Total	Entity
0.726	0.803	0.663	2.191	3.020
0.181	0.201	0.221	0.603	3.006
0.081	0.067	0.074	0.221	3.002
		Lambda Max =		3.009
		Consistency Index =		0.005
		Consistency Ratio =		0.008

B2 Profitability		P-1	P-2	P-3	Decimal Equivalents P-1	P-2	P-3	Normalized Matrix P-1	P-2	P-3	Row Sum	Average
	P-1	1	1/2	1/4	1.000	0.500	0.250	0.143	0.143	0.143	0.429	0.143
	P-2	2	1	1/2	2.000	1.000	0.500	0.286	0.286	0.286	0.857	0.286
	P-3	4	2	1	4.000	2.000	1.000	0.571	0.571	0.571	1.714	0.571
					7.000	3.500	1.750					1.000

P-1	P-2	P-3	Row Total	Entity
0.143	0.143	0.143	0.429	3.000
0.286	0.286	0.286	0.857	3.000
0.571	0.571	0.571	1.714	3.000
		Lambda Max =		3.000
		Consistency Index =		0.000
		Consistency Ratio =		0.000

C1: Employee Satisfaction		P-1	P-2	P-3	Decimal Equivalents P-1	P-2	P-3	Normalized Matrix P-1	P-2	P-3	Row Sum	Average
	P-1	1	1/3	1/6	1.000	0.333	0.167	0.100	0.100	0.100	0.300	0.100
	P-2	3	1	1/2	3.000	1.000	0.500	0.300	0.300	0.300	0.900	0.300
	P-3	6	2	1	6.000	2.000	1.000	0.600	0.600	0.600	1.800	0.600
					10.000	3.333	1.667					1.000

P-1	P-2	P-3	Row Total	Entity
0.100	0.100	0.100	0.300	3.000
0.300	0.300	0.300	0.900	3.000
0.600	0.600	0.600	1.800	3.000
		Lambda Max =		3.000
		Consistency Index =		0.000
		Consistency Ratio =		0.000

C2 Employee Productivity		P-1	P-2	P-3	Decimal Equivalents P-1	P-2	P-3	Normalized Matrix P-1	P-2	P-3	Row Sum	Average
	P-1	1	1/5	1/9	1.000	0.200	0.111	0.067	0.038	0.082	0.187	0.062
	P-2	5	1	1/4	5.000	1.000	0.250	0.333	0.192	0.184	0.709	0.236
	P-3	9	4	1	9.000	4.000	1.000	0.600	0.769	0.735	2.104	0.701
					15.000	5.200	1.361					1.000

P-1	P-2	P-3	Row Total	Entity
0.062	0.047	0.078	0.187	3.011
0.311	0.236	0.175	0.723	3.059
0.560	0.946	0.701	2.207	3.147
		Lambda Max =		3.072
		Consistency Index =		0.036
		Consistency Ratio =		0.062

D1 Payer Satisfaction		P-1	P-2	P-3	Decimal Equivalents P-1	P-2	P-3	Normalized Matrix P-1	P-2	P-3	Row Sum	Average
	P-1	1	1/7	1/9	1.000	0.143	0.111	0.059	0.023	0.085	0.167	0.056
	P-2	7	1	1/5	7.000	1.000	0.200	0.412	0.163	0.153	0.727	0.242
	P-3	9	5	1	9.000	5.000	1.000	0.529	0.814	0.763	2.106	0.702
					17.000	6.143	1.311					1.000

P-1	P-2	P-3	Row Total	Entity	
0.056	0.035	0.078	0.168	3.025	
0.389	0.242	0.140	0.772	3.185	
0.500	1.212	0.702	2.414	3.439	
		Lambda Max =		3.217	
		Consistency Index =		0.108	
		Consistency Ratio =		0.187	> 0.10

D2. Physician Satisfaction		P-1	P-2	P-3	Decimal Equivalents P-1	P-2	P-3	Normalized Matrix P-1	P-2	P-3	Row Sum	Average
	P-1	1	1/4	1/8	1.000	0.250	0.125	0.077	0.040	0.094	0.211	0.070
	P-2	4	1	1/5	4.000	1.000	0.200	0.308	0.160	0.151	0.619	0.206
	P-3	8	5	1	8.000	5.000	1.000	0.615	0.800	0.755	2.170	0.723
					13.000	6.250	1.325					1.000

P-1	P-2	P-3	Row Total	Entity
0.070	0.052	0.090	0.212	3.016
0.282	0.206	0.145	0.633	3.069
0.563	1.031	0.723	2.318	3.204
		Lambda Max =		3.096
		Consistency Index =		0.048
		Consistency Ratio =		0.083

STEP 7: CALCULATE PRIORITY WEIGHTINGS FOR ALTERNATIVES

	Attributes and Subattributes											
Weighting Elements	A	A1	A2	B	B1	B2	C	C1	C2	D	D1	D2
Subattribute to Alternative P-1 Weight		0.068	0.065		0.726	0.143		0.100	0.062		0.056	0.070
Subattribute to Attribute Weight (A/A1, A/A2)		0.500	0.500		0.333	0.667		0.167	0.833		0.143	0.857
Subattribute Alternative P-2 Weight		0.275	0.199		0.201	0.286		0.300	0.236		0.242	0.206
Subattribute to Attribute Weight (A/A1, A/A2)		0.500	0.500		0.333	0.667		0.167	0.833		0.143	0.857
Subattribute to Alternative P-3 Weight		0.657	0.735		0.074	0.571		0.600	0.701		0.702	0.723
Subattribute to Attribute Weight (A/A1, A/A2)		0.500	0.500		0.333	0.667		0.167	0.833		0.143	0.857
Attribute to Objective Weight	0.223			0.580			0.055			0.142		

ALTERNATIVE TOTAL WEIGHTINGS	
P-1 Clinic Total Weight	0.224
P-2 Clinic & OB Total Weight	0.246
P-3 Clinic, OB & Inpatient Weight	0.530

APPENDIX B

INTEGRIS HEALTH E-BUSINESS VALUE MATRIX PROJECT ASSESSMENT QUESTIONNAIRE

E-Business Value Matrix
Project Assessment Team

The Finance and Operations Committee needs your assessment of every initiative you submit for review. Please answer all of the questions that apply to each initiative.

Date: ____________________________

Initiative: ____________________________ (Check One) ☐ Customer Satisfaction ☐ Cost ☐ Quality

P & V Committee Member Contact __________ F & O Committee Member Contact __________

A. **Internal Business Processes**

Does the initiative require processes to be reengineered? Yes No

Does INTEGRIS Health already have a product, system, or service in place that this initiative will be able to leverage? If so, please indicate the "leverage".

Does this initiative increase operational efficiency? If so, how?

Does the initiative improve the supply and demand chain?

Is this initiative critical to a business process? If, so, how?

What specific target(s) can be identified?

B. **Learning and Growth**

Describe the fit or gap between this idea or product and the current state of INTEGRIS' operational competencies and/or culture.

What steps or initiatives are required to meet these objectives?

How does this idea or product position INTEGRIS for the future?

How much risk do you think the organization will take if it decides to implement the initiative?
(Circle one) Low Risk Some Risk Moderate Risk High Risk

C. **Customers**

Who are the customers identified with this idea or product?

How do we know what these customers want or need?

How will we know when they are satisfied or their needs have been met?

Will this initiative sustain an existing competitive advantage for INTEGRIS Health? If so, how?

Does this initiative create a new product or service? If so, will it become a key component to existing business?

How long will our competitive advantage be sustained if initiative is implemented?

Will a new market be created with this initiative? Yes No

Will this initiative change the entire market in the delivery of healthcare?

D. **Finance and Value**

If no direct financial objective can be identified, please describe how value is added to the organization and its Mission, Vision, Values or Strategy.

Is there an example of financial success associated with this idea or product

How will these objectives and targets be reached?

Does the project produce cost savings? If so, how much?

If known, what is the return on investment?

What are the startup and ongoing costs?

Will initiative create a new revenue source? Yes No

APPENDIX C
INFORMED CONSENT FORM

Informed Consent Form
Under the Auspices of the University of Oklahoma – Norman Campus

Individual Consent to Voluntary Participation

Improving Group Consistency in the Analytic Hierarchy Process through Knowledge Weighting and Knowledge Transfer

Leva K. Swim, Principal Investigator, (405) 949-6961
Randa L. Shehab, Ph.D., Faculty Sponsor, (405) 325-2307
Office of Research Administration, (405) 325-4757

INTRODUCTION
I, ________________________, voluntarily agree to participate in this study entitled "Comparison of Two Techniques for Improving Group Consistency in the Analytic Hierarchy Process." I understand that this study involves research that will be carried out under the supervision of Leva K. Swim.

It is important for me to understand: 1) that participation in this study is completely voluntary; 2) that I may not personally benefit from this study, but that the knowledge gained may benefit others; and 3) that I am free to refuse to participate and to withdraw from the experiment at any time without prejudice to me. The study is described as follows:

PURPOSE
Capital resource allocation decisions are important in all organizations and to society. The purpose of this study is to gather information on how the process for making capital resource allocation decisions can be improved.

DESCRIPTION
In this experiment you will be asked to review a pre-established decision hierarchy containing attributes that reflect the potential impact of a new capital investment. In the first part of the experiment, you will be asked to compare the relative importance of attributes using a paired comparison tool. You will also be asked to assess the knowledge level you have about the attributes and rate yourself on a knowledge scale. You will submit your pairwise comparison tool and your knowledge self-assessment to Leva K. Swim for scoring. In the second part of the experiment you will be asked to convene in the Newly Emerging Strategic Technology (NEST) conference room and participate in a group discussion regarding the logic behind variations in individual opinions on the relative importance of the hierarchical elements. The group discussion will be facilitated by the Groupware electronic meeting software. After this discussion, you will be asked to re-evaluate the relative importance of attributes using the paired comparison tool. In conjunction with each experimental task, you will be asked to evaluate your mental workload using a NASA-Task Load Index instrument. The total time required for participation will be approximately 2.5 hours.

