FORMULATED PROBLEM VERIFICATION AS AN EXPLICIT REQUIREMENT OF MODEL CREDIBILITY*#

by

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ABSTRACT

This paper deals with the formulation and formulation verification of a class of problems to which "modeling solutions" are applied. Two main objectives are to develop a procedure for problem formulation and to propose indicators for the formulated problem verification. The class of problems considered is analyzed in two categories as requiring prescriptive or descriptive solutions. A detailed study of each category results in a procedure to guide the analyst during the problem formulation. This procedure is illustrated by a traffic intersection problem. The formulated problem is measured by using indicators to accomplish an evaluation for the formulated problem verification. Indicators are developed to measure: (1) the probability of failing to solve the *actual* problem, (2) the acceptability of an alternative set of possible outcomes, and (3) how well the formulated problem is structured. An evaluation questionnaire, included in the Appendix, is employed in applying the proposed indicators.

Keywords: formulated problem verification, measurement, modeling, model credibility, problem formulation

1. INTRODUCTION

It has been said that a problem correctly formulated is half solved[18]. Albert Einstein once indicated that the correct formulation of a problem was even more crucial than its solution. The ultimate goal is not to find a solution to a problem but to produce a *correct* one that will be *accepted* and *used*.

A problem is recognized under varying situations, for example: (1) when a set of current conditions deviate from a range of acceptable conditions, (2) when a set of conditions reflecting no significant deviation are sought (see Figure 1 part A), or (3) when the need is perceived to obtain some required information (see Figure 1 part B). Confronted by one of the above situations, a decision maker (a client or sponsor group) initiates a study by communicating the problem to an analyst (a problem-solver, consultant or research group). The communication of the problem rarely is clear, specific, or organized. Consequently, an essential study to formulate the *actual* problem usually follows. *Problem Formulation* (problem structuring or problem definition) is the process by which the initially communicated problem is translated into a formulated problem sufficiently well defined to begin the attempt at solution[19].

Problem formulation is the first process in the life cycle of decision-aiding models[10]. It greatly affects the credibility and acceptability of model results. Insufficient problem definition and inadequate user participation in defining the problem are identified as two important problems in the management of computer-based models in a report submitted to the U.S. Congress by the General Accounting Office[17]. The extreme importance of the problem formulation in the successful conclusion of a simulation project has motivated the research described herein.

This paper has two primary objectives: (1) to develop a procedure which (a) guides the analyst during the problem formulation, (b) structures the verification of the formulated problem, and (c) seeks to increase the likelihood that the results are utilized by decision makers, and (2) to propose indicators for the formulated problem verification. A secondary but important, objective is to develop an understanding of the problem formulation task and the degree to which computer assistance can be provided as a function of a Model Management System (see Reference 10).

The procedure is presented and illustrated by an example in Section 2 following a review of the literature. Formulated problem verification is discussed in Section 3 and is introduced as an explicit requirement of model credibility in Section 4. Conclusions are given in Section 5.

2. PROBLEM FORMULATION

After an extensive literature review, Woolley and Pidd[19] identified four broad approaches to problem formulation, none of which are completely distinct, but rather represent clusters of ideas. A brief description is given below. (For more details see Reference 14.)

The Checklist Approach (*Do this, then that, then ...*)

Auto engine fault finding check-lists exemplify this approach. Problems are viewed as deviations from a desired set of conditions, breakdowns, failures, or things gone wrong. The analyst is guided through a series of questions from which he gains all the information required to identify the exact cause of the problem.

The Definition Approach (*What are the decision parameters?*)

In this view, the analyst is advised to identify the elements of a problem in terms of decision makers, objectives, alternative courses of action, measures, etc. This is undertaken with some sort of modeling in mind. Problem formulation according to this approach is basically a procedure for obtaining a collection of variables from which to build a model.

The Science Approach (What is really going on here?)

This approach views the problem formulation as an analysis of the problem domain with the purpose of discovering what is "really" happening. The analysis is undertaken by collecting quantitative data, observing the problem domain so as to gain a clear understanding of the object system and to identify the "actual" problem.

The People Approach (What is everyone saying and why?)

This view sees problem formulation as a function of different perceptions of the same situation, or different realities constructed by various people. The situation is problematic in the context of the perceptions of the decision maker(s) and any useful definition must take account of the varying perceptions. Thus, problem formulation is viewed as a process of negotiating a problem definition which is (mutually) acceptable to the decision maker(s).

Pidd and Woolley[14] concluded that the four approaches are all defective in some way or other, perhaps being too rigid or too "blinkered," i.e. concentrating primarily on tangible or intangible aspects. In another paper[13], they suggested the Exploration Approach, combining features of the Definition, Science, and People approaches.

The Exploration Approach (Question ---> Answer ---> Reflect ---> Question ---> ...)

This approach is characterized by four fundamental aspects, namely, informality, hierarchy, continuance, and inclusiveness. A continual cycle includes three actions: question, answer, and reflect. The answers obtained to the questions allow the analyst to reflect on the situation as it is understood so far. Then, in the light of this reflection, a whole new series of questions are created. Answering these questions stimulates another reflection, and the process is continued until the problem is sufficiently structured.

The need for procedural guidance in problem formulation is clearly established in the literature. Such guidance must be subjective for the most part; however, some aspects of the problem formulation process are sufficiently understood to admit description in objective (more formal) terms. While a procedure that is generally applicable to problem solving appears impossible, the development of a procedure generically applicable to a distinctive class of problems seems both achievable and useful. The class of problems treated herein require prescriptive and/or descriptive solutions which are decision-aiding. *Prescriptive (or Normative) Solutions* convey to the decision makers what course(s) of action to take in a problematic situation with a value judgment on the "goodness" or "badness" of such course(s) of action. *Descriptive Solutions* provide some knowledge to the decision makers with no value judgment on the "goodness" or "badness" of such knowledge. Examples of the class of problems considered are presented in Figure 1. A procedure guiding the analyst in formulating a problem within this class is outlined in Figure 2 and discussed below.

The steps of the procedure should in no way be interpreted as sequential. Similar to the model life cycle[4,9], an iterative procedure is employed to permit non-sequential transitions among the steps. Problem formulation may continue throughout the entire model life cycle. The formulated problem may be revised by new information or recognized changes in the problem context in connection with the objectives, constraints, alternatives, decision makers, and so forth.

2.1 Problem Formulation by Example

The stages of problem formulation are shown by the boxes marked (1) through (15) in Figure 2. The essential steps of Stage j will be presented in Table j, where j=1,2,...,9. Stages (10) through (15) can be followed with the help of the guidance gained in (4), (5), and (8). The communicated problem A5 in Figure 1 is chosen as an example to illus-

A. Problems That Require Prescriptive Solutions

<A1> Where should a nuclear power plant be built?

<A2> What operating policy should be implemented to maximize the profits?

<A3> Which items should be stored in which warehouse and which route should be taken with which transportation mode to achieve the highest productivity with the least total transportation cost?

<A4> What is the optimum tactic which would minimize the vulnerability and maximize the state of readiness and mobility of a unit?

<A5> What traffic light timing minimizes the average waiting times of vehicles at an intersection?

B. Problems That Require Descriptive Solutions

<B1> How much will the computer system resources be utilized next year?

<B2> What would be the effect of a ten percent increase in interest rates on the U.S. economy?

<B3> What are the most significant factors which affect the overall performance of the IBM S/370 computer system?

<B4> What is the average response time under the present interactive operating system?

<B5> What significant relationships can be identified among the types of jobs, the priority levels, and the overall performance of the VAX 11/780 computer system?

Figure 1. Examples of the class of problems considered.

trate the steps of Stages (1) through (9) concurrently with their tabular presentation.

2.1.1 Stages 1-3: Solution Value, Root Causes, and Potential Outcomes

The essential steps of Stage (1) are presented in Table 1. Assume that the example problem is perceived during a rush-hour period as a result of a deviation from a range of acceptable vehicle waiting times.

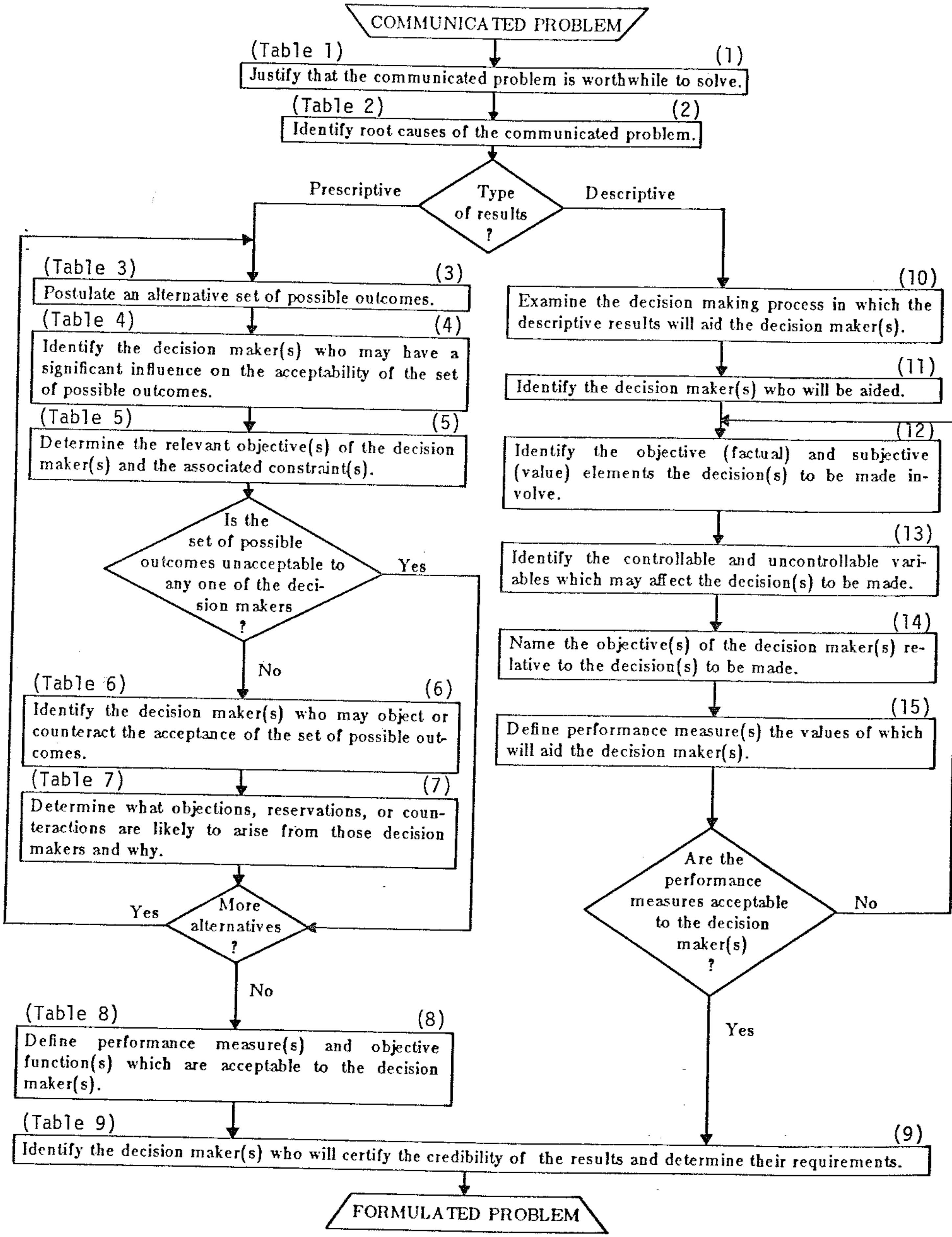

Figure 2. A high-level procedure for problem formulation.

Then, we go to <1d> to estimate the significance of this deviation and

Table 1. Justify that the communicated problem is worthwhile to solve.

<1a> If it is perceived that a set of current conditions deviate from a range of acceptable conditions or a desired set of conditions, go to <1d>.

<1b> If a need is perceived to obtain some required information for decision making, go to <1e>.

<1c> If a set of conditions reflecting no significant deviation are sought, go to <1f>; otherwise go to <1g>.

<1d> Is this deviation significant? If not go to <1h>. Does the comparison of potential benefits of correcting this deviation with the estimated cost of correcting it justify an attempted solution? If not go to <1h>; otherwise go to Table 2.

<1e> Does the comparison of potential utility of this information with the estimated cost of obtaining it justify obtaining this information? If not go to <1h>; otherwise go to Table 2.

<1f> Does the comparison of potential benefits of this set of conditions with the estimated cost of achieving it justify the attempt to obtain this set of conditions? If not go to <1h>; otherwise go to Table 2.

<1g> Examine the context of the communicated problem and reexamine the B/C ratio to justify a solution attempt. Go to Table 2.

<1h> The problem is not worthwhile to solve. The solution cost is likely to exceed the return. Terminate.

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the benefits/cost (B/C) ratio. Suppose that the four-way intersection (IM) is critical, and the B/C ratio indicates the desirability of reducing the currently unacceptable vehicle waiting times.

Problems are embedded each within the other. The root problem(s) should be extracted or abstracted from the enclosing context[13]. A detailed analysis of the context of the communicated problem becomes essential for identifying the exact nature of the "actual" problem. This, however, may be time consuming and very costly depending upon the complexity of the problem context[1].

An obvious problem may actually be a symptom of a more fundamental problem especially in a large and complex problem environment. To identify more fundamental problem(s) causing the communicated one, we go to Stage (2), shown in Table 2[18]. The intersection and its environment

Table 2. Identify root causes of the communicated problem.

<2a> Examine the symptoms described within the communicated problem and analyze causality relationships within the context of the problem environment.

<2b> List and label all the symptoms, problematic situations, problems, factors, and conditions that affect each other in causing the communicated problem.

<2c> Construct a causality network by drawing a series of edges crossing the labeled elements in <2b> to represent how they relate to each other. (One can contribute to another, be caused by another, or be independent of another.)

<2d> Identify the root cause(s) as the one(s) with no indirected edges.

<2e> If the communicated problem requires a prescriptive solution, go to Table 3. If it requires a descriptive solution, go to Stage (10); otherwise if it requires a solution which is both prescriptive and descriptive, perform the Stages from (3) to (8) in parallel with the Stages from (10) to (15).

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are diagnosed and analyzed in <2a>.

The following list is prepared in <2b> containing the elements affecting the waiting times of vehicles (WT): (1) current light timing (LT), (2) pedestrian crossings (PC), (3) physical layout (PL), (4) current operating policy (CP), and (5) adjacent intersections (Assume four and label as IA, IB, IC, and ID). In step <2c>, the causality network shown in Figure 3 is constructed. Thus in step <2d>, we identify LT, PL, IA, IB, IC, and ID as the potential root causes of the communicated problem WT.

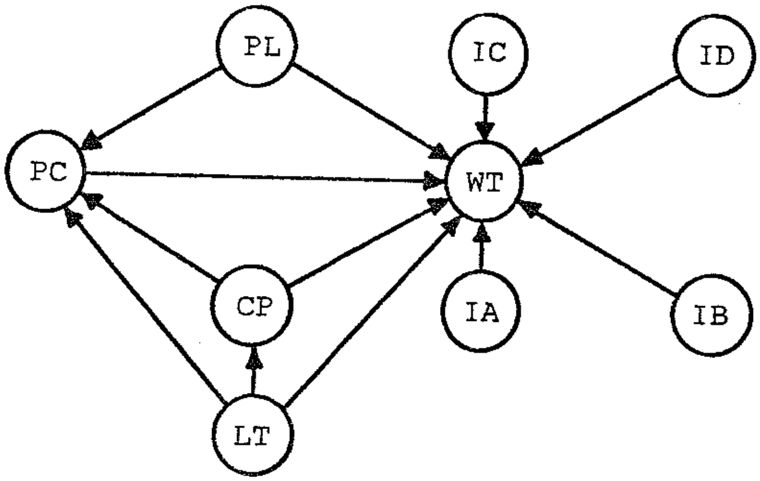

Figure 3. The causality network of the example problem.

Here, we realize that LT is one of several causes of long waiting times. Therefore, implementing the optimal light timing may not necessarily effect a sufficient reduction. At this point, the communicated problem should be restated as:

> "What should be done at a reasonable cost to bring the average waiting times of vehicles within an acceptable range?"

This change should be understood and accepted by the decision maker(s) who earlier communicated the problem.

Since the example problem is stipulated as requiring a prescriptive solution, we go to Table 3[1] that contains the essential steps of Stage (3). In step <3a>, assume that the adjacent intersections, physical layout, and operating policies are the elements significantly affecting the vehicle waiting times. After exploring and examining these elements, the controllable quantitative and qualitative variables are identified with their sets of allowable values as follows:

Adjacent Intersections:

1. Intersection identifier = (IM, IA, IB, IC, ID)

Physical Layout:

2. Street traffic flow = (one way, two ways)

Table 3. Postulate an alternative set of possible outcomes.

<3a> Explore the elements of the problem environment that significantly affect the outcomes of the problem.

<3b> Examining those elements, identify the controllable variables that significantly influence the outcomes of the problem.

<3c> Type each controllable variable as "quantitative" or "qualitative".

<3d> Determine the set of allowable values each controllable variable may have.

<3e> Identify each feasible combination of values of the quantitative and qualitative variables that can lead to alternative outcomes.

<3f> Postulate an alternative set of possible outcomes from the ones identified. Go to Table 4.

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3. Direction of traffic flow = (South-to-North (SN), North-to-South (NS), East-to-West (EW), West-to-East (WE))

4. Number of lanes = (1, 2, 3, 4)

5. Directional rules = (left turn, right turn, straight)

6. Layouts = (current layout, layout with a bridge, etc.)

Operating Policies:

Traffic light

7-8. Red or Green = (5, 6, 7,..., 180) seconds

9. Yellow = (3, 4, 5,..., 15) seconds

10. Red to every direction for intersection clearance = (5, 6, 7,..., 20) seconds

11. Right turn rule on red = (turn, no turn)

12. Sensor detection = (yes, no)

Flashing light

13-16. Flashing light in SN, NS, EW, or WE direction = (yellow, red)

Stop sign

17-20. Stop sign in SN, NS, EW, or WE direction = (yes, no)

Policeman

21. Number of policemen = (1, 2,..., 8)

The variables 4, 7-10 and 21 are quantitative and the others are qualitative. Any feasible combination of values of these variables can lead to a possible set of outcomes.

2.1.2 Stages 4-7: Decision Makers - Objectives, Constraