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Ullman et al.

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(54) **GENERAL DECISION-MAKING SUPPORT METHOD AND SYSTEM**

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(73) Assignee: **Robust Decisions**

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(51) **Int. Cl.**[7] **G06F 17/00**; G06F 15/18

(52) **U.S. Cl.** **706/60**; 706/21; 706/47

(58) **Field of Search** 706/60, 21, 47

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Primary Examiner—George B. Davis
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(57) **ABSTRACT**

To identify the best choice from a set of alternatives, team members select the criteria to be used in identifying the best choice. Each criterion describes at least one feature of the alternatives. Each team member then, for each alternative, defines a target value for the feature of the criteria and sets a level of knowledge about the feature of the criteria. Using the target values and the team member's knowledge of each feature, each team member estimates how well the alternatives meet the target values for the features. The system then calculates an expected utility for each alternative based on the team member's estimations and a probability that each alternative is the best choice. Finally, based on the expected utility and probability that each alternative is best, a best choice is identified.

27 Claims, 9 Drawing Sheets

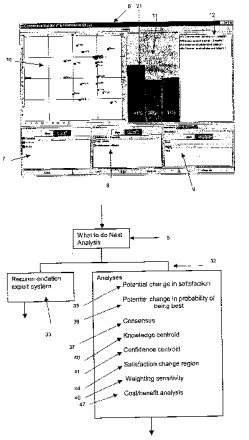

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Figure 1

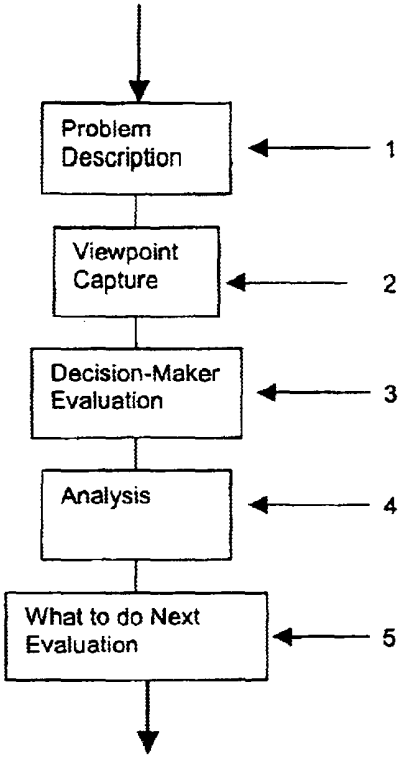

Figure 2

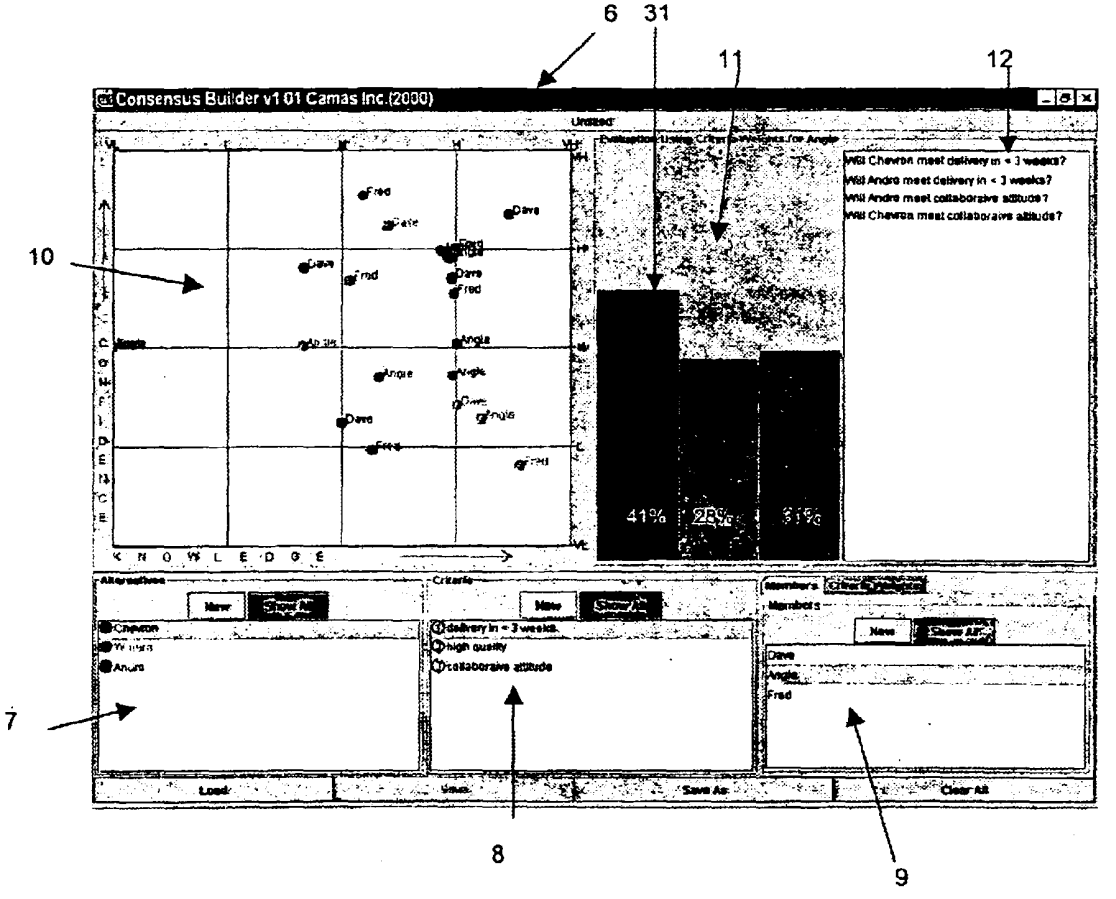

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Figure 3

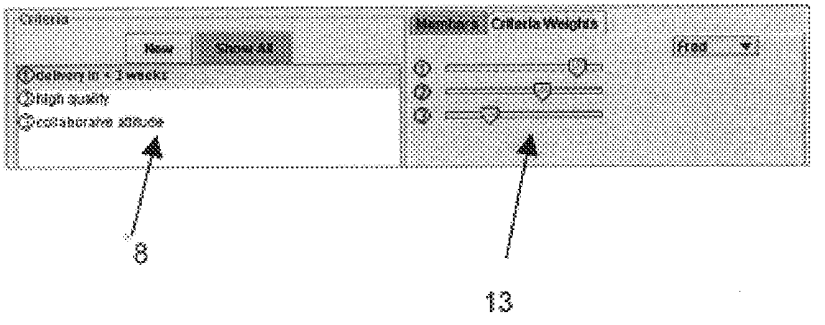

Figure 4

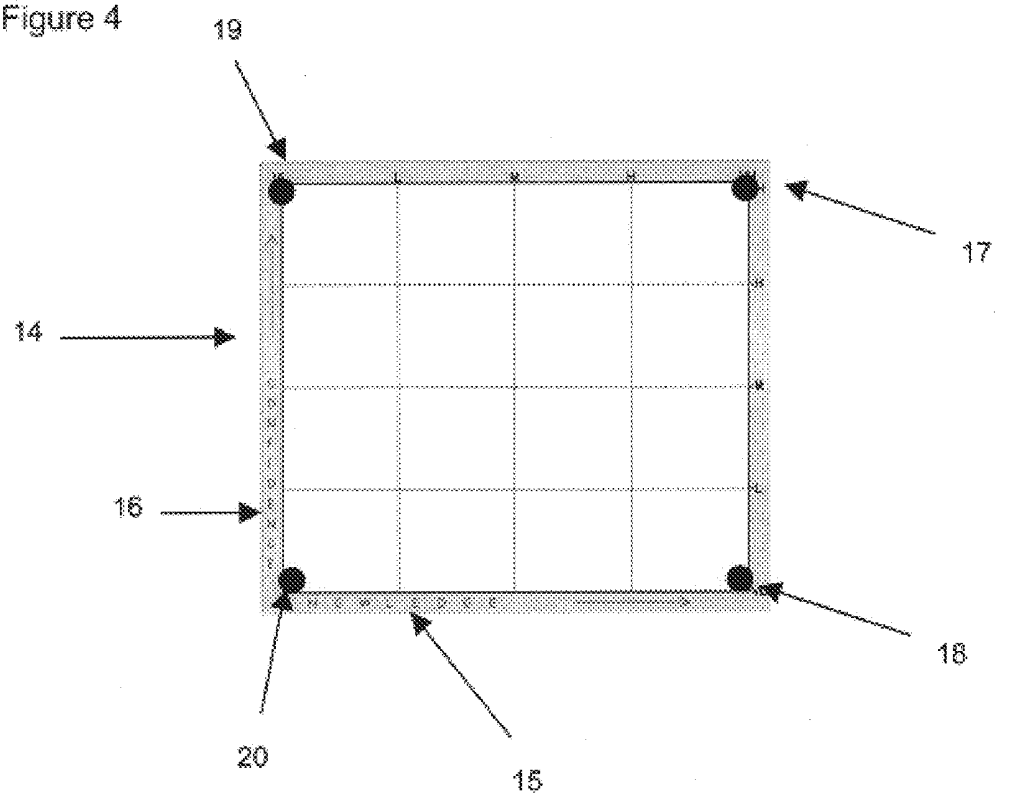

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Figure 5

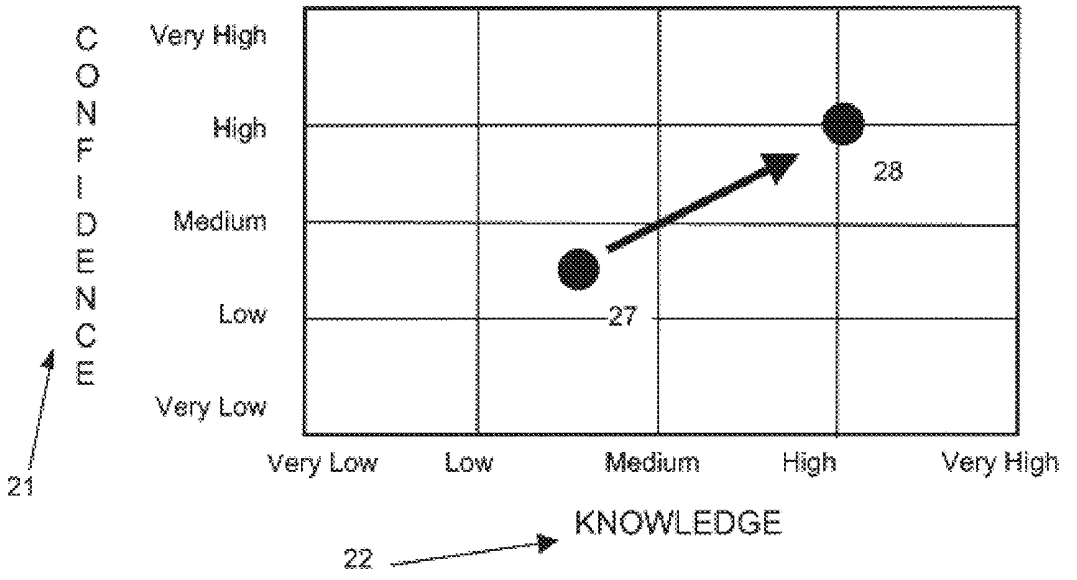

Figure 6

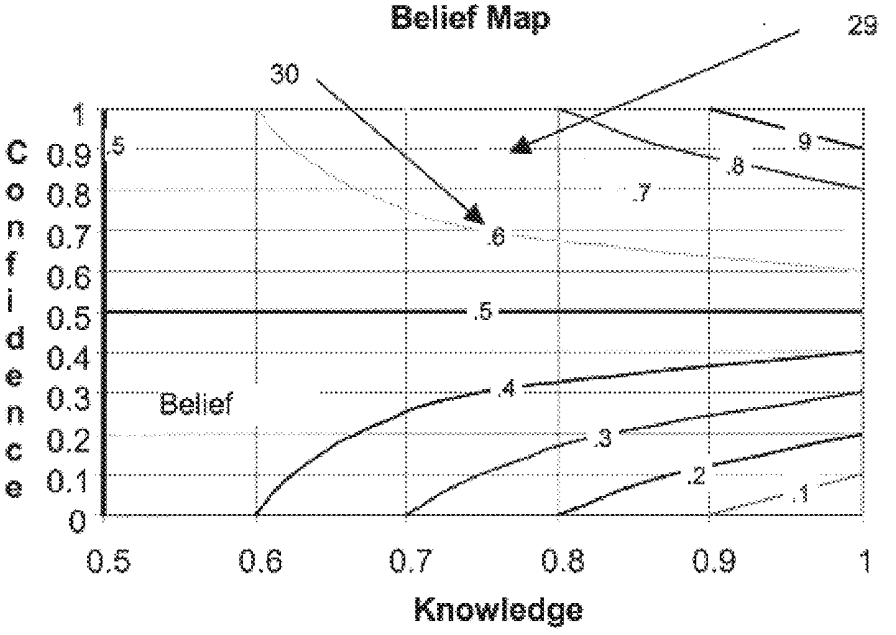

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Figure 7

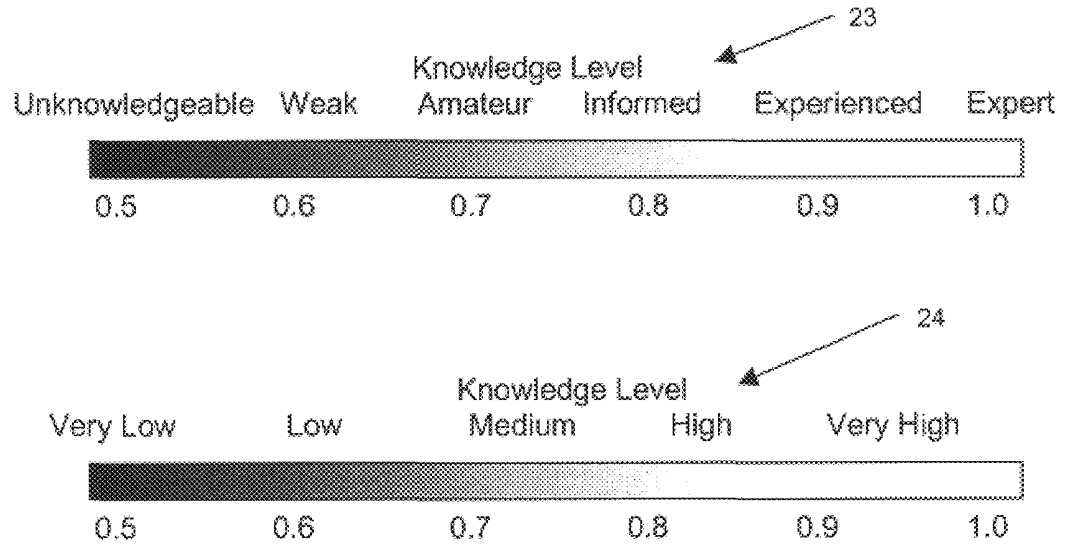

Figure 8

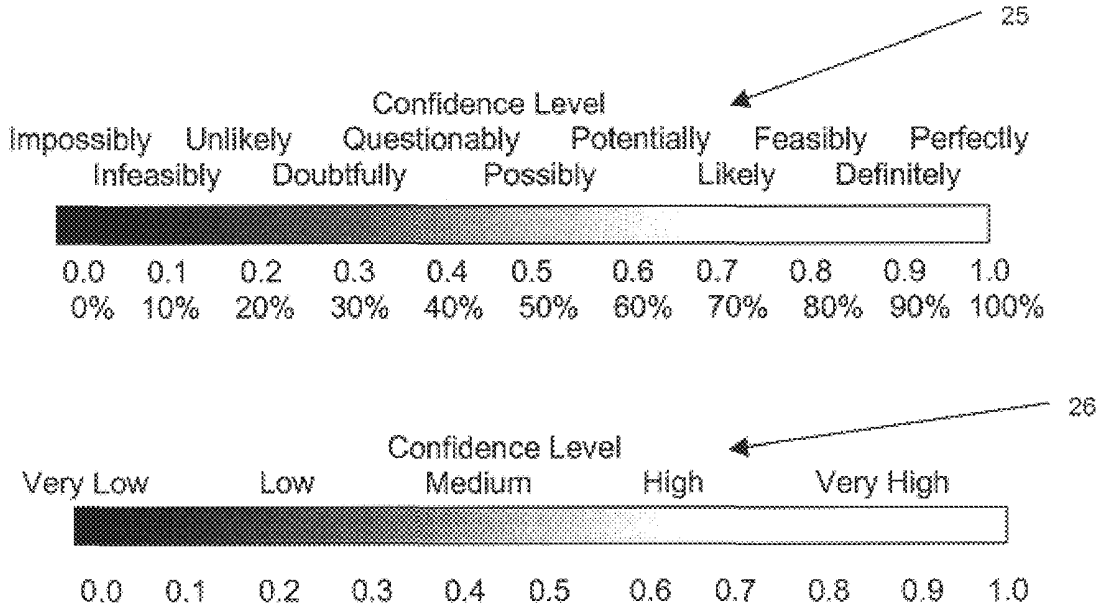

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Figure 9

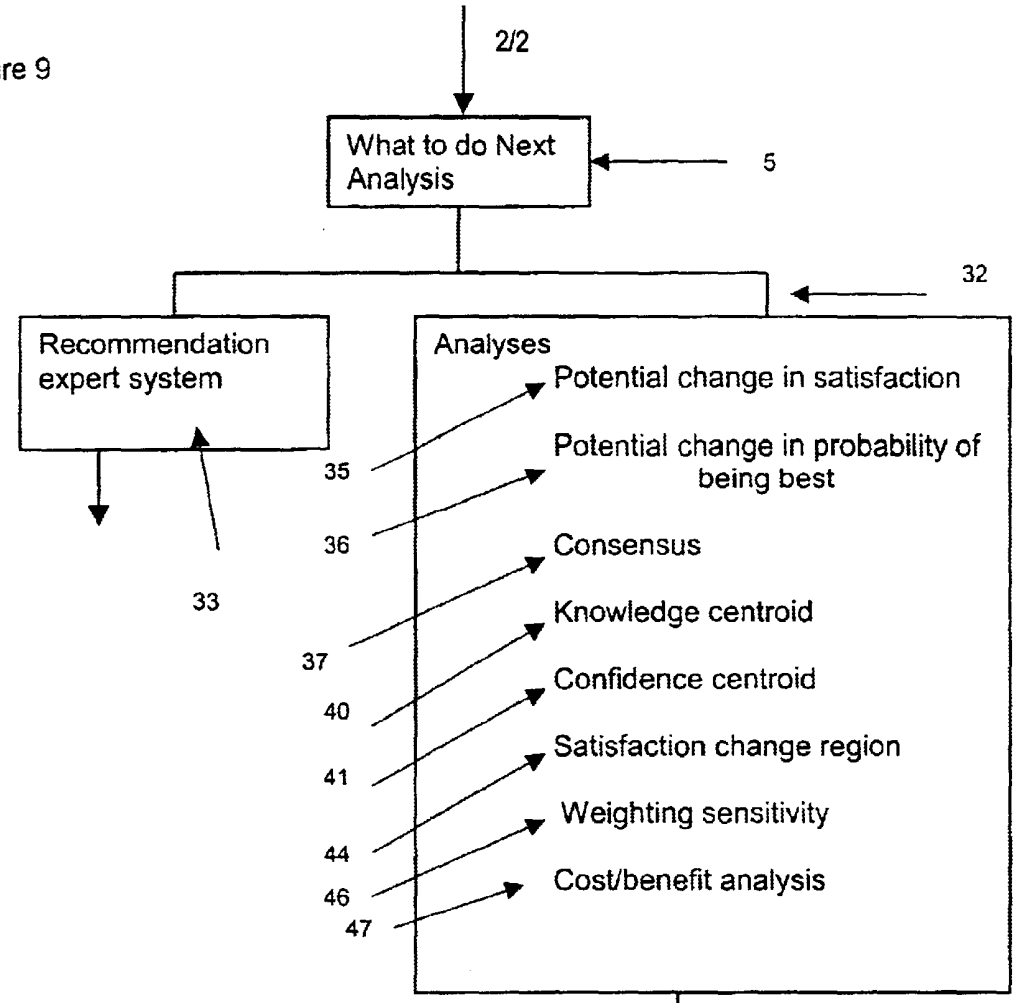

Figure 10

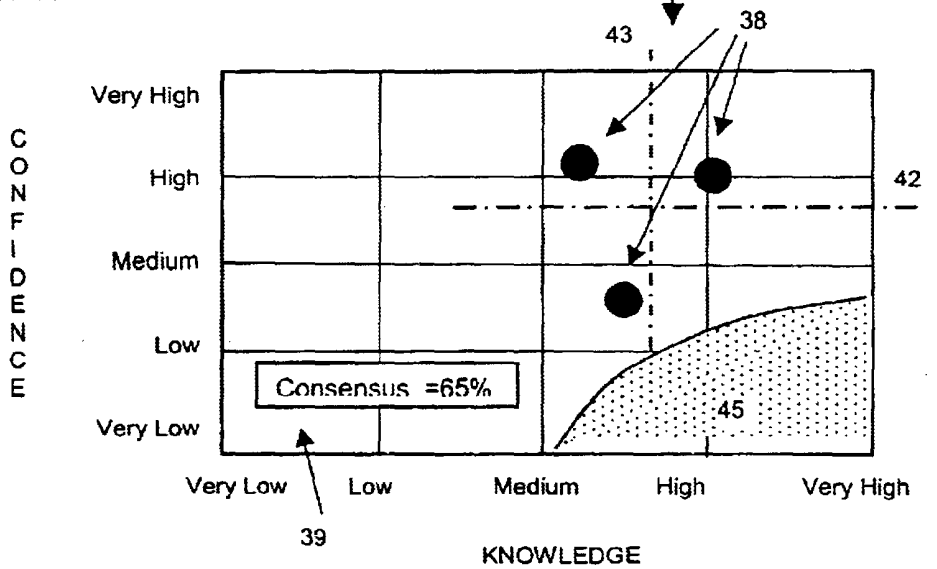

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Figure 11

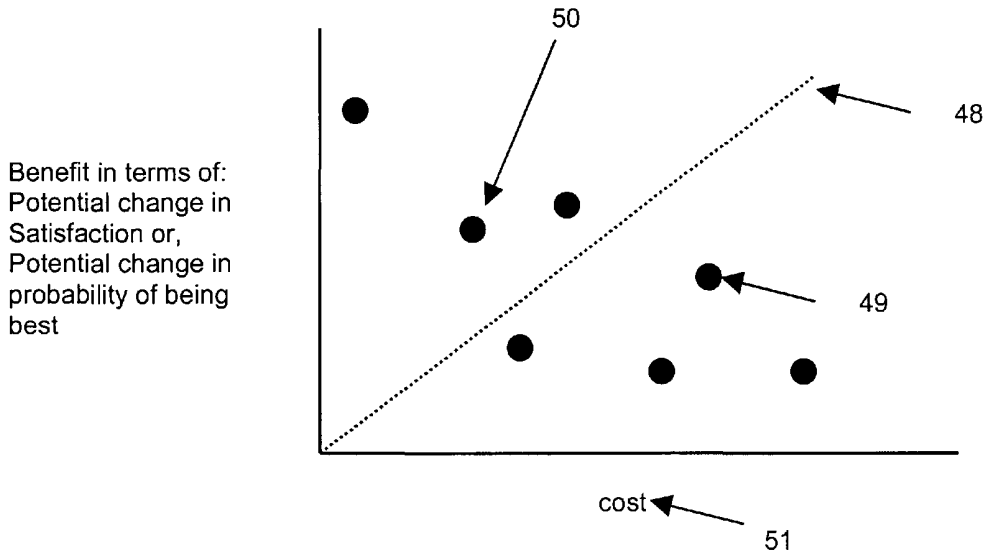

Figure 12

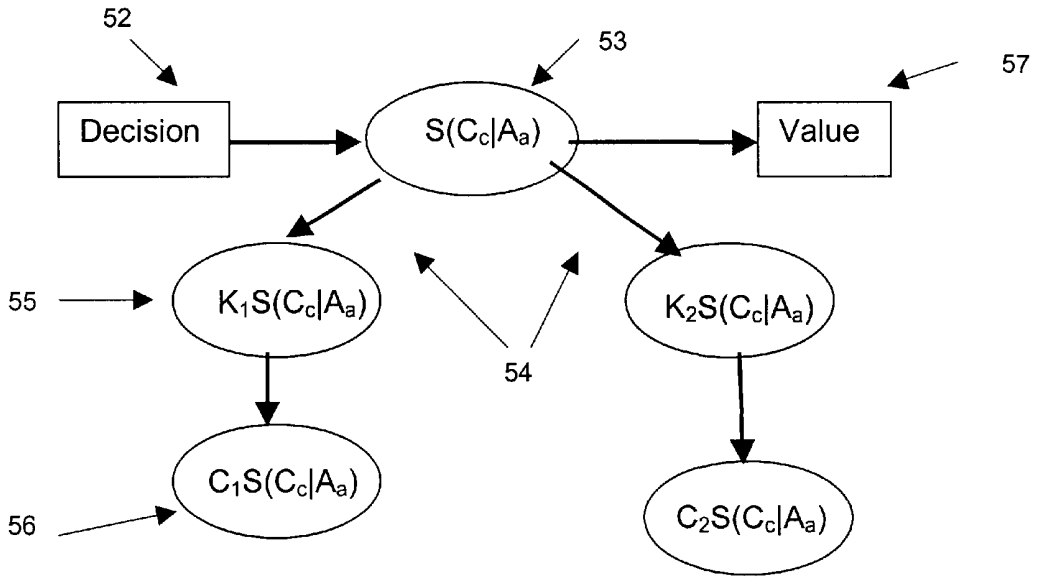

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Figure 13.

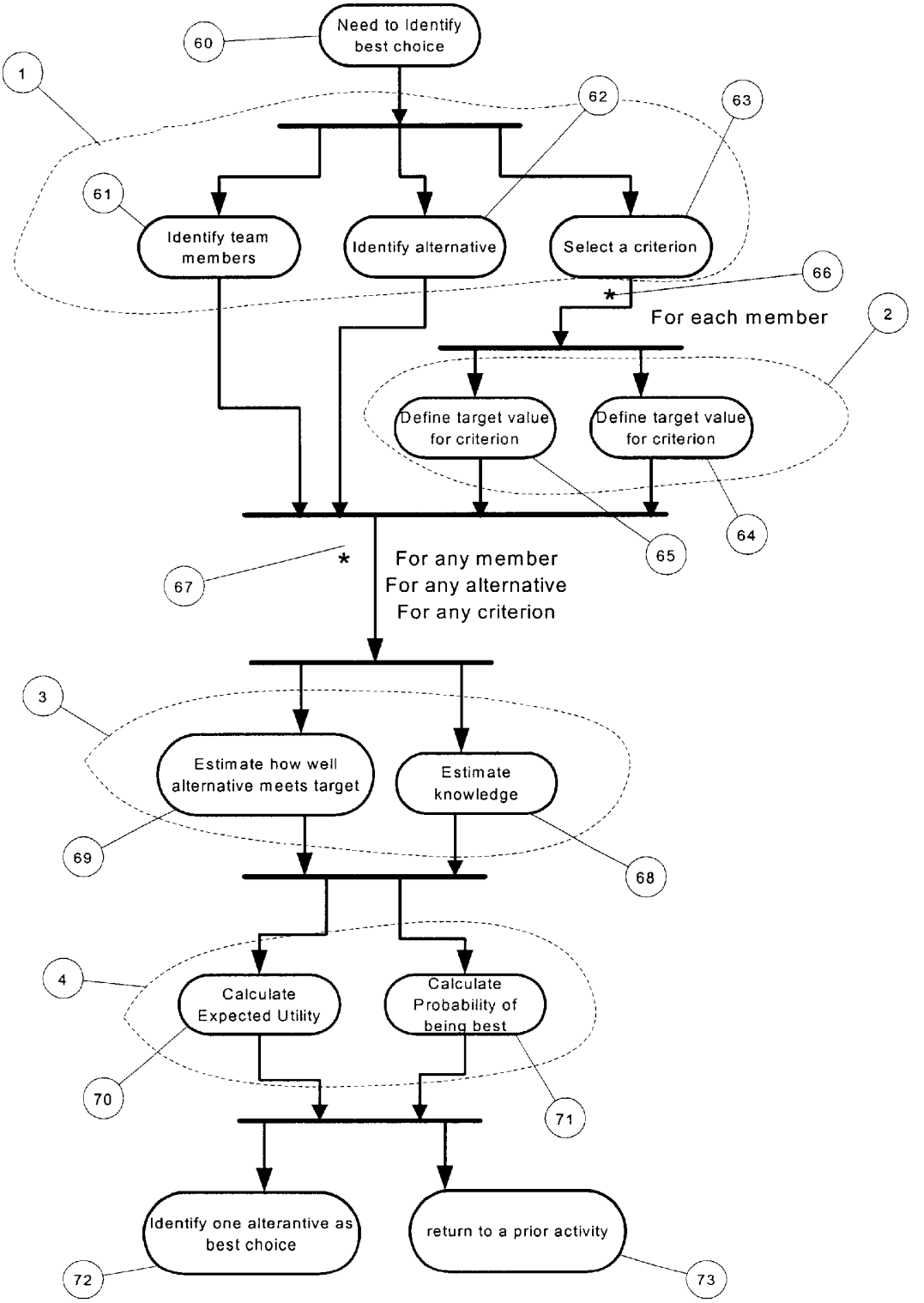

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Figure 14.

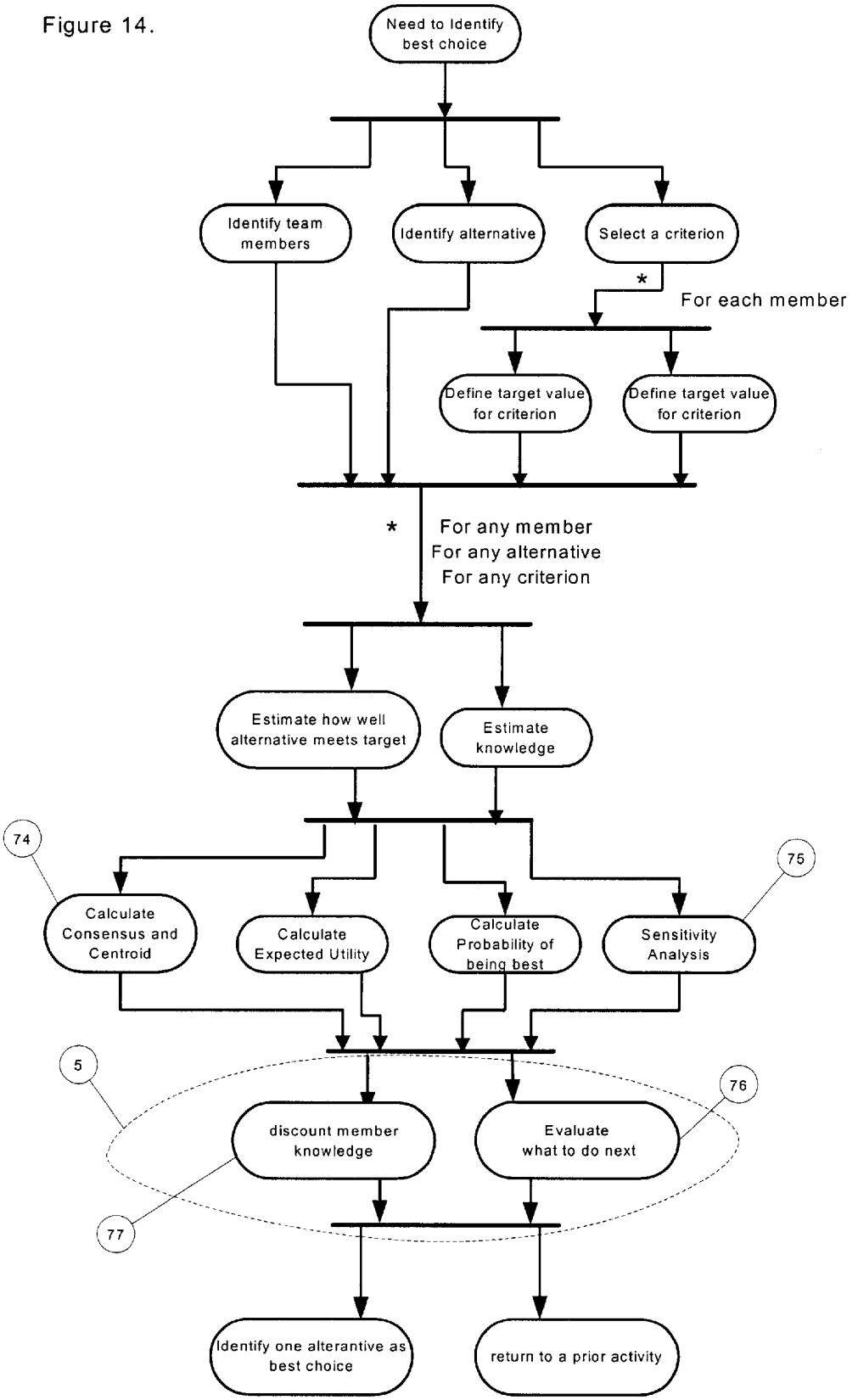

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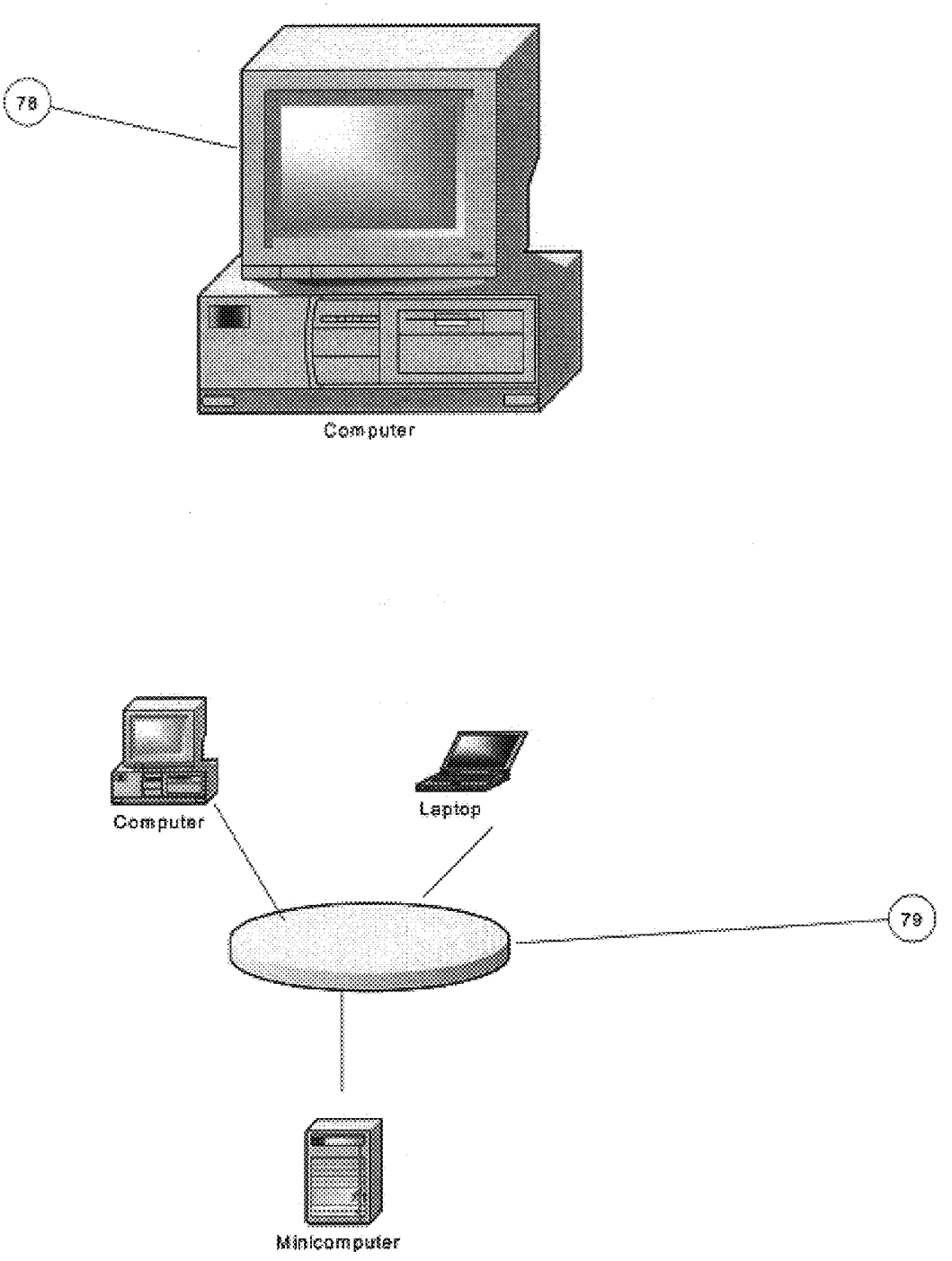
Figure 15.



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GENERAL DECISION-MAKING SUPPORT METHOD AND SYSTEM

This application claims the benefit of provisional application No. 60/203,023, filed May 9, 2000.

This invention was made with Government support under contract DAAH01-99-C-R191 awarded by the U.S. Army Aviation and Missile Command. The Government has certain right in the invention.

FIELD OF THE INVENTION

This invention relates to methods and systems that assist users in evaluating multiple alternatives and decision-making based on this evaluation.

BACKGROUND OF THE INVENTION

Based on a natural model of team deliberation, a system that enables team decision support has been developed. This is the result of over fifteen years of studying and modeling design engineers and the integration of research results from the fields of negotiation and argumentation modeling, design rationale capture, decision theoretics, and engineering best practices. The method underlying the system integrates concepts such as criteria development, value modeling, argumentation, negotiation and evaluation into the engineering design workflow.

Patents in the field of general decision support are not common. U.S. Pat. No. 5,182,793 to Alexander et al., entitled "Computer-Aided Decision Making With A Symbolic Spreadsheet," issued Jan. 26, 1993, and U.S. Pat. No. 6,012,051 to Sammon Jr. et al., entitled "Consumer Profiling System With Analytic Decision Processor," issued Jan. 4, 2000, both use other methods to support decision-makers.

Accordingly, a need remains for a way to assign semantic meaning to documents without requiring user involvement, and for a way to search for documents with content similar to a given document.

SUMMARY OF THE INVENTION

One aspect of this invention is a method for aiding individuals or teams in making a decision that requires selecting from a list of alternatives. The method is applicable to any problem that has: known or discoverable boundaries; many potentially acceptable alternatives for solving the problem; criteria that can be developed to measure how well the alternatives solve the problem; one or more decision-makers that have a stake in the solution of the problem; decision-makers with expertise in different areas and may represent different, even conflicting viewpoints; and all decision-makers must be interested in solving the problem.

Features of the method allow for analytical support even when information about the alternatives is incomplete or conflicting and when the decision-makers have different opinions about what features of the alternatives are important. Information describing the evaluation can be both quantitative and qualitative and can be changing as more is learned about the problem. Results from the analysis are measures of each alternative's satisfaction, its probability of being the best choice, decision-maker consensus and a sensitivity analysis tailored to give guidance about what to do next to refine the decision.

Technical advantages of this system are that it supports human decision-makers by enhancing their natural behavior. It helps them organize information and encourages sound decision-making skills. Further, it provides an analytical

basis for decision-making that is transparent and can be used with no need for analysis by the decision-makers. The results help the decision-makers by giving them a strategy to resolve issues. Often, if a problem is not being resolved, the only action is frustration. The methods help get problems unstuck by giving cost/benefit information so they can rationally decide what to do next to reach a decision.

The input, evaluation, and resulting information serve as a medium to communicate what is important to other team members. The largest single problem in teamwork is poor communication. The method and system presented give a framework for decision-making communication. The representation and analysis also helps the team develop a common understanding of issues and alternative solutions. Further it provides documentation of the decision and the rationale for it.

The foregoing and other features, objects, and advantages of the invention will become more readily apparent from the following detailed description, which proceeds with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of the decision-making steps in the preferred embodiment in this invention.

FIG. **2** illustrates a display screen showing how the embodiment of the invention is used.

FIG. **3** illustrates a display screen showing how the input of importance weightings is performed in the preferred embodiment.

FIG. **4** shows a basic Belief Map.

FIG. **5** illustrates how a Belief Map works.

FIG. **6** illustrates the isolines of fused belief.

FIG. **7** illustrates scales for quantifying knowledge.

FIG. **8** illustrates scales for quantifying confidence.

FIG. **9** details the "what to do next" analysis.

FIG. **10** shows some of the results of the "what to do next" analysis on a Belief Map.

FIG. **11** shows one method of displaying a cost/benefit analysis.

FIG. **12** shows an influence diagram.

FIG. **13** shows an activity diagram for core methodology.

FIG. **14** shows an activity diagram for complete methodology.

FIG. **15** shows a computer system on which invention can be operated.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. **1** represents a flow chart of the major sections of the present invention. The methodology of any embodiment of the invention includes the steps of describing the problem **1**, that allows recording of the alternative to be considered, the criteria that will be used to judge them and the decision-makers who are evaluating the alternatives; a method for viewpoint capture **2**, that allows each decision-maker to express the relative importance of the criteria; a mechanism for allowing the decision-makers to evaluate the alternatives relative to the criteria **3**; an analysis engine **4**, that, based on the captured information, calculates the satisfaction of each alternative, its probability of being the best choice and sensitivity information; and a what to do next evaluation **5**, that advises the decision-makers how to interpret the results and what information to refine that will increase the satis-

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faction and probability of being the best choice. The what to do next evaluation recommends iteration back to items **1–3** for further work only as needed, saving wasted effort.

According the present embodiment FIG. **2**, all the activities in FIG. **1**, are captured, displayed and managed on a single screen **6**. The problem description **1** is captured in areas **7**,**8**,**9**. Area **7** allows for a plurality of alternatives input by the decision maker(s). This can include text strings as shown or links to other material on the host computer or elsewhere on the Internet.

Area **8** allows for representation of a plurality of quantitative or qualitative criteria to be used to measure the features of the alternatives as a basis for choosing which is best. These criteria are characterized by the feature measured, the type of target (<, >, = or Y/N), target values, and units. For Y/N criteria there are no target values as this type is for qualitative criteria. For other types, each target is defined by at least two values describing each member's "delighted" value, and their "disgusted" or "displeased" value. For example, a decision-maker may be delighted with a car that got 30 miles per gallon (mpg) and disgusted with one that got 22 mpg. Each member can have a different set of target defining values. Continuing the example, another member of the decision-making team may be delighted with 34 mpg and disgusted with 27 mpg. Input of criteria can include text strings as shown or links to other material on the host computer or elsewhere on the Internet.

A plurality of decision-makers ranging from a single individual to a team is captured in area **9**. This list is input directly as a text string or from a list elsewhere on the host computer or on the Internet.

Each of the decision-makers may have a unique opinion about what is important. A user interface shown in FIG. **3** allows each member to signify the relative importance **13** of each criterion **8**. This importance expresses each member's viewpoint. The embodiment shown in FIG. **3** uses sliders to capture the importance weightings. Other possible methods base this on ranking, pairwise comparisons or normalization.

Each decision-maker evaluates the alternatives relative to the features defined by the criteria. Evaluation does not have to be complete or consistent. Evaluation is captured on a Belief Map **10**, and FIGS. **4**, **5**, and **6**. The belief map provides a novel, yet intuitive means for entering/displaying the evaluation results in terms of knowledge and confidence. Each decision-maker has unique knowledge about each feature of each alternative. Belief maps offer a quick and easy to use tool for an individual or a team to ascertain the status of an alternative's ability to meet a criterion and to visualize the change resulting from analysis, experimentation or other knowledge increase.

Evaluation on a Belief Map is based on two orthogonal parameters as shown in FIGS. **4** and **5**: knowledge **15** and **22** and confidence **16** and **21**. The level of satisfaction with an alternative is based on the belief in how well the alternatives meet the targets. In a Belief Map, knowledge about an alternative is plotted against the decision-maker's confidence in the alternative's ability to meet a target.

Knowledge was defined as "a measure of the information held by a decision-maker about some feature of an alternative." The greater the decision-maker's knowledge about a feature of an alternative, the less uncertainty there is in the evaluation of this feature. FIG. **7** shows two ways to measure knowledge. One way is to associate words generally used to describe knowledge with the probability of having correct information **23**. An individual with "expert" knowledge would be able to correctly answer 100% of the questions concerning an alternative's feature (probability=1.0). At the other end of the scale an "unknowledgeable" individual would have a 50/50 chance of guessing correct information (probability=0.5). A second method to measure knowledge is to use a simple 5-step scale **24**.

Confidence is a measure of how well an alternative meets the target set in a criterion. Each decision-maker may have a different level of confidence for each feature of each alternative. Two members of the same team can look at the same data developed through analysis experimentation or other means and have different confidences based on the same results. Confidence is based on the individual's judgment of all the available information. This judgment is dependent on prior knowledge, and on understanding of the alternative and the criterion being used to measure it.

As with knowledge, words describing confidence can be associated with probabilities. Confidence measures for qualitative criteria can be made using qualitative terms. Two scales for qualitatively measuring confidence are given in FIG. **8**. The first scale **25** uses words that indicate some level of confidence. A second method to measure confidence is to use a simple 5-step scale **26**.

For quantitative criteria, ones where the features are measurable and there are numerical targets, confidence is a measure of how well an alternative meets the ideal goal for the feature. For these types of criteria numerical values representing the target are fitted to the confidence scale. One embodiment of this, for example, is to ask the decision-maker "what is the value for the feature that will delight you" and also ask, "what will be the value for the feature that will disgust you". The delighted value corresponds to full confidence (1.0) and the disgust value corresponds to no confidence (0.0). The vales in between can be distributed linearly or by some other method. What makes this unique is that the decision-maker puts his/her point on the resulting scale removing the need for estimating the relationship between value and resulting satisfaction found in most other methods.

For quantitative criteria knowledge is a measure of the uncertainty in the estimation of value for the alternative. For example, if the decision-maker is sure that the gas mileage is 26 mpg then knowledge is high. If it is-only known to be between 25 and 28 then uncertainty is high and knowledge is low. It is possible to relate the uncertainty to the delighted and disgusted values to obtain an estimate of knowledge.

Belief is a single value that incorporates knowledge and confidence to give a probability of how well an alternative meets a target. Belief is entered on a Belief Map as in FIGS. **4**,**5**,**6**.

In FIG. **4** a Belief Map **14** is shown with four points **17**, **18**, **19**, and **20** signifying four different evaluations. If a feature of an alternative is plotted in the upper right corner **17**, then the person who put it there is an expert, confident that the alternative meets the criterion (knowledge=1.0, confidence=1.0), if in the lower right corner **18**, the expert is confident that it does not meet the criterion (knowledge= 1.0, confidence=0.0), if in the upper left corner **19** the decision maker knows little but is sure that the target is met (knowledge=0.5, confidence=1.0) and, evaluation in the lower left corner **20** (knowledge=0.5, confidence=0.0) is for the evaluation based on no knowledge but confidence that the alternative does not meet the target at all.

FIG. **5** shows the evolutionary use of a Belief Map. Here a decision maker has evaluated an alternative **27** and determined that, based on medium low knowledge, they have medium low confidence in the alternative meeting the target.

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Later in their evaluation they may have learned enough **28** to rate their knowledge about this feature of the alternative as high and this increased knowledge has increased their confidence to high also.

Input of information about alternative, criteria (features and targets), decision-makers, importance weightings and the evaluation of alternative's features in terms of knowledge and confidence complete the information gathering necessary for analysis. It may seem that this representation for a decision problem is rather simplistic and ad-hoc. However, extensive research into modeling decision-making processes in design supports this representation. In addition, there is a fairly straightforward mapping from our embodiment of the representation to an influence diagram as shown in FIG. **12**. This diagram contains representations of the alternatives available, the criteria by which alternatives will be judged, the relative importance of the criteria, and design team member opinions on the likelihood that various alternatives meeting various criteria.

In FIG. **12** the box labeled "Decision" **52** takes as values the alternatives for resolving the issue represented by the diagram. The circle labeled $S(C_c|A_a)$ **53** represents the satisfaction of criterion C_c given alternative A_a and will be called a satisfaction node. While we show only one, there can be one for each alternative/criterion combination. This is nonstandard, as a usual influence diagram would have only one node for each criterion. We use contingent nodes to represent each alternative/criterion pair separately, since we may not have arguments for every pair. The pair of two-node chains **54** hanging from $S(C_c|A_a)$ represents opinions posted by decision-makers. Two are shown here, but there can be any number of such chains hanging from each of the $S(C_c|A_a)$ satisfaction nodes. The higher of the two circles **55** represents the state of participant knowledge about the ability of the alternative to meet the criterion, and the lower circle **56** is a diagram artifact used to encode probabilistic evidence. The upper node (we will call this a knowledge node) is denoted as $K_mS(C_c|A_a)$, where a is the alternative, c is the criterion, and m is the decision-maker. The lower node takes a single value, true. The conditional probability of the knowledge node given the actual satisfaction has two degrees of freedom. We reduce this to a single degree by assuming symmetry to simplify knowledge acquisition. That is, we assume

$$P(K_mS(C_c|A_a)=\text{yes}|S(C_c|A_a)=\text{yes})=P(K_mS(C_c|A_a)=\text{no}|S(C_c|A_a)=\text{no}).$$

This single degree of freedom is the knowledge the participant has about the alternative/criterion combination, because this single parameter encodes how accurately the participant belief reflects the actual world state. The complete distribution for a knowledge node, then, is:

$S(C_c\|A_a)$	$P(K_mS(C_c\|A_a) = \text{yes}\|S(C_c\|A_a))$
yes	$K_{c,a,m}$
no	$1 - K_{c,a,m}$
$S(C_c\|A_a)$	$P(K_mS(C_c\|A_a) = \text{no}\|S(C_c\|A_a))$
yes	$1 - K_{c,a,m}$
no	$K_{c,a,m}$

We allow $K_{c,a,m}$ to range between 0.5 and 1.0, where 1.0 represents perfect knowledge and 0.5 represents complete ignorance, and use the textual scale describe FIG. **7** to acquire it.

We will refer to the lower node **56** as the Confidence node, $C_mS(C_c|A_a)$. The confidence node has only one value, all that matters is the ratio of the probabilities for that value given $K_mS(C_c|A_a)$. We acquire this as the "probability that the alternative will satisfy the criterion, given the participant state of knowledge" That is, we treat the participant as a making a noisy or soft observation (report) on his or her belief. We encode this as a pair of numbers constrained to sum to one, as follows:

$K_mS(C_c\|A_a)$	$C_mS(C_c\|A_a)$
Yes	$C_{c,a,m}$
no	$1 - C_{c,a,m}$

Finally, we assume value is additively decomposed into subvalues for each criterion, and that the value of not satisfying any criterion is 0, and assign weights to the relative values of criteria with the constraint that weights sum to 1.

Given the above semantics, the expected value or satisfaction of an alternative is:

$$Ev(A_a)=\Sigma_c V(C_c)P(S(C_c|A_a)=\text{yes})$$

where

$$P(S(C_c|A_a)=\text{yes})=\alpha\pi_m(C_{c,a,m}K_{c,a,m}+(1-C_{c,a,m})(1-K_{c,a,m}))$$

and α is a normalization factor:

$$\alpha=1/(\pi_m(C_{c,a,m}K_{c,a,m}+(1-C_{c,a,m})(1-K_{c,a,m}))+\pi_m(C_{c,a,m}(1-K_{c,a,m})+(1-C_{c,a,m})(K_{c,a,m}))$$

The expected value for the decision, then, is just:

$$Ev(\text{Decision})=\max_A Ev(A_a)$$

The probability of an alternative being the best is calculated by determining the probability mass of that portion of the outcome space in which the selected alternative has a higher utility that any other alternative. One particularly efficient method for performing this calculation is to compute by exact means the fused belief for each alternative/criterion pair, and then use Monte Carlo sampling starting from the fused beliefs to construct utility value samples for each alternative.

In FIG. **6** the curved lines **29** on the Belief Map represent the calculated belief in the alternative's feature meeting the target. The numerical values **30** are those calculated using the formulas above. These compute the exact Bayesian posterior probability.

Values **30** also represent 1—evaluation risk. Evaluation risk is the exposure to chance that the alternative chosen will not be able to meet the targets set for it. In other words, it is the chance that the decision-maker's evaluation is not correct. Risk is a result of limitations in knowledge and confidence.

The expected value or satisfaction of each of the alternatives, the results of decision analysis **4** of FIG. **1** is displayed in the current embodiment on the bar chart **11**, FIG. **2**. In this embodiment, the highest bar represents the most satisfactory alternative. Prior art only finds a single value of satisfaction for each alternative. By allowing satisfaction to be calculated using each member's importance weightings and based on all the knowledge and confidence evaluation information, this invention adds the ability to look at satisfaction (and all other results) from each member's viewpoint.

The decision analysis **4** of FIG. **1** is unique in its ability not only to calculate satisfaction, but also, based on the

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information input through the decision-maker evaluation **3** of FIG. **1** to find the probability that each alternative has the highest satisfaction. In the current embodiment, the value for the probability **31** of FIG. **2** is shown in the satisfaction bar chart **11**. An alternative that may have the highest satisfaction may not have a particularly high probability of being the best. The ideal is to choose an alternative that has high satisfaction and a high probability of having the highest satisfaction regardless of viewpoint taken.

Usually the first evaluation of alternatives by the decision-makers does not end in a decision, but rather an indication of where further evaluation or other rethinking is necessary to reach a decision. The "what to do next evaluation" **5** of FIG. **1** expanded in FIG. **9** provides the decision-makers with guidance. This material is unique to this invention. Shown in FIG. **9** are a list of analyses **32** and a recommendation expert system **33** that comprise the "what to do next evaluation" **5**.

The "what to do next evaluation" **5** provides sensitivity analyses **35** and **36** that relates to the decision-makers, for each feature of each alternative, the potential change in satisfaction **35** or change in probability **36** of being best, that can result from further evaluation. In the current embodiment, the most sensitive alternatives/criterion pairs are listed **12** of FIG. **2** with most sensitive first.

The statistics for sensitivity analyses **35** and **36** can be calculated in many ways: Unweighted satisfaction or probability based on evaluation with a virtual team member who is an expert with complete and accurate knowledge, and who is either fully delighted or completely disgusted with the alternative's ability to meet the criterion. Weighted satisfaction or probability based on evaluation with a virtual team member who is an expert with complete and accurate knowledge, and who is either fully delighted or completely disgusted with the alternative's ability to meet the criterion. In either case this analysis is the value of perfect information **57** of FIG. **12**. It is calculated for each criterion/alternative combination by:

$$VPI(C_c|A_a)=P(S(C_c|A_a)=\text{yes}*Ev(\text{Decision}|S(C_c|A_a)=\text{yes})+P(S(C_c|A_a)=\text{no}*Ev(\text{Decision}|S(C_c|A_a)=\text{no})-Ev(\text{Decision})$$

where $Ev(\text{Decision}|S(C_c|A_a))=\text{yes}$ is computed as for Ev(Decision), but with a pair of nodes added indicating perfect knowledge and confidence that alternative a will satisfy criterion C (K=I.0, C=1.0), and $Ev(\text{Decision}|S(C_c|A_a))=\text{no}$ is similarly computed, but with the added nodes recording perfect knowledge and confidence that the alternative will not satisfy the criterion (K=I.0, C=0.0). Note that $P(S(C_c|A_a)=\text{yes})$ and $P(S(C_c|A_a)=\text{no})$ must be computed before any perfect knowledge nodes are added. This value can then be used, as is standard in decision analysis, to order the utilities of obtaining additional information about the probability of satisfaction of various criterion/alternative pairs.

When teams of decision-makers are evaluating alternatives, there will naturally be differences in the team members' knowledge **15, 22** and confidence **16, 21** as shown by points **38** of FIG. **10**. The "what to do next evaluation" **5** calculates the level of consensus **37** based on this evaluation information. The analysis takes into account that differences in knowledge are less important to consensus than are differences in confidence in the alternative's ability to meet the criterion. This is evident in the math. To develop the level of consensus value, the confidence centroid must first be developed.

The confidence centroid **41** FIG. **9**, **43** FIG. **10** is the weighted sum of the confidence values for each member, weighted by member knowledge, as shown by the pseudo-code below:

```
centroid=0.0;
kSum=0.0;
for (int m=0; m<members.size( ); m++) {
k=2*(knowledge(a, c, m)–0.49);
centroid+=k*confidence(a, c, m);
kSum+=k;
}
centroid=centroid/kSum;
```

In the current embodiment, the confidence centroid is not displayed to the decision-makers.

To help guide the decision-makers, the "what to do next evaluation" **5** also calculates for each feature of each alternative evaluated by the decision-makers a region **44** of the belief map that indicates where the team's centroid must fall to change the satisfaction ranking and the probability of being best of the alternative. One such region in the current embodiment is shown **45** in FIG. **10**.

In the current implementation, consensus **39** is shown in the lower left corner of the Belief Map when performing a "what to do next evaluation." Consensus is the normalized additive inverse of the knowledge-weighted sum of the difference between member confidence and the confidence centroid, as shown by the pseudo-code below:

```
consensus=0.0;
for (int m=0; m<members.size( ); m++) {
k=2*(knowledge(a, c, m).–0.49);
distance=
k*(centroid–confidence(a, c, m));
consensus+=distance*distance;
kSumSq+=k*k;
}
consensus=Math.sqrt(consensus/kSumSq);
normalizedConsensus=1.0–(2*consensus);
```

Also developed is the knowledge centroid **40, 42** for each feature of each alternative evaluated by the decision-makers. This is needed for the recommendation expert system **33**. In the current embodiment this centroid is not shown to the decision makers.

Sensitivity of the satisfaction or probability of being best based on importance weightings **46** are also accomplished. Prior art either uses a single decision-maker's importance weightings **13** or develops an average importance weighting and has no methodology for exploring decision-making team variation on the results. This invention honors the variety of viewpoints that are important in a complex decision by not only developing the satisfaction, the probability of being best and "What to do next" analysis from each viewpoint, but also calculating the sensitivity of these results to the variation in these viewpoints. This invention uses the statistical distribution of importance weightings for each criterion as a basis for a Monte Carlo analysis of the statistics for the satisfaction and probability of being best.

Each criterion weight is sampled from the range defined by the weights assigned by members (that is, the range extending from the lowest assigned weight to the highest assigned weight for that criterion, using a uniform sampling distribution (this could be generalized to any suitable distribution, perhaps incorporating the distribution of assigned weights if more than two members). The expected value of each alternative is then computed, and the best alternative noted for each weight sample.

The potential changes in satisfaction **35** and probability of being best **36** give the potential benefits of further decision-maker evaluation **3** of FIG. **1**. This combined with decision

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maker input of the costs (either in terms of money or time) for each of the extended analyses results in the data needed for a cost/benefit analysis **47**. FIG. **11** shows one embodiment of the cost benefit display with cost **51** either in terms of time or money, plotted against benefit in terms of satisfaction **35** and probability of being best **36** for a specific feature of a specific alternative. In FIG. **11**, points for each feature of each alternative **49**,**50** are plotted showing the potential benefit that could result from continued decision-maker evaluation plotted against the cost. A line representing a threshold **48** separates the points into those worth pursuing **50** and those not worth pursuing **49**.

Guidance for what to do next **33**, FIG. **9**, uses the statistics generated in the analyses **32**, to help the decision-makers decide the next best steps in reaching a decision. Using an internal rule base, the what to do next analysis takes the information developed and generates a list of what the decision-maker(s) should do next to improve the differentiation in satisfaction between the highest ranked alternative or the probability that the highest ranked alternative is best. Based on the statistics, the rule base recommends one or more of the following:

- <Alternative x> has high satisfaction and probability of being the first choice is high from all viewpoints, you may want to choose it.
- <Alternative x/Feature y> is sensitive and consensus evaluation is low. Discussion about this is advised.
- Knowledge of <alternative x/Feature y> is sensitive and consensus evaluation is low. Develop more information using experiments, analysis or experts.
- <Criteria x and y> are weak yet important. Refine these criteria features and targets.
- The team is having difficulty differentiating between alternatives, either generate new criteria that better measure features that vary from alternative to alternative or generate new alternatives.
- None of the alternatives have very high satisfaction. Generate new alternative solutions.
- The importance weightings vary too much among team members to reach consensus. Discuss importance weightings.

This information can be used to choose a specific alternative or to return to any prior activity and refine the problem description, the customer viewpoint or the evaluation. Since the analysis can be based on the input of many decision-makers, it is important to be able include or exclude their evaluations as part of exploring the results. Thus, it is possible to discount an individual's knowledge to see the effect on the results. This is not the same as changing the importance as in **13** but lowers the influence of a discounted member's evaluation on calculation of satisfaction and other statistics. This facility allows using one individual's evaluation independently as seen from each member's viewpoint or reducing the effect of one person whose knowledge self estimate is deemed too high.

The above invention can be used to support any type of decision-making problem where there are multiple alternatives, criteria for evaluating the alternatives and an individual or team judging the alternative relative to the criteria. It can also be applied to specific types of problems. One area of application is the purchase of goods. In such cases there is an additional element, a suggestion engine.

A suggestion engine that takes a set of alternative purchases identified by a buyer and compares it to sets of purchase alternatives of other buyers to recommend additional alternatives for consideration. It accepts and stores any level of information from a multi-level decision model purchasers build while shopping; extracts a background representation of the features purchasers consider important from inputs of multiple purchasers, extracts feature ratings for products from inputs of multiple users, generates product recommendations based on aggregated past input, plus the purchaser's current model, regardless of level of detail in the model selects user-specific advertising based on the above information. An embodiment of this uses a drag and drop method for building multi-level purchase decision models. The multi-level is key, as it can work with just a choice set, or just choice and tradeoffs.

FIGS. **13** and **14** detail the flow of activities in the invention. These are in the format of UML Activity Diagrams. FIG. **13** shows the core methodology. The first activity is to identify the problem for which a best choice is needed, **60**. To fully describe the problem, **1** in FIG. **1**, team members **61**, alternatives **62** and criteria **63** must be identified. As shown by the notation of the activity diagram, these can happen in any order, as is the case in the embodiment, FIG. **2**.

Each member's viewpoint is captured **2**, by defining a target for each criterion **64**, and setting weights **65**, as in FIG. **2**. As shown in the notation **66**, viewpoint can be set for each member and in any order.

Decision-maker evaluation **3**, can be made by any member for and alternative as measured by any criterion as is shown in the notation **67**. Evaluation requires estimating the member's knowledge **68** about the feature defined by the chosen criterion of the chosen alternative, and the member's confidence about how well the alternative meets the target set by the criterion **69**.

Based on the above information, the analysis **4**, in the core methodology calculates the expected utility, **70** and the probability of being best **71**. As shown in FIG. **14**, additional calculations include the Consensus and Centroid **74**, and Sensitivity **75**. In the core methodology, the result of these analyses is used to either identify one alternative as the best choice **72** or to return to any prior activity in the problem description, viewpoint capture or decision-maker evaluation for refinement **73**.

In FIG. **14** the additional capability of the "what to do next evaluation" **76** and discounting member knowledge **77** are shown to proceed **72** and **73**. These additional forms of evaluation give the ultimate decision maker(s) more information on which to decide on the best choice or iteration.

Finally, any embodiment of this invention can be run on an individual computer **77** or a network of computers **78** as shown in FIG. **15**.

Having illustrated and described the principles of our invention in a preferred embodiment thereof, it should be readily apparent to those skilled in the art that the invention can be modified in arrangement and detail without departing from such principles. We claim all modifications coming within the spirit and scope of the accompanying claims.

We claim:

1. A method for processing information to identify a best choice from among a set of alternatives, the method comprising:

identifying a plurality of team members;

selecting a criterion for use in identifying the best choice, wherein the criterion includes a feature of the alternatives;

for each alternative:

for each team member, defining a target value for the feature;

for each team member, setting a level of knowledge for the feature of the criterion;

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for each team member, estimating how well at least one of the alternatives meets the team member's target value for the feature of the criterion based on the team member's level of knowledge;

calculating an expected utility for each alternative based on the feature value estimations of all the team members;

calculating a probability that each alternative is best based on the feature value estimations of all the team members; and

identifying one of the set of alternatives as the best choice according to the expected utility for each alternative.

2. A method according to claim **1**, wherein:

selecting a criterion includes selecting a plurality of criteria for use in identifying the best choice;

the method further comprises, for each team member, assigning weights to the plurality of criteria;

setting a level of knowledge includes, for each team member, setting a level of knowledge for each criteria;

estimating how well at least one of the alternatives meets the team member's target value includes estimating how well at least one of the alternatives meets at least one of the team members' target value for the feature of at least one of the criterion based on the team member's level of knowledge of the feature; and

calculating a expected utility includes:

for each criteria, calculating a fused belief from the feature value estimations of all team members;

weighing the fused beliefs of all criteria based on the weights assigned to the plurality of criteria for a first team member; and

calculating a expected utility for the alternative based on the weighted fused beliefs of all criteria.

3. A method according to claim **2**, wherein calculating a probability includes calculating a probability that the alternative is best based on all the feature value estimations of all the team members.

4. A method for processing information to identify a best choice from among a set of alternatives, the method comprising:

identifying a plurality of team members;

selecting a criterion for use in identifying the best choice, wherein the criterion includes a feature of the alternatives;

for each alternative:

for each team member, defining a target value for the feature;

for each team member, setting a level of knowledge for the feature;

for each team member, estimating how well at least one of the alternatives meets the team member's target value based on the team member's level of knowledge for the feature of the criterion;

calculating an expected utility for each alternative and a probability of each alternative being best based on the feature value estimations of all the team members;

identifying one of the set of alternatives as the best choice according to the expected utility for each alternative; and

performing a sensitivity analysis to inform the team members what information can change a ranking of the alternatives, where the sensitivity analysis is based on one of at least a distribution of criteria weights across all team members, a distribution of the level of knowledge of each team member, and a distribution of the feature value estimations.

5. A method according to claim **4**, wherein performing a sensitivity analysis includes calculating, for each alternative, a weighted expected utility for each alternative or probability of each alternative being best based on a virtual team member who is an expert and is alternatively completely satisfied and completely dissatisfied with the alternative.

6. A method according to claim **4**, wherein:

selecting a criterion includes selecting a plurality of criteria for use in identifying the best choice;

the method further comprises, for each team member, assigning the criteria weights to the plurality of criteria.

7. A method for processing information to identify a best choice from among a set of alternatives, the method comprising:

identifying a plurality of team members;

selecting a criterion for use in identifying the best choice, wherein the criterion includes a feature of the alternatives;

for each alternative:

for each team member, defining a target value for the feature;

for each team member, setting a level of knowledge for the feature;

for each team member, estimating how well at least one of the alternatives meets the team member's target value based on the team member's level of knowledge for the feature of the criterion;

determining a team consensus for each criteria/alternative pair; and

identifying one of the set of alternatives as the best choice.

8. A method for processing information to identify a best choice from among a set of alternatives, the method comprising:

identifying a plurality of team members;

selecting a criterion for use in identifying the best choice, wherein the criterion includes a feature of the alternatives;

for each alternative:

for each team member, defining a target value for the feature;

for each team member, setting a level of knowledge for the feature;

for each team member, estimating how well at least one of the alternatives meets the team member's target value based on the team member's level of knowledge for the feature of the criterion;

determining a centroid of the feature value estimations;

determining a region of knowledge and confidence into which the centroid must fall to change the satisfaction ranking of the alternative; and

identifying one of the set of alternatives as the best choice.

9. A method for processing information to identify a best choice from among a set of alternatives, the method comprising:

identifying a plurality of team members;

selecting a criterion for use in identifying the best choice, wherein the criterion includes a feature of the alternatives;

for each alternative:

for each team member, defining a target value for the feature;

for each team member, setting a level of knowledge for the feature;

for each team member, estimating how well at least one of the alternatives meets the team member's target

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value based on the team member's level of knowledge for the feature of the criterion;

calculating an expected utility for each alternative and probability of each alternative being best based on the feature value estimations of all the team members;

identifying one of the set of alternatives as the best choice according to the expected utility of each alternative; and

suggesting additional evaluations to each team member that would aid in identifying the best choice.

10. A method according to claim **9**, wherein suggesting additional evaluations includes suggesting that the team members have done sufficient analysis and there is low risk in making a decision based on current information.

11. A method according to claim **9**, wherein suggesting additional evaluations includes suggesting additional evaluations using at least one of the expected utility for each alternative, a probability of each alternative being best based on a virtual team member who is an expert and is alternatively completely satisfied and completely dissatisfied with the alternative, a distribution of team consensuses and the distribution of criteria weights.

12. A method according to claim **11**, wherein:

selecting a criterion includes selecting a plurality of criteria for use in identifying the best choice;

the method further comprises, for each team member, assigning weights to the plurality of criteria; and

suggesting additional evaluations includes suggesting additional evaluations using at least one of the expected utility for each alternative, a probability that each alternative is best, a distribution of team consensuses on a belief map, a set of types for the plurality of criteria, and a distribution of weights for the plurality of criteria.

13. A method according to claim **9**, wherein suggesting additional evaluations includes using an internal rule base to determine suggestions for the team members.

14. A method for processing information to identify a best choice from among a set of alternatives, the method comprising:

identifying a plurality of team members;

selecting a criterion for use in identifying the best choice, wherein the criterion includes a feature of the alternatives;

for each alternative:

for each team member, defining a target value for the feature;

for each team member, setting a level of knowledge for the feature of the criterion;

discounting the level of knowledge for at least one team member;

for each team member, estimating how well at least one of the alternatives meets the team member's target value for the feature of the criterion based on the team member's level of knowledge;

calculating an expected utility for each alternative based on the feature value estimations of all the team members;

calculating a probability that each alternative is best based on the feature value estimations of all the team members; and

identifying one of the set of alternatives as the best choice according to the expected utility for each alternative.

15. A system for processing information on a computer to reach a consensus among a plurality of team members on a decision, the system comprising:

a set of alternatives from which to select;

for each team member, a knowledge level;

at least a first criterion to be used by the plurality of team members to select one of the alternatives; and

a computer adapted to aid the plurality of team members in selecting one of the alternatives using the criterion, the computer including a user display adapted to display an expected utility for each alternative and probability that each alternative is best.

16. A system according to claim **15**, wherein the computer includes means for discounting the knowledge level of at least one team member before calculating the expected utility for each alternative and the probability that each alternative is best.

17. A system for processing information on a computer to reach a consensus among a plurality of team members on a decision, the system comprising:

a set of alternatives from which to select;

for each team member, a knowledge level;

at least a first criterion to be used by the plurality of team members to select one of the alternatives; and

a computer adapted to aid the plurality of team members in selecting one of the alternatives using the criterion, the computer adapted to perform a sensitivity analysis and inform the team members as to what information can change a ranking of the alternatives by satisfaction levels.

18. A system for processing information on a computer to reach a consensus among a plurality of team members on a decision, the system comprising:

a set of alternatives from which to select;

for each team member, a knowledge level;

at least a first criterion to be used by the plurality of team members to select one of the alternatives; and

a computer adapted to aid the plurality of team members in selecting one of the alternatives using the criterion, the computer including a user display adapted to suggest a course of action for the team members to consider.

19. A system for processing information on a computer to reach a consensus among a plurality of team members on a decision, the system comprising:

a set of alternatives from which to select;

for each team member, a knowledge level;

at least a first criterion to be used by the plurality of team members to select one of the alternatives; and

a computer adapted to aid the plurality of team members in selecting one of the alternatives using the criterion, the computer adapted to perform a sensitivity analysis and inform the team members what information can change a ranking of the alternatives by probabilities of being the best choice.

20. A system for processing information on a computer to reach a consensus among a plurality of team members on a decision, the system comprising:

a set of alternatives from which to select;

for each team member, a knowledge level;

at least a first criterion to be used by the plurality of team members to select one of the alternatives; and

a computer adapted to aid the plurality of team members in selecting one of the alternatives using the criterion, the computer adapted to calculate a level of consensus among the team members as to which alternative is best.

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21. A system according to claim 20, wherein the computer includes a user display adapted to display the level of consensus on a belief map.

22. A computer-readable medium containing a program to process information on a computer to identify a best choice from among a set of alternatives by a plurality of team members, the program comprising:

identification software to identify a plurality of team members;

selection software to select a criterion for use in identifying the best choice, wherein the criterion includes a feature of the alternatives;

for each alternative:

for each team member, definition software to define a target value for the feature;

for each team member, setting software to set a level of knowledge for the feature of the criterion;

for each team member, estimation software to estimate how well at least one of the alternatives meets the team member's target value for the feature of the criterion based on the team member's level of knowledge;

calculation software to calculate an expected utility for each alternative based on the feature value estimations of all the team members;

calculation software to calculate a probability that each alternative is best based on the feature value estimations of all the team members; and

identification software to identify one of the set of alternatives as the best choice according to the expected utility for each alternative.

23. A computer-readable medium containing a program to process information on a computer to identify a best choice from among a set of alternatives by a plurality of team members, the program comprising:

identification software to identify a plurality of team members;

selection software to select a criterion for use in identifying the best choice, wherein the criterion includes a feature of the alternatives;

for each alternative:

for each team member, definition software to define a target value for the feature;

for each team member, setting software to set a level of knowledge for the feature of the criterion;

for each team member, estimation software to estimate how well at least one of the alternatives meets the team member's target value for the feature of the criterion based on the team member's level of knowledge;

calculation software to calculate an expected utility for each alternative based on the feature value estimations of all the team members;

identification software to identify one of the set of alternatives as the best choice according to the expected utility for each alternative; and

performance software to perform a sensitivity analysis to inform the team members what information can change a ranking of the alternatives by satisfaction levels, where the sensitivity analysis is based on one of at least a distribution of criteria weights across all team members, the expected utility for each alternative, and probabilities of each alternative being the best choice.

24. A computer-readable medium containing a program to process information to identify a best choice from among a set of alternatives, the program comprising:

identification software to identify a plurality of team members;

selection software to select a criterion for use in identifying the best choice, wherein the criterion includes a feature of the alternatives;

for each alternative:

for each team member, definition software to define a target value for the feature;

for each team member, setting software to set a level of knowledge for the feature of the criterion;

for each team member, estimation software to estimate how well at least one of the alternatives meets the team member's target value for the feature of the criterion based on the team member's level of knowledge;

determination software to determine a team consensus for each criteria/alternative pair; and

identification software to identify one of the set of alternatives as the best choice.

25. A computer-readable medium containing a program to process information to identify a best choice from among a set of alternatives, the program comprising:

identification software to identify a plurality of team members;

selection software to select a criterion for use in identifying the best choice, wherein the criterion includes a feature of the alternatives;

for each alternative:

for each team member, definition software to define a target value for the feature;

for each team member, setting software to set a level of knowledge for the feature;

for each team member, estimation software to estimate how well at least one of the alternatives meets the team member's target value based on the team member's level of knowledge for the feature of the criterion;

determination software to determine a centroid of the feature value estimations;

determination software to determine a region of knowledge and confidence into which the centroid must fall to change the satisfaction ranking of the alternative; and

identification software to identify one of the set of alternatives as the best choice.

26. A computer-readable medium containing a program to processing information to identify a best choice from among a set of alternatives, the program comprising:

identification software to identify a plurality of team members;

selection software to select a criterion for use in identifying the best choice, wherein the criterion includes a feature of the alternatives;

for each alternative:

for each team member, definition software to define a target value for the feature;

for each team member, setting software to set a level of knowledge for the feature of the criterion;

for each team member, estimation software to estimate how well at least one of the alternatives meets the team member's target value for the feature of the criterion based on the team member's level of knowledge;

calculation software to calculate an expected utility for each alternative based on the feature value estimations of all the team members;

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identification software to identify one of the set of alternatives as the best choice according to the expected utility for each alternative; and

suggestion software to suggest additional evaluations to each team member that would aid in identifying the best choice.

27. A method for processing information to identify a best choice from among a set of alternatives, the method comprising:

identification software to identify a plurality of team members;

selection software to select a criterion for use in identifying the best choice, wherein the criterion includes a feature of the alternatives;

for each alternative:

for each team member, definition software to define a target value for the feature;

for each team member, setting software to set a level of knowledge for the feature of the criterion;

discounting software to discount the level of knowledge for at least one team member;

for each team member, estimation software to estimate how well at least one of the alternatives meets the team member's target value for the feature of the criterion based on the team member's level of knowledge;

calculation software to calculate an expected utility for each alternative based on the feature value estimations of all the team members;

calculation software to calculate a probability that each alternative is best based on the feature value estimations of all the team members; and

identification software to identify one of the set of alternatives as the best choice according to the expected utility for each alternative.

* * * * *

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