SUBJECT ASSURANCES
By signing this consent form, I acknowledge that my participation in this study is voluntary. I acknowledge that I have not waived my legal rights or released this organization form liability or negligence. I understand that records from this study will be kept confidential, and that I will not be identifiable by name in any reports or publications of this study. My name will be kept confidential and any data gathered will not be identifiable by name. I understand that the risks of participation do not exceed the risks of normal computer use.

INFORMATION
You can get more information or answers to your questions about this study from Leva K. Swim at 949-6961. If you have any questions about your rights as a research subject, you may contact Office of Research Administration at 325-4757.

SIGNATURES
I have read this informed consent document. I understand its contents and I freely consent to participate in this study under the conditions described in this document. I understand that I may receive a copy of this signed consent form.

__________________________(research participant) ______________DATE

__________________________(researcher) ______________DATE

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APPENDIX D
POTENTIAL PARTICIPANT E-MAIL

Swim, Leva K.

From: Swim, Leva K.
Sent: Thursday, May 10, 2001 6:33 PM
To: Abston, Karen C.; Ainsworth, Nancy L.; Ashcraft, Randy L.; Boevers, R Kent; Booker, Shirley F.; Brewer, Roger W.; Briggs, Jim N.; Bryant, Charles A.; Camp, Vicki L.; Caram, Denise D.; Carpenter, Sharon Z.; Cloud, Avery C; Coleman, Brett A.; Conner, Marsha A.; Cordray, Shelley S.; Dean, Barbara A.; Elfert, Thomas A.; Gorman, Martha C; Gustin, Deanie A; Hilterbrand, Cynthia; Horton, Lynn; Jobe, Larry D.; Ketring, Susan D.; Krywicki, Julie A. Scott; Lance, Philip S.; Meyers, Greg A.; Miller, Wentz J.; Mirtz, Carol A.; Pantry, Joyce A.; Pearson, Richard G; Pippin, Patti R.; Pointer, Kim M.; Purvis, Elaine A.; Quiring, Robert K; Sampson, Jay W.; Scott, Pam A.; Shah, Dinesh M.; Shipley, Trevor D; Suttles, Cheryl M.; Tucker, Rebecca A.; Tyburczy, Deana M; Wandel, Bill R.; Wetz, Harry F.; Winn, Sheila C.; Wood, Tom J.; Merkey, Linda L.; Hammes, Chris M.; Mitchell, Errol A.; Sultan, Akbar A.; Carpenter, Jeff L; Barron, Mary A.; Bedlion, Rick D.; DeWitt, Maurie B.; Hamilton, Ed X.; Jackson, Bob D.; Lawrence, C Bruce; Ouart, J Dianne; Pauchnik, Beth A.; Smith, Lori E.; Smith, Mike G.; Splitt, Richie R.; Woloszyn, J William; Hall, Robin M.; White, James P.
Subject: New Capital Investment Project Evaluation Process

I am requesting your participation in establishing a new method for evaluating and ranking the merit of proposed capital investment projects (new business initiatives) for INTEGRIS Health. Your role will be to provide input for defining weightings of importance for project evaluation criteria (e.g., revenue source potential, ability to increase operational efficiency, implementation initiatives required).

The process that will be used to define the weightings is a multicriteria evaluation technique known as the Analytic Hierarchy Process (AHP). The AHP has been used in a wide variety of industries for making decisions relative to planning, allocation of resources, project selection, etc.

The estimated time requirement for your participation is:

Part One (will occur independently at your desk)

Task 1: Individually, read and understand participant packet: 0.25 hours

Task 2: Individually complete the initial AHP attribute pairwise comparison judgment task and complete a mental workload survey [Estimated Time to Complete: 0.50 hours].

Task 3: Individually, complete the Hierarchical Element Knowledge Self-Assessment Questionnaire and complete a mental workload survey [Estimated Time to Complete: 0.25 hours].

Part Two (will occur with a group in the NEST conference room)

Task 4: Participate with a group in a face-to-face meeting using Groupware electronic meeting technology to discuss attribute pairwise judgments, individually complete a revised AHP attribute pairwise comparison judgment task, and complete a mental workload survey [Estimated Time To Complete: 1.50 hours].

The total time expenditure is estimated to be **2.50 hours**.

Tentative dates and times for Part Two are:

A: Thursday, May 17, 2001 from 7:30 a.m. to 9:00 a.m.
B: Thursday, May 17, 2001 from 4:30 p.m. to 6:00 p.m.
C: Tuesday, May 22, 2001 from 7:30 a.m. to 9:00 a.m.
D: Wednesday, May 23, 2001 from 7:30 a.m. to 9:00 a.m.
E: Wednesday, May 23, 2001 from 3:30 p.m. to 5:00 p.m.
F: Friday, May 25, 2001 from 7:30 a.m. to 9:00 a.m.
G: Thursday, May 31, 2001 from 7:30 a.m. to 9:00 a.m.
H: Thursday, May 31, 2001 from 3:30 p.m. to 5:00 p.m.

Please respond by return e-mail no later than May 15, 2001 if you are able to participate and specify any of the Part Two meeting options (A-H, above) that work for you. Since I am attempting to group individuals with varied perspectives in each of the Part Two meetings, it is important that I know all of the tentative dates and times that will work for you.

Feel free to call me at 949-6961 if you have questions. I will send you a participant packet containing detailed instructions once you communicate that you are interested in participating. I would very much appreciate your participation and perspective.

Leva K. Swim
Director, Decision Support
INTEGRIS Health
5300 N. Independence, Suite 230
Oklahoma City, OK 73112

Telephone: (405) 949-6961
Fax: (405) 945-5408
E-mail: swimlk@integris-health.com

2

APPENDIX E

PICTURE OF NEST CONFERENCE ROOM

Welcome to...

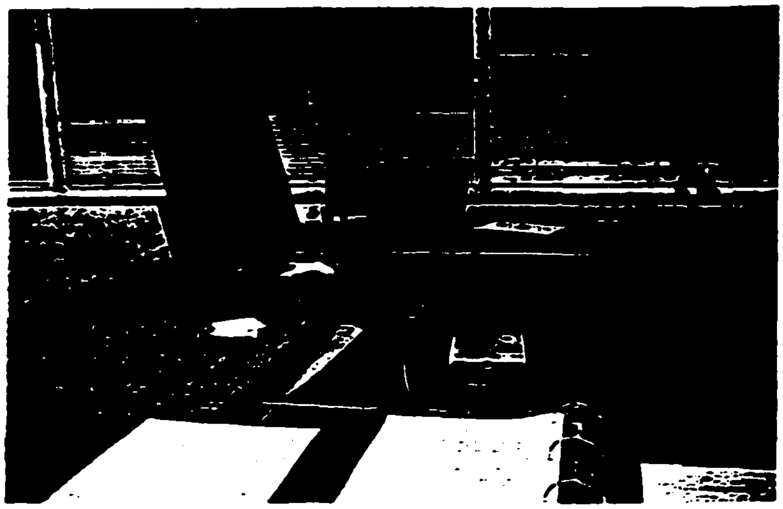
The

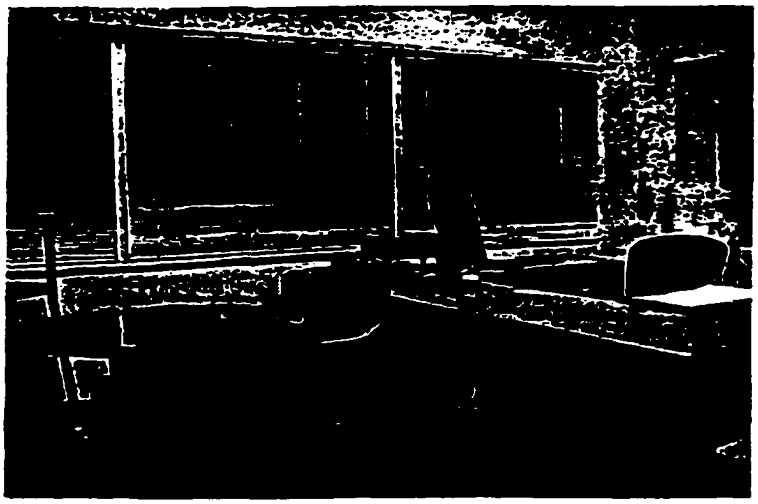
Newly

Emerging

Strategic

Technologies





The NEST

is an experimental suite including one high tech office and a conference room. It is designed to test new office technologies that might benefit INTEGRIS Health and provide a high tech conference room for extremely efficient meetings.

APPENDIX F
PARTICIPANT PACKET

May 15, 2001

Dear

Thank you for agreeing to participate in this process to define a new method for allocating dollars for proposed capital investment projects. The following paragraphs will familiarize you with the process objectives, methodology, and benefits.

Purpose/Objectives

The healthcare sector is facing significant challenges to reduce expenses while maintaining or improving the quality of services provided. Many of the challenges faced by healthcare administrators are related to gaining and maintaining efficiency of operations through determining the best way to allocate capital resources required for quality healthcare delivery. The traditional process for evaluating the economic feasibility of a proposed capital investment project is through the analysis of the Net Present Value or Internal Rate of Return for the service on a five-year timeline. This approach for new project evaluation has several limitations. First, it is incorporates only financial attributes of the decision problem. Second, it is based on the judgment of a single decision-maker instead of the opinions of multiple subject matter experts.

Decisions that impact organizational system performance should be driven by decision support tools that are effective in analyzing the multiple attributes of the decision problem from the perspective of multiple perspectives of individuals within the organizational system. The Analytic Hierarchy Process (AHP) is a multi-attribute decision model that can be used by a group of individuals representing multiple perspectives.

The use of the AHP by individual decision-makers and groups of decision-makers to solve multi-attribute decision problems has been well documented in the literature. Since its introduction in the 1980's, numerous applications of the AHP in a variety of decision problem areas have been described in the literature.

This process will examine two techniques for improving consistency in the AHP. One technique involves the use of electronic meeting technology to discuss areas where there are significant variations in decision-maker opinions. The other technique involves the use of a knowledge self-assessment questionnaire to weight individual judgments. These two techniques will be compared to the standard AHP in terms of the AHP consistency index, a metric for assessing the quality of the decision. In addition, mental workload and staff time will be measured to assess the cost of improving the quality of the decision. The primary objective of the process is to compare the use of electronic meeting technology and a hierarchical self-assessment questionnaire on decision-maker judgment consistency.

Protocol

The first step in the AHP is to create a decision hierarchy comprised of all attributes that should be considered in the decision. A pre-defined decision hierarchy will be used in this process. This hierarchy is based on the work of the INTEGRIS-Health E-Business Value Matrix Project Assessment Team and is provided as Attachment A. A flowchart of the experimental research process is provided as Attachment B. The gray-shaded area reflects modifications to the standard AHP process. The three different models to be used in the experiment are: (1) Baseline, (2) Electronic Meeting Technology, and (3) Knowledge Self-Assessment Weighting.

You will perform three tasks in two separate parts. The NASA-Task Load Index (TLX) will be computed for each task to measure mental workload. The tasks for each part are:

Part One (to be performed individually at your desk)

Read Participant Packet: 0.25 hours

Task 1: Individually complete the initial AHP attribute pairwise comparison judgment task and complete NASA-TLX survey [Estimated Time to Complete: 0.50 hours].

Task 2: Individually, complete the Hierarchical Element Knowledge Self-Assessment Questionnaire and complete NASA-TLX survey [Estimated Time to Complete: 0.25 hours].

Part Two (to be performed with a group in the NEST)

Task 3: Participate with a group in a face-to-face meeting using Groupware electronic meeting technology to discuss attribute pairwise judgments through the Topic Commenter task, individually complete the revised AHP attribute pairwise comparison judgment task, and complete NASA-TLX survey [Estimated Time To Complete: 1.50 hours].

You are scheduled to participate in the Part Two meeting on:

Please arrive 10 minutes early. If you are not able to attend your meeting as scheduled, please contact me 24 hours in advance so I can arrange for another participant to attend in your place.

The NEST conference room is located in the Gernsey Building, in the Information Technology offices. A map to guide you to the NEST is provided in your packet.

An estimated completion time is provided for each task with the total time estimated to be 2.50 hours. You will be asked to provide the actual time expended to complete each task.

Confidentiality

You will be identifiable by identification number. All documentation will be stored to prevent access by anyone other than the primary researcher. The data collected will not be used to evaluate participant job performance. Your name will never be associated with the data.

Participant Benefit/Risk

The results of this process will provide data to establish a new method for evaluating proposed capital investment projects. It will also provide scientific knowledge to enhance the effectiveness of the AHP as a multi-attribute decision technique. Assuming the electronic meeting technology and/or the hierarchical knowledge self-assessment weighting significantly increase the quality of the decision produced by the AHP, users can weigh the cost and quality trade-off of both models in determining which model meets their specific cost and quality parameters.

Participant Packet

Your participant packet includes a cover sheet, which lists all experimental tasks and identifies the part of the process the tasks fall within. The data collection tools for each task, as well as the NASA-TLX mental workload survey, are provided. Instructions regarding the submission and timeframe for submission of all forms are outlined in the form submission schedule.

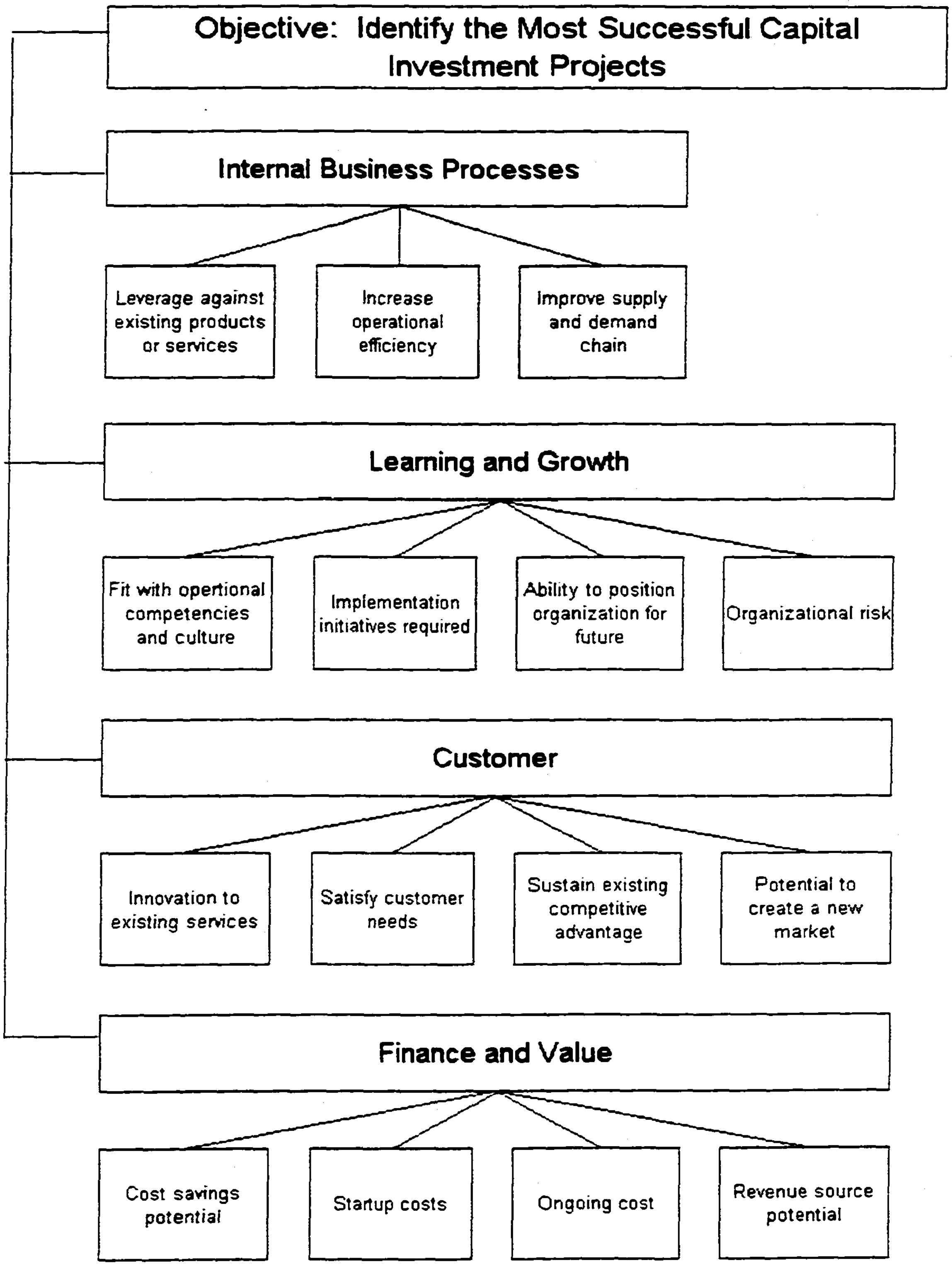
Informed Consent

In addition to providing INTEGRIS Health with data to enhance the process for evaluating proposed capital investment projects, you input will contribute to my dissertation research. The University of Oklahoma Internal Review Board requires each participant to sign an informed consent form. Two copies of this form are included in your packet. One of the forms will be submitted as specified in the form submission schedule. The other form is provided for you to retain for your records.

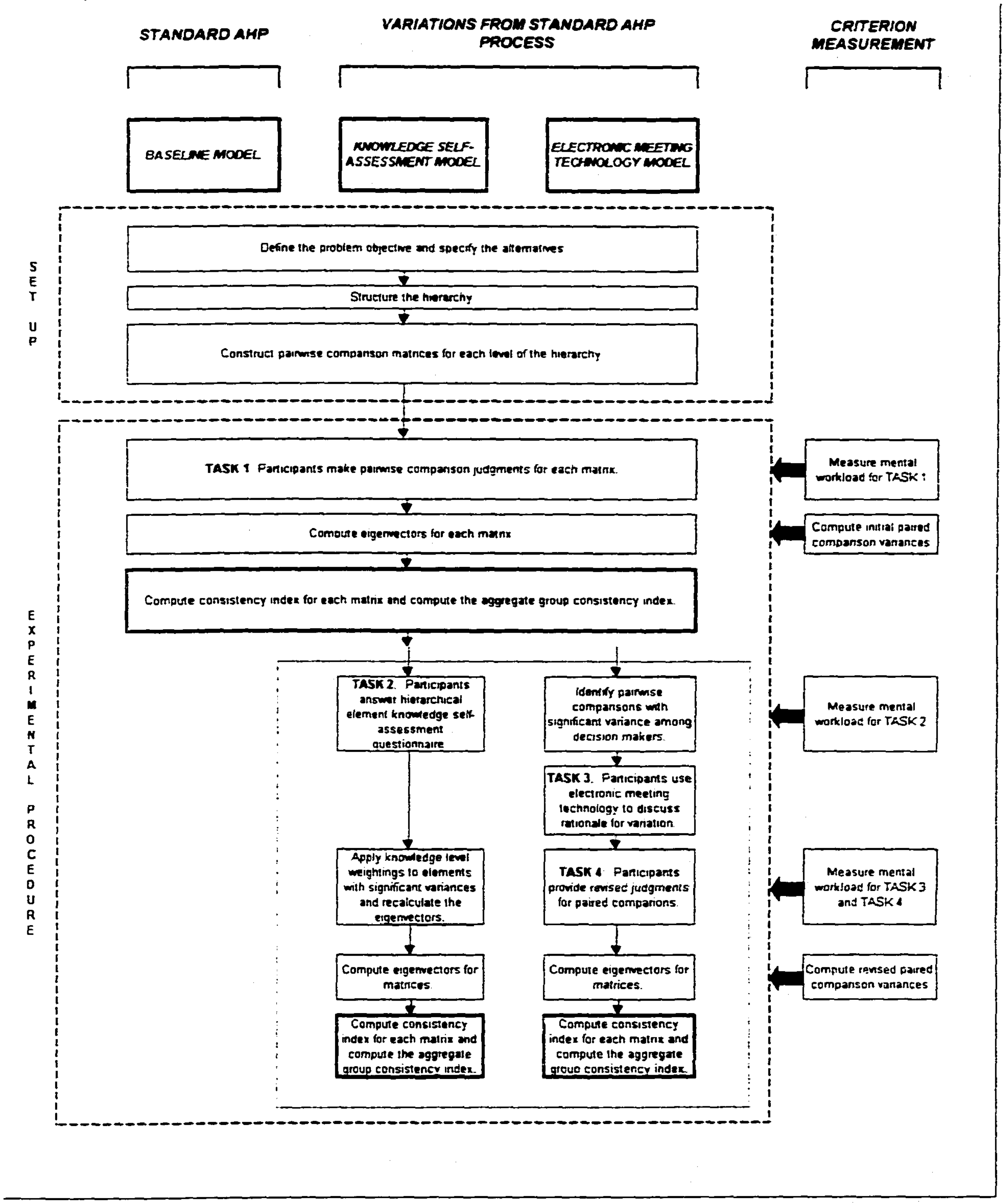
Please do not hesitate to contact me at 949-6961 (telephone) or swimlk@integris-health.com if you have questions.

Leva K. Swim
Director, Decision Support

ATTACHMENT A



ATTACHMENT B



SUMMARY OF EXPERIMENTAL TASKS

This experiment will be conducted in two sessions. A listing of the tasks involved in each session, data collection tools, and instructions for submission of data collection forms is provided in the Task Schedule below:

PART ONE:

TASK #	TASK DESCRIPTION	DATA COLLECTION TOOLS	DATA COLLECTION FORM SUBMISSION
1	Sign the two Informed Consent Forms: keep one copy for yourself. Complete the Participant Demographic Information form Individually complete the initial paired comparison tool (Form A). Individually complete the NASA-TLX mental workload measurement tool (Form D1).	Informed Consent Form (pink), Participant Demographic Information form (purple), Form A (blue) and Form D1 (green)	Complete no later than ____________. Notify Leva Swim when complete (X96961).
2	Individually complete the knowledge self-assessment tool (Form B). Individually complete the NASA-TLX mental workload measurement tool (Form D2).	Form B (yellow), Form D2 (green)	Complete no later than ____________. Notify Leva Swim when complete (X96961).

PART TWO:

TASK #	TASK DESCRIPTION	DATA COLLECTION TOOL(S)	DATA COLLECTION FORM SUBMISSION
3	Participate in group discussion of initial paired comparisons. Individually complete the revised paired comparison tool. Individually complete the NASA-TLX mental workload measurement tool (part 3).	Form C ivory), Form D3 (green)	Will complete the group discussion electronically: no data collection form is needed. Will complete and provide to Leva Swim the revised paired comparison tool (Form C) and the NASA-TLX Form D3) prior to leaving the NEST conference room.

PARTICIPANT DEMOGRAPHIC INFORMATION

Please circle your response or provide a specific answer, if requested.

NAME: ______________________ ID #:____________________

1. Area of Responsibility

   A. Financial
   B. Clinical
   C. Operations
   D. Human Resources
   E. Marketing
   F. Information Technology
   G. Other: _______________

2. Level of Responsibility

   A. Vice President or above
   B. Non Vice-President

3. Gender

   A. Female
   B. Male

4. Age Range

   A. less than 30 years of age
   B. 30 to 40 years of age
   C. 41 to 50 years of age
   D. 51 to 60 years of age
   E. greater than 60 years of age

5. Years of Experience in Healthcare

   Specifiy: __________________

6. How would you rate your skill level for using a computer?
   A. Very good
   B. Somewhat good
   C. Neutral
   D. Somewhat limited
   E. Very limited

DIRECTIONS TO NEST CONFERENCE ROOM

1. The NEST is located in the Guernsey Building (Two Corporate Plaza), 5555 N. Grand Blvd. The Guernsey Building is a gray building with a red and white Guernsey logo on the east side of the building (you can see it from Lake Hefner Parkway).

2. The easiest way to access the Guernsey Building is to go west on 56th street over Lake Hefner Parkway. Turn left onto the access road as if you are going to go south on Lake Hefner Parkway .

3. Before you get on Lake Hefner Parkway, turn right into the Guernsey Building south parking lot.

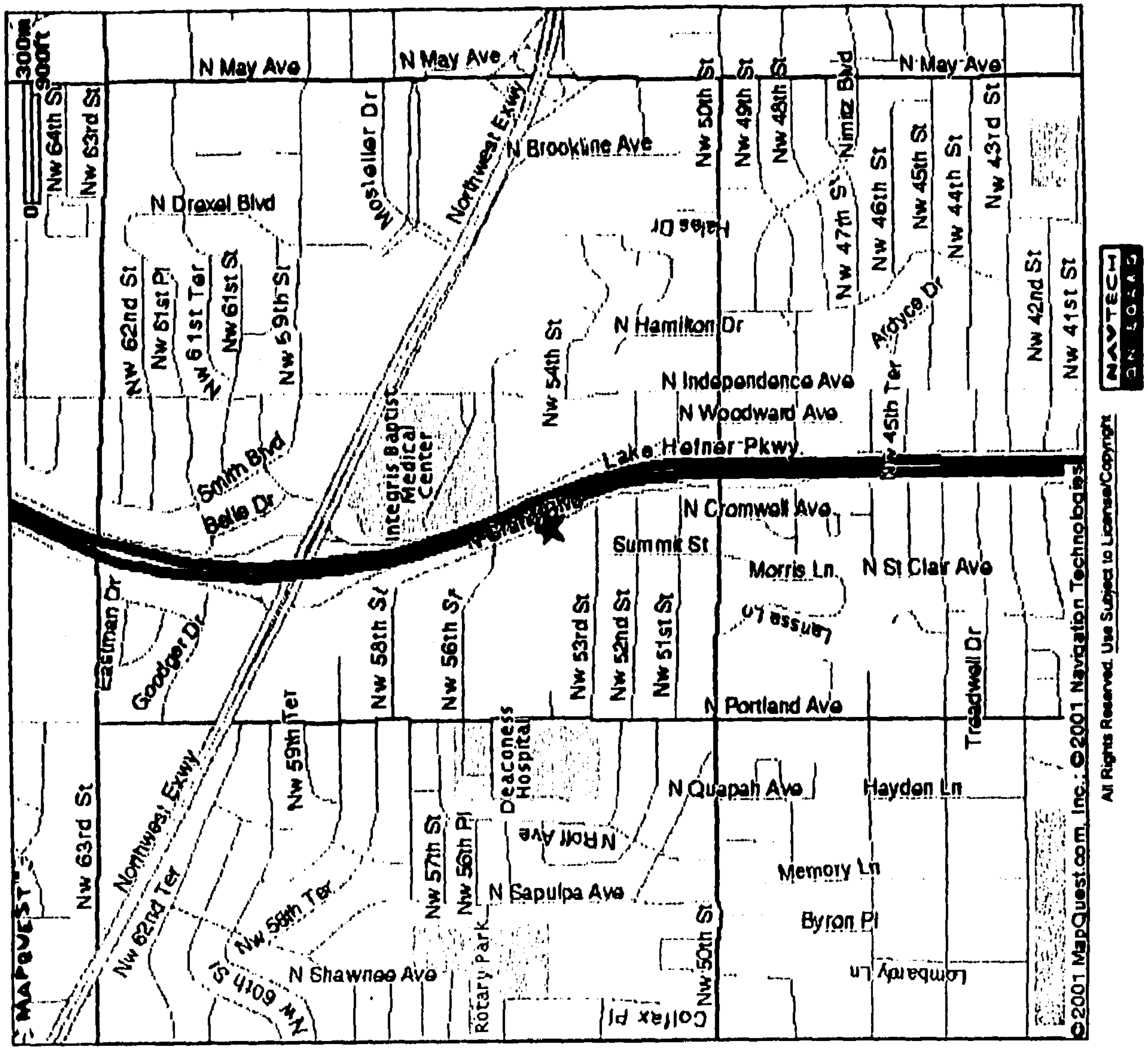
4. Park your car and enter the Guernsey Building through the double doors.

5. Turn right once you enter the building. You will stay on the first floor. Go down the long hallway until you see a door. The sign on the door says INTEGRIS Health Information Technology. YOU ARE CLOSE!

6. Go through this door and turn right. Wind around the cubicles and then head straight east. At the end of the cubicles you will be facing an east wall that has honorary placques on it. YOU ARE ALMOST THERE!

7. Look for a coffee pot to your left and look for a sign that says "YOU ARE HERE!" YOU ARE THERE!

(MAP PROVIDED ON BACK SIDE)



N May Ave
N May Ave
N May Ave
Northwest Exwy
N Brookline Ave
Nw 64th St
Nw 63rd St
N Drexel Blvd
Mosteller Dr
Nw 62nd St
Nw 61st Pl
Nw 61st Ter
Nw 61st St
Nw 59th St
Nw 50th St
Nw 49th St
Nw 48th St
Nimitz Blvd
Nw 47th St
Nw 46th St
Nw 45th St
Nw 44th St
Nw 43rd St
Nw 42nd St
Nw 41st St
Hales Dr
N Hamilton Dr
Ardyce Dr
Nw 54th St
N Independence Ave
N Woodward Ave
Nw 45th Ter
Integris Baptist Medical Center
Lake Hefner Pkwy
Smith Blvd
Belle Dr
N Cromwell Ave
Summit St
Morris Ln
N St Clair Ave
Lanssa Ln
Eastman Dr
Goodger Dr
Nw 58th St
Nw 56th St
Nw 53rd St
Nw 52nd St
Nw 51st St
Treadwell Dr
N Portland Ave
Nw 59th Ter
Deaconess Hospital
N Quapah Ave
Haydon Ln
Nw 63rd St
Northwest Exwy
N Rolf Ave
Nw 57th St
Nw 56th Pl
N Sapulpa Ave
Memory Ln
Nw 62nd Ter
Nw 58th Ter
Byron Pl
N Shawnee Ave
Nw 60th St
Rotary Park
Nw 50th St
Colfax Pl
Lombardy Ln
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NAVTECH ON BOARD
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APPENDIX G

BASELINE PAIRWISE COMPARISON DATA COLLECTION FORM AND INSTRUCTIONS

***** INSTRUCTIONS *****

ANALYTIC HIERARCHY PROCESS
PAIRED COMPARISON TOOL

For each paired comparison, circle the factor (Factor A or Factor B) that is more important/preferred in the selection of a proposed capital investment project. A definition of each factor is provided on the next page. If both factors are equally important, circle both. Evaluate the more important factor by circling the degree of importance/preference using the 9-point scale below:

If the more important factor is ...	the rating to assign is
Equally important/preferred	1
Weakly important/preferred	3
Strongly important/preferred	5
Very strongly important/preferred	7
Absolutely important/preferred	9

Even numbers (2, 4, 6, and 8) may be used to represent compromises among the preferences above.

Document your rationale for your preference selection and rating in the space provided.

PLEASE MONITOR AND DOCUMENT THE TIME (IN MINUTES) REQUIRED TO COMPLETE THIS TASK IN THE SPACE PROVIDED IN THE UPPER LEFT CORNER OF THE DATA COLLECTION FORM.

***** EXAMPLE *****

FACTOR A	FACTOR B	Equally Important		Weakly More Important		Strongly More Important		Very Strongly More Important		Absolutely More Important	RATIONALE
	PRIMARY FACTORS										
Internal Business Processes	Learning and Growth	1	2	3	4	5	6	7	8	9	Business process imp. drives L+G
Internal Business Processes	Customers	1	2	3	4	5	6	7	8	9	Can't have one without the other
Internal Business Processes	Finance and Value	1	2	3	4	5	6	7	8	9	Must be strong financially to support IBP
Learning and Growth	Customers	1	2	3	4	5	6	7	8	9	Customers are most important component
Learning and Growth	Finance and Value	1	2	3	4	5	6	7	8	9	Must be strong financially to support L+G
Customers	Finance and Value	1	2	3	4	5	6	7	8	9	Customers drive financial strength

FACTOR DEFINITIONS

FACTOR	FACTOR DEFINITION
INTERNAL BUSINESS PROCESSES	
Leverage against existing products and services	Degree to which organization already has a product, system or service in place that this initiative will be able to leverage against
Increase operational efficiency	Ability of initiative to reduce wait times or cycle times
Improve suply and demand chain	Degree to which initiative increases demand for business and provides the ability to support that demand
LEARNING AND GROWTH	
Fit with operational competencies	Ability of initiative to establish a fit with the current state of organization's operational competencies and/or culture
Implementation initiatives required	Magnitude of the work effort to implement new initiative
Ability to position organization for future	Degree to which the initiative postions the organization for the future
Organizational risk	Degree of risk the organization must take to implement the new initiative
CUSTOMER	
Innovation to existing services	Ability of initiative to positively change existing services
Satisfy customer needs	Ability of initiative to positively impact customer (patient, physician, employees, board of directors)
Sustain existing competitive advantage	Ability of the organization to sustain an existing competitive advantage through the initiative
Potential to create a new market	Degree to which the initiative creates an opportunity to grow a new market
FINANCE AND VALUE	
Cost savings potential	Ability of initiative to reduce operating expenses
Startup costs	Estimated cost to establish initiative
Ongoing costs	Estimated annual operating expenses of initiative
Revenue source potential	Estimated annual revenue generation potential of initiative

START TIME: ________

END TIME: ________

ID #: ____________

ANALYTIC HIERARCHY PROCESS
INITIAL PAIRWISE COMPARISON TOOL
(FORM A)

FACTOR A	FACTOR B	Equally Important		Weakly More Important		Strongly More Important		Very Strongly More Important		Absolutely More Important	RATIONALE
PRIMARY FACTORS											
Internal Business Processes	Learning and Growth	1	2	3	4	5	6	7	8	9	
Internal Business Processes	Customers	1	2	3	4	5	6	7	8	9	
Internal Business Processes	Finance and Value	1	2	3	4	5	6	7	8	9	
Learning and Growth	Customers	1	2	3	4	5	6	7	8	9	
Learning and Growth	Finance and Value	1	2	3	4	5	6	7	8	9	
Customers	Finance and Value	1	2	3	4	5	6	7	8	9	
SECONDARY FACTORS (INTERNAL BUSINESS PROCESSES)											
Ability to leverage against existing products or services	Ability to increase operational efficiency	1	2	3	4	5	6	7	8	9	
Ability to leverage against existing products or services	Ability to improve supply and demand chain	1	2	3	4	5	6	7	8	9	
Ability to increase operational efficiency	Ability to improve supply and demand chain	1	2	3	4	5	6	7	8	9	
SECONDARY FACTORS (LEARNING AND GROWTH)											
Fit with operational competencies and culture	Implementation initiatives required	1	2	3	4	5	6	7	8	9	
Fit with operational competencies and culture	Ability to position INTEGRIS Health for the future	1	2	3	4	5	6	7	8	9	
Fit with operational competencies and culture	Organizational risk	1	2	3	4	5	6	7	8	9	
Implementation initiatives required	Ability to position INTEGRIS Health for the future	1	2	3	4	5	6	7	8	9	
Implementation initiatives required	Organizational risk	1	2	3	4	5	6	7	8	9	
Ability et position INTEGRIS Health for the future	Organizational risk	1	2	3	4	5	6	7	8	9	
SECONDARY FACTORS (CUSTOMERS)											
Innovation to existing services	Ability to satisfy customers' needs	1	2	3	4	5	6	7	8	9	
Innovation to existing services	Ability to sustain an existing competitive advantage	1	2	3	4	5	6	7	8	9	
Innovation to existing services	Potential to create a new market	1	2	3	4	5	6	7	8	9	
Ability to satisfy customers' needs	Ability to sustain an existing competitive advantage	1	2	3	4	5	6	7	8	9	
Ability to satisfy customers' needs	Potential to create a new market	1	2	3	4	5	6	7	8	9	
Ability to sustain an existing competitive advantage	Potential to create a new market	1	2	3	4	5	6	7	8	9	
SECONDARY FACTORS (FINANCE AND VALUE)											
Cost savings potential	Startup Cost	1	2	3	4	5	6	7	8	9	
Cost savings potential	Ongoing cost	1	2	3	4	5	6	7	8	9	
Cost savings potential	Revenue source potential	1	2	3	4	5	6	7	8	9	
Startup cost	Ongoing cost	1	2	3	4	5	6	7	8	9	
Startup cost	Revenue source potential	1	2	3	4	5	6	7	8	9	
Ongoing cost	Revenue source potential	1	2	3	4	5	6	7	8	9	

APPENDIX H
NASA-TLX DATA COLLECTION FORMS AND INSTRUCTIONS

***** INSTRUCTIONS *****

NASA-TASK LOAD INDEX (TLX)
MENTAL WORKLOAD MEASUREMENT

The NASA-TLX workload measurement involves assessing a task in terms of six factors the six factors are:

Mental Demand (low/high): How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching)? Was the task easy or demanding, simple or complex, exacting or forgiving?

Physical Demand (low/high): How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Temporal Demand (low/high): How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

Operator Performance (good/poor): How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

Effort (low/high): How hard did you have to work (mentally and physically) to accomplish your level of performance?

Frustration Level (low/high): How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

This measurement requires the completion of two tasks. The first task is to pairwise compare the factors associated with mental workload. The second task is to rate the magnitude of each mental workload factor for the task performed. Instructions for each task are provided below.

PAIRWISE COMPARISON OF FACTORS:

CIRCLE the member of each pair that provided the most significant source of workload variation for the task. Disregard the gray shaded area.

Physical Demand / Mental Demand
Temporal Demand / Physical Demand
Temporal Demand / Mental Demand

Operator Performance / Physical Demand
Operator Performance / Mental Demand
Frustration Level / Physical Demand
Frustration Level / Mental Demand
Effort / Physical Demand
Effort / Mental Demand
Temporal Demand / Operator Performance
Temporal Demand / Frustration Level
Temporal Demand / Effort
Operator Performance / Frustration Level
Operator Performance / Effort
Effort / Frustration Level

TASK RATING:

PLACE AN "X" on the scale from 1 to 10 (1=low, 10=high) that represents the magnitude of each factor for the task performed.

		1	2	3	4	5	6	7	8	9	10	
Mental Demand	LOW											HIGH
Physical Demand	LOW											HIGH
Temporal Demand	LOW											HIGH
Operator Performance	GOOD											POOR
Effort	LOW											HIGH
Frustration Level	LOW											HIGH

***** EXAMPLE *****

PAIRED COMPARISON OF FACTORS:

INSTRUCTIONS: CIRCLE the member of each pair that provided the most significant source of workload variation in this task. Disregard the gray shaded area.

Physical Demand / Mental Demand
Temporal Demand / Mental Demand
Operator Performance / Mental Demand
Frustration Level / Mental Demand
Effort / Mental Demand
Temporal Demand / Physical Demand
Operator Performance / Physical Demand
Frustration Level / Physical Demand
Effort / Physical Demand
Temporal Demand / Operator Performance
Temporal Demand / Frustration Level
Temporal Demand / Effort
Operator Performance / Frustration Level
Operator Performance / Effort
Effort / Frustration Level

TASK RATING:

TASK #1: Completion of the initial AHP pairwise comparison judgments.

		1	2	3	4	5	6	7	8	9	10	
Mental Demand	LOW										X	HIGH
Physical Demand	LOW		X									HIGH
Temporal Demand	LOW							X				HIGH
Operator Performance	GOOD								X			POOR
Effort	LOW					X						HIGH
Frustration Level	LOW						X					HIGH

RATING	WEIGHT	PRODUCT
SUM		
WEIGHTS (TOTAL)		
MEAN WWL SCORE		

ID #:___________

QUESTIONNAIRE
NASA-TLX
MENTAL WORKLOAD MEASUREMENT

(FORM D1)

PAIRWISE COMPARISON OF FACTORS

INSTRUCTIONS: ***CIRCLE*** **the member of each pair that provided the most significant source of workload variation in this task. Disregard the gray shaded area.**

Physical Demand / Mental Demand
Temporal Demand / Mental Demand
Operator Performance / Mental Demand
Frustration Level / Mental Demand
Effort / Mental Demand

Temporal Demand / Physical Demand
Operatior Performance / Physical Demand
Frustration Level / Physical Demand
Effort / Physical Demand
Temporal Demand / Operator Performance

Temporal Demand / Frustration Level
Temporal Demand / Effort
Operator Performance / Frustration Level
Operator Performance / Effort
Effort / Frustration Level

TALLY OF IMPORTANCE FACTORS		
	COUNT	WEIGHT
MD		
PD		
TD		
OP		
FR		
EF		
SUM		

RATING SCALES

INSTRUCTIONS: ***PLACE A MARK*** **on each scale that represents the magnitude of each factor for each task performed. Disregard the gray shaded areas.**

TASK #1: Completion of the initial AHP pairwise comparison judgments.

		RATINGS										
		1	2	3	4	5	6	7	8	9	10	
Mental Demand	LOW											HIGH
Physical Demand	LOW											HIGH
Temporal Demand	LOW											HIGH
Operator Performance	GOOD											POOR
Effort	LOW											HIGH
Frustration Level	LOW											HIGH

RATING	WEIGHT	PRODUCT
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

ID #:____________

QUESTIONNAIRE
NASA-TLX
MENTAL WORKLOAD MEASUREMENT

(FORM D2)

PAIRWISE COMPARISON OF FACTORS

INSTRUCTIONS: *CIRCLE* the member of each pair that provided the most significant source of workload variation in this task. Disregard the gray shaded area.

Physical Demand / Mental Demand
Temporal Demand / Mental Demand
Operator Performance / Mental Demand
Frustration Level / Mental Demand
Effort / Mental Demand

Temporal Demand / Physical Demand
Operator Performance / Physical Demand
Frustration Level / Physical Demand
Effort / Physical Demand
Temporal Demand / Operator Performance

Temporal Demand / Frustration Level
Temporal Demand / Effort
Operator Performance / Frustration Level
Operator Performance / Effort
Effort / Frustration Level

TALLY OF IMPORTANCE FACTORS		
	COUNT	WEIGHT
MD		
PD		
TD		
OP		
FR		
EF		
SUM		

TASK #2: *Completion of the Hierarchical Element Knowledge Self-Assessment Questionnaire.*

		RATINGS										
		1	2	3	4	5	6	7	8	9	10	
Mental Demand	LOW											HIGH
Physical Demand	LOW											HIGH
Temporal Demand	LOW											HIGH
Operator Performance	GOOD											POOR
Effort	LOW											HIGH
Frustration Level	LOW											HIGH

RATING	WEIGHT	PRODUCT
SUM		
WEIGHTS	TOTAL	
MEAN WWL	SCORE	

ID #:__________

QUESTIONNAIRE
NASA-TLX
MENTAL WORKLOAD MEASUREMENT

(FORM D3)

PAIRWISE COMPARISON OF FACTORS

INSTRUCTIONS: *CIRCLE* the member of each pair that provided the most significant source of workload variation in this task. Disregard the gray shaded area.

Physical Demand / Mental Demand
Temporal Demand / Mental Demand
Operator Performance / Mental Demand
Frustration Level / Mental Demand
Effort / Mental Demand

Temporal Demand / Physical Demand
Operatior Performance / Physical Demand
Frustration Level / Physical Demand
Effort / Physical Demand
Temporal Demand / Operator Performance

Temporal Demand / Frustration Level
Temporal Demand / Effort
Operator Performance / Frustration Level
Operator Performance / Effort
Effort / Frustration Level

TALLY OF IMPORTANCE FACTORS		
	COUNT	WEIGHT
MD		
PD		
TD		
OP		
FR		
EF		
SUM		

TASK #3: Participation in face-to-face meeting using Groupware electronic meeting technology to discuss outlier pairwise judgments and completing the revised pairwise comparison judgments.

		RATINGS										
		1	2	3	4	5	6	7	8	9	10	
Mental Demand	LOW											HIGH
Physical Demand	LOW											HIGH
Temporal Demand	LOW											HIGH
Operator Performance	GOOD											POOR
Effort	LOW											HIGH
Frustration Level	LOW											HIGH

RATING	WEIGHT	PRODUCT
SUM		
WEIGHTS TOTAL		
MEAN [illegible] SCORE		

APPENDIX I

KNOWLEDGE SELF-ASSESSMENT DATA COLLECTION FORM AND INSTRUCTIONS

***** INSTRUCTIONS *****

ANALYTIC HIERARCHY PROCESS
KNOWLEDGE SELF-ASSESSMENT TOOL

Rate you overall knowledge and ability to assess the merits of a proposed project with respect to each of the AHP hierarchical elements by placing an "X" on the 5-point Likert scale.

PLEASE MONITOR AND DOCUMENT THE TIME (IN MINUTES) REQUIRED TO COMPLETE THIS TASK IN THE SPACE PROVIDED IN THE UPPER LEFT CORNER OF THE DATA COLLECTION FORM.

***** EXAMPLE *****

	LIKERT SCALE				
Level 1: Primary Factors	Very Unknowledgeable	Somewhat Unknowledgeable	Neutral	Somewhat Knowledgeable	Very Knowledgeable
Internal Business Processes (Factor A) compared to Learning and Growth (Factor B)	X				
Internal Business Processes (Factor A) compared to Customers (Factor B)				X	
Internal Business Processes (Factor A) compared to Finance and Value (Factor B)					X
Learning and Growth (Factor A) compared to Customers (Factor B)		X			
Learning and Growth (Factor A) compared to Finance and Value (Factor B)				X	
Customers (Factor A) compared to Finance and Value (Factor B)					X

START TIME: _______

END TIME: ________

ID #: ________________

ANALYTIC HIERARCHY PROCESS
KNOWLEDGE SELF-ASSESSMENT QUESTONNAIRE
(FORM B)

	LIKERT SCALE				
	Very Unknowledgable	Somewhat Unknowledgable	Neutral	Somewhat Knowledgable	Very Knowledgable
Level 1: Primary Factors					
Internal Business Processes (Factor A) compared to Learning and Growth (Factor B)					
Internal Business Processes (Factor A) compared to Customers (Factor B)					
Internal Business Processes (Factor A) compared to Finance and Value (Factor B)					
Learning and Growth (Factor A) compared to Customers (Factor B)					
Learning and Growth (Factor A) compared to Finance and Value (Factor B)					
Customers (Factor A) compared to Finance and Value (Factor B)					
Level 2A: Secondary Factors (Internal Business Processes)					
Ability to Leverage Against Existing Products or Services (Factor A) compared to Ability to Increase Operational Efficiency (Factor B)					
Ability to Leverage Against Existing Products or Services (Factor A) compared to Abilty to Improve Supply and Demand Chain (Factor B)					
Abilitiy to Increase Operational Efficiency (Factor A) compared to Abilty to Improve Supply and Demand Chain (Factor B)					
Level 2B: Secondary Factors (Learning and Growth)					
Fit with Operational Competencies and Culture (Factor A) compared to Implementation Initiatives Required (Factor B)					
Fit with Operational Competencies and Culture (Factor A) compared to Ability to Position INTEGRIS Health for the Future (Factor B)					
Fit with Operational Competencies and Culture (Factor A) compared to Organizational Risk (Factor B)					
Implementation Initiatives Required (Factor A) compared to Ability to Position INTEGRIS Helath for the Future (Factor B)					
Implementation Initiatives Required (Factor A) compared to Organizational Risk (Factor B)					
Ability to Position INTEGRIS Health for the Future (Factor A) compared to Organizational Risk (Factor B)					
Level 2C: Secondary Factors (Customers)					
Innovation to Existing Services (Factor A) compared to Ability to Satisfy Customers' Needs (Factor B)					
Innovation to Existing Services (Factor A) compared to Ability to Sustain on Existing Competitive Advantage (Factor B)					
Innovation to Existing Services (Factor A) compared to Potential to Create a New Market (Factor B)					
Ability to Satisfy Customers' Needs (Factor A) compared to Ability to Sustain on Existing Competitive Advantage (Factor B)					
Ability to Satisfy Customers' Needs (Factor A) compared to Potential to Create a New Market (Factor B)					
Ability to Sustain on Existing Competitive Advantage (Factor A) compared to Potential to Create a New Market+A9 (Factor B)					
Level 2D: Secondary Factors (Finance and Value)					
Cost Savings Potential (Factor A) compared to Startup Cost (Factor B)					
Cost Savings Potential (Factor A) compared to Ongoing Cost (Factor B)					
Cost Savings Potential (Factor A) compared to Revenue Source Potential (Factor B)					
Startup Cost (Factor A) compared to Ongoing Cost (Factor B)					
Startup Cost (Factor A) compared to Revenue Source Potential (Factor B)					
Ongoing Cost (Factor A) compared to Revenue Source Potential (Factor B)					

APPENDIX J

ELECTRONIC MEETING TECHNOLOGY PAIRWISE COMPARISON DATA COLLECTION FORM AND INSTRUCTIONS

***** INSTRUCTIONS *****

ANALYTIC HIERARCHY PROCESS
PAIRED COMPARISON TOOL

For each paired comparison, circle the factor (Factor A or Factor B) that is more important/preferred in the selection of a proposed capital investment project. A definition of each factor is provided on the next page. If both factors are equally important, circle both. Evaluate the more important factor by circling the degree of importance/preference using the 9-point scale below:

If the more important factor is ...	the rating to assign is
Equally important/preferred	1
Weakly important/preferred	3
Strongly important/preferred	5
Very strongly important/preferred	7
Absolutely important/preferred	9

Even numbers (2, 4, 6, and 8) may be used to represent compromises among the preferences above.

Document your rationale for your preference selection and rating in the space provided.

PLEASE MONITOR AND DOCUMENT THE TIME (IN MINUTES) REQUIRED TO COMPLETE THIS TASK IN THE SPACE PROVIDED IN THE UPPER LEFT CORNER OF THE DATA COLLECTION FORM.

***** EXAMPLE *****

FACTOR A	FACTOR B	Equally Important		Weakly More Important		Strongly More Important		Very Strongly More Important		Absolutely More Important	RATIONALE
	PRIMARY FACTORS										
Internal Business Processes	Learning and Growth	1	2	3	4	5	6	7	8	9	Business process imp. drives L+G
Internal Business Processes	Customers	1	2	3	4	5	6	7	8	9	Can't have one without the other
Internal Business Processes	Finance and Value	1	2	3	4	5	6	7	8	9	Must be strong financially to support IBP
Learning and Growth	Customers	1	2	3	4	5	6	7	8	9	Customers are most important component
Learning and Growth	Finance and Value	1	2	3	4	5	6	7	8	9	Must be strong financially to support L+G
Customers	Finance and Value	1	2	3	4	5	6	7	8	9	Customers drive financial strength

FACTOR DEFINITIONS

FACTOR	FACTOR DEFINITION
INTERNAL BUSINESS PROCESSES	
Leverage against existing products and services	Degree to which organization already has a product, system or service in place that this initiative will be able to leverage against
Increase operational efficiency	Ability of initiative to reduce wait times or cycle times
Improve suply and demand chain	Degree to which initiative increases demand for business and provides the ability to support that demand
LEARNING AND GROWTH	
Fit with operational competencies	Ability of initiative to establish a fit with the current state of organization's operational competencies and/or culture
Implementation initiatives required	Magnitude of the work effort to implement new initiative
Ability to position organization for future	Degree to which the initiative postions the organization for the future
Organizational risk	Degree of risk the organization must take to implement the new initiative
CUSTOMER	
Innovation to existing services	Ability of initiative to positively change existing services
Satisfy customer needs	Ability of initiative to positively impact customer (patient, physician, employees, board of directors)
Sustain existing competitive advantage	Ability of the organization to sustain an existing competitive advantage through the initiative
Potential to create a new market	Degree to which the initiative creates an opportunity to grow a new market
FINANCE AND VALUE	
Cost savings potential	Ability of initiative to reduce operating expenses
Startup costs	Estimated cost to establish initiative
Ongoing costs	Estimated annual operating expenses of initiative
Revenue source potential	Estimated annual revenue generation potential of initiative

START TIME: __________

END TIME: __________

ANALYTIC HIERARCHY PROCESS
REVISED PAIRWISE COMPARISON TOOL
(FORM C)

ID#: __________

FACTOR A	FACTOR B	Equally Important		Weakly More Important		Strongly More Important		Very Strongly More Important		Absolutely More Important	RATIONALE
PRIMARY FACTORS											
Internal Business Processes	Learning and Growth	1	2	3	4	5	6	7	8	9	
Internal Business Processes	Customers	1	2	3	4	5	6	7	8	9	
Internal Business Processes	Finance and Value	1	2	3	4	5	6	7	8	9	
Learning and Growth	Customers	1	2	3	4	5	6	7	8	9	
Learning and Growth	Finance and Value	1	2	3	4	5	6	7	8	9	
Customers	Finance and Value	1	2	3	4	5	6	7	8	9	
SECONDARY FACTORS (INTERNAL BUSINESS PROCESSES)											
Ability to leverage against existing products or services	Ability to increase operational efficiency	1	2	3	4	5	6	7	8	9	
Ability to leverage against existing products or services	Ability to improve supply and demand chain	1	2	3	4	5	6	7	8	9	
Ability to increase operational efficiency	Ability to improve supply and demand chain	1	2	3	4	5	6	7	8	9	
SECONDARY FACTORS (LEARNING AND GROWTH)											
Fit with operational competencies and culture	Implementation initiatives required	1	2	3	4	5	6	7	8	9	
Fit with operational competencies and culture	Ability to position INTEGRIS Health for the future	1	2	3	4	5	6	7	8	9	
Fit with operational competencies and culture	Organizational risk	1	2	3	4	5	6	7	8	9	
Implementation initiatives required	Ability to position INTEGRIS Health for the future	1	2	3	4	5	6	7	8	9	
Implementation initiatives required	Organizational risk	1	2	3	4	5	6	7	8	9	
Ability at position INTEGRIS Health for the future	Organizational risk	1	2	3	4	5	6	7	8	9	
SECONDARY FACTORS (CUSTOMERS)											
Innovation to existing services	Ability to satisfy customers' needs	1	2	3	4	5	6	7	8	9	
Innovation to existing services	Ability to sustain an existing competitive advantage	1	2	3	4	5	6	7	8	9	
Innovation to existing services	Potential to create a new market	1	2	3	4	5	6	7	8	9	
Ability to satisfy customers' needs	Ability to sustain an existing competitive advantage	1	2	3	4	5	6	7	8	9	
Ability to satisfy customers' needs	Potential to create a new market	1	2	3	4	5	6	7	8	9	
Ability to sustain an existing competitive advantage	Potential to create a new market	1	2	3	4	5	6	7	8	9	
SECONDARY FACTORS (FINANCE AND VALUE)											
Cost savings potential	Startup Cost	1	2	3	4	5	6	7	8	9	
Cost savings potential	Ongoing cost	1	2	3	4	5	6	7	8	9	
Cost savings potential	Revenue source potential	1	2	3	4	5	6	7	8	9	
Startup cost	Ongoing cost	1	2	3	4	5	6	7	8	9	
Startup cost	Revenue source potential	1	2	3	4	5	6	7	8	9	
Ongoing cost	Revenue source potential	1	2	3	4	5	6	7	8	9	

APPENDIX K
EXAMPLE GROUPWARE REPORT

Secondary Factors (Customers) (Topic Commenter)

Participant Instructions

1. Specify the factor you have selected that is the most important
2. Specify the importance rating you have assigned to the most important factor
3. Describe the rationale supporting your opinion

1. Innovation to existing services and Ability to satisfy customers' needs

Ability to satisfy customers (5): customers need to drive innovations {#7}

Ability to satisfy customer needs (5): Customers drive profitability {#8}

Innovation and customer needs (1): which came first, the chicken or the egg??? {#9}

Ability to satisfy customer's needs /9// Customers drive success {#10}

Ability to satisfy Customer need(9): Paramount to business success and revenue growth {#11}

Innovation to existing services/Ability to satisfy customers' needs (1) Positively changing existing services results in satisfied customers. {#13}

Innovation/customer needs (1): customer need drives innovation but innovation necessary to continually improve meeting customer need {#14}

2. *****Innovation to existing services and Ability to sustain an existing competitive advantage*****

Ability to sustain an existing competitive advandtage(5): need to focus on competitive advantage {#12}

Ability to sustain an existing competitive advantage (5) Cometitive Advant. must be maintained {#15}

Ability to sustain an existing competitive advantage/7// Need a strong base of operations from which to innovate {#16}

Competitive Advantage(5): May not always be related to innovation... {#17}

Innovation and competitive advantage (1): which drives which? {#18}

Innovation (7): Necessary to sustain competative advantage {#20}

Innovation to existing services (4) Improving current services is necessary to sustain the competitive advantage. {#21}

3. *****Innovation to existing services and Potential to create a new market*****

Potential to create a new market (7) New markets drive NEW revenue {#19}

Innovation to existing services and potential to create a new market (1): equally important to business growth {#22}

Potential to create a new market (3): drives innovation {#23}

Potential to create a new market//5//Need strength in operations but flexible enough to explore
new market opportunities {#24}

Potential to create new market(3): Advantage from a competitive perspective {#25}

Innovation to existing services (4) Improving the current service is necessary to support the new market. {#26}

Innovation(7): Necessary to have products and services to enter new markets {#31}

4. *****Ability to satisfy customers' needs and Ability to sustain an existing competitive advantage*****

Ability to satisfy customer needs(3): it's all about what the customer wants and needs {#27}

Ability to sustain an existing competitive advantage (5): Competitive advant drives profitability (and includes customer needs) {#28}

Ability to satisfy customers' needs and ability to sustain an existing competitive advantage (1): factors go hand in hand {#29}

Equal(1): Both are interrelated {#30}

Ability to satisfy customers' needs/9// if you can not satisfy customers then you have no competitive advantage {#32}

Ability to satisfy customers' needs (7) Satisfying customer needs feeds the competitive advantage. {#34}

Customer needs (9): Necessary to success short and long term {#37}

5. *****Ability to satisfy customers' needs and Potential to create a new market*****

Potential new market (3): why not satisfy customers in a new market? {#33}

Ability to satisfy custome need (5): paramount to revenue growth {#35}

Ability to satisy customer needs and Potential to creaste a new market (1): Must be complimentry {#36}

Ability to satisfy customers' needs / 7// If your customers are satisfied they will build strength
for a new market {#38}

Ability to satisfy customers needs and potential to create a new market (1): must be able to sustain customer needs while growing new business {#39}

Ability to satisfy customers' needs /Potential to create a new market (1) A new market can bring in customers and customers demand new markets. {#41}

customer needs(8): identifies/defines the new market and the parameters of success {#46}

6. *****Ability to sustain an existing competitive advantage and Potential to create a new market*****

Competitive advantage and new market(1): create competitive advantage in a new market {#40}

Ability to sustain an existing competitive advantage (3): Must protect current advantage before moving on. {#42}

Equal (1): new markets and competitive advantage are both critical to growth... {#43}

Ability to sustain an existing competitive advantage (5): maintaining competitive status means assuring market position {#44}

Potential to create a new market /3// if you create new markets, you can continue to strengthen
your competitive advantage {#45}

Ability to sustain an existing competitive advantage/Potential to create a new market (1) Equal-Creating a new market leads to a competitive advantage. {#47}

sustain/create new market (1): sustain to have resources to grow - grow or die {#48}

APPENDIX L

POST ELECTRONIC MEETING SURVEY

PARTICIPANT POST-ELECTRONIC MEETING SURVEY

Please circle your response or provide a specific answer, if requested.

NAME: ______________________ ID #:____________________

1. To what degree did the discussion contribute to the revision of your pairwise comparison ratings?

   A. Very strongly influenced
   B. Strongly influenced
   C. Weakly influenced
   D. Very weakly influenced
   E. Did not influence at all

2. To what degree do you believe your revised pairwise comparison ratings were influenced by the desire to come to group consensus?

   A. Very strongly influenced
   B. Strongly influenced
   C. Weakly influenced
   D. Very weakly influenced
   E. Did not influence at all

3. To what degree did the technology (laptop, mouse) influence your ability to effectively participate in the meeting?

   A. Helped very significantly
   B. Helped significantly
   C. Neutral
   D. Impaired significantly
   E. Impaired very significantly

4. *Had you used the Groupware software prior to your participation in the electronic meeting?*
   A. Yes
   B. No

5. To what degree did the Groupware software influence your ability to effectively participate in the meeting?

   A. Helped very significantly
   B. Helped significantly
   C. Neutral
   D. Impaired significantly
   E. Impaired very significantly

APPENDIX M
DISSERTATON PILOT EVALUATON QUESTIONNAIRE

DISSERTATION PILOT EVALUATION FORM

Agreement Scale					
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Evaluation Questions
					EXPERIMENTAL TASKS
					1. The paired comparison data collection form was easy to use.
Comments:					
					2. The knowledge self-assessment tool was easy to use.
Comments:					
					3. The NASA-TLX workload measurement tool was easy to use.
Comments:					
					4. The experimental tasks flowed together smoothly.
Comments:					
					5. The Groupware software was easy to use.
Comments:					
					6. The NEST equipment was easy to use.
Comments:					
					7. The Groupware activity provided an opportunity for knowledge transfer.
Comments:					
					8. I considered the opinions of others when I completed my revised Pairwise Comparison tool..
Comments:					

DISSERTATION PILOT EVALUATION FORM

Agreement Scale					
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Evaluation Questions
					[illegible]
					1. The instructions were easy to understand.
Comments:					
					2. The instructions were helpful.
Comments:					
					3. The letter describing the experiment increased my understanding of the experimental objective and related tasks.
Comments:					
					4. The Informed Consent Form was easy to understand.
Comments:					
Other Comments:					

APPENDIX N

AHP MODEL SELECTION SENSITIVITY ANALYSIS

							Group Size = 5			Group Size = 7		
Scenario	**Cost**	**Quality**	**Task Time**	**Mental Workload**	**Consistency**	**Individual Consensus**	**Baseline**	**KSA**	**EMT**	**Baseline**	**KSA**	**EMT**
A	0.90	0.10	0.50	0.50	0.50	0.50	4.667	4.749	5.470	5.711	5.729	3.271
B	0.90	0.10	0.50	0.50	0.30	0.70	4.640	4.749	5.535	5.689	5.720	3.337
C	0.90	0.10	0.50	0.50	0.70	0.30	4.693	4.749	5.406	5.733	5.737	3.204
D	0.90	0.10	0.30	0.70	0.50	0.50	3.227	3.516	6.080	4.734	4.971	3.925
E	0.90	0.10	0.30	0.70	0.30	0.70	3.200	3.516	6.145	4.712	4.962	3.992
F	0.90	0.10	0.30	0.70	0.70	0.30	3.253	3.516	6.016	4.756	4.980	3.859
G	0.90	0.10	0.70	0.30	0.50	0.50	6.107	5.983	4.860	6.689	6.486	2.616
H	0.90	0.10	0.70	0.30	0.30	0.70	6.080	5.983	4.925	6.667	6.477	2.682
I	0.90	0.10	0.70	0.30	0.70	0.30	6.133	5.983	4.796	6.711	6.495	2.549
J	0.80	0.20	0.50	0.50	0.50	0.50	4.333	4.333	5.449	6.015	5.994	3.722
K	0.80	0.20	0.50	0.50	0.30	0.70	4.280	4.333	5.578	5.971	5.977	3.855
L	0.80	0.20	0.50	0.50	0.70	0.30	4.387	4.333	5.320	6.059	6.011	3.589
M	0.80	0.20	0.30	0.70	0.50	0.50	3.053	3.236	5.992	5.147	5.321	4.304
N	0.80	0.20	0.30	0.70	0.30	0.70	3.000	3.236	6.121	5.103	5.303	4.437
O	0.80	0.20	0.30	0.70	0.70	0.30	3.107	3.236	5.862	5.191	5.338	4.171
P	0.80	0.20	0.70	0.30	0.50	0.50	5.613	5.430	4.907	6.884	6.667	3.140
Q	0.80	0.20	0.70	0.30	0.30	0.70	5.560	5.430	5.036	6.840	6.650	3.273
R	0.80	0.20	0.70	0.30	0.70	0.30	5.667	5.430	4.778	6.928	6.685	3.007
S	0.60	0.40	0.50	0.50	0.50	0.50	3.667	3.500	5.407	6.624	6.524	4.625
T	0.60	0.40	0.50	0.50	0.30	0.70	3.560	3.500	5.686	6.536	6.490	4.891
U	0.60	0.40	0.50	0.50	0.70	0.30	3.773	3.500	5.149	6.712	6.559	4.358
V	0.60	0.40	0.30	0.70	0.50	0.50	2.707	2.677	5.814	5.972	6.019	5.061
W	0.60	0.40	0.30	0.70	0.30	0.70	2.600	2.677	6.072	5.884	5.985	5.328
X	0.60	0.40	0.30	0.70	0.70	0.30	2.813	2.677	5.556	6.060	6.054	4.795
Y	0.60	0.40	0.70	0.30	0.50	0.50	4.627	4.322	5.001	7.276	7.029	4.188
Z	0.60	0.40	0.70	0.30	0.30	0.70	4.520	4.322	5.259	7.188	6.995	4.455
AA	0.60	0.40	0.70	0.30	0.70	0.30	4.733	4.322	4.742	7.364	7.064	3.922
AB	0.50	0.50	0.50	0.50	0.50	0.50	3.333	3.083	5.386	6.928	6.790	5.076
AC	0.50	0.50	0.50	0.50	0.30	0.70	3.200	3.083	5.709	6.818	6.746	5.410
AD	0.50	0.50	0.50	0.50	0.70	0.30	3.467	3.083	5.063	7.038	6.833	4.743
AE	0.50	0.50	0.30	0.70	0.50	0.50	2.533	2.398	5.725	6.385	6.369	5.440
AF	0.50	0.50	0.30	0.70	0.30	0.70	2.400	2.398	6.048	6.275	6.326	5.773
AG	0.50	0.50	0.30	0.70	0.70	0.30	2.667	2.398	5.402	6.495	6.412	5.107
AH	0.50	0.50	0.70	0.30	0.50	0.50	4.133	3.768	5.047	7.471	7.211	4.712
AI	0.50	0.50	0.70	0.30	0.30	0.70	4.000	3.768	5.370	7.361	7.167	5.046
AJ	0.50	0.50	0.70	0.30	0.70	0.30	4.267	3.768	4.724	7.581	7.254	4.379
AK	0.40	0.60	0.50	0.50	0.50	0.50	3.000	2.666	5.365	7.232	7.055	5.528
AL	0.40	0.60	0.50	0.50	0.30	0.70	2.840	2.666	5.753	7.100	7.003	5.928
AM	0.40	0.60	0.50	0.50	0.70	0.30	3.160	2.666	4.978	7.365	7.107	5.128
AN	0.40	0.60	0.30	0.70	0.50	0.50	2.360	2.118	5.636	6.798	6.718	5.819
AO	0.40	0.60	0.30	0.70	0.30	0.70	2.200	2.118	6.024	6.666	6.666	6.219
AP	0.40	0.60	0.30	0.70	0.70	0.30	2.520	2.118	5.249	6.930	6.771	5.419
AQ	0.40	0.60	0.70	0.30	0.50	0.50	3.640	3.215	5.094	7.667	7.392	5.237
AR	0.40	0.60	0.70	0.30	0.30	0.70	3.480	3.215	5.482	7.535	7.340	5.637
AS	0.40	0.60	0.70	0.30	0.70	0.30	3.800	3.215	4.707	7.799	7.444	4.837
AT	0.20	0.80	0.50	0.50	0.50	0.50	2.333	1.833	5.323	7.841	7.586	6.430
AU	0.20	0.80	0.50	0.50	0.30	0.70	2.120	1.833	5.840	7.665	7.516	6.964
AV	0.20	0.80	0.50	0.50	0.70	0.30	2.547	1.833	4.807	8.017	7.655	5.897
AW	0.20	0.80	0.30	0.70	0.50	0.50	2.013	1.559	5.459	7.624	7.417	6.576
AX	0.20	0.80	0.30	0.70	0.30	0.70	1.800	1.559	5.976	7.448	7.348	7.109
AY	0.20	0.80	0.30	0.70	0.70	0.30	2.227	1.559	4.942	7.800	7.487	6.043
AZ	0.20	0.80	0.70	0.30	0.50	0.50	2.653	2.107	5.188	8.058	7.754	6.285
BA	0.20	0.80	0.70	0.30	0.30	0.70	2.440	2.107	5.704	7.882	7.684	6.818
BB	0.20	0.80	0.70	0.30	0.70	0.30	2.867	2.107	4.671	8.234	7.823	5.752
BC	0.10	0.90	0.50	0.50	0.50	0.50	2.000	1.417	5.302	8.145	7.851	6.882
BD	0.10	0.90	0.50	0.50	0.30	0.70	1.760	1.417	5.884	7.947	7.773	7.482
BE	0.10	0.90	0.50	0.50	0.70	0.30	2.240	1.417	4.721	8.343	7.929	6.282
BF	0.10	0.90	0.30	0.70	0.50	0.50	1.840	1.280	5.370	8.037	7.767	6.955
BG	0.10	0.90	0.30	0.70	0.30	0.70	1.600	1.280	5.951	7.839	7.689	7.555
BH	0.10	0.90	0.30	0.70	0.70	0.30	2.080	1.280	4.789	8.235	7.845	6.355
BI	0.10	0.90	0.70	0.30	0.50	0.50	2.160	1.554	5.235	8.254	7.935	6.809
BJ	0.10	0.90	0.70	0.30	0.30	0.70	1.920	1.554	5.816	8.056	7.857	7.409
BK	0.10	0.90	0.70	0.30	0.70	0.30	2.400	1.554	4.653	8.452	8.013	6.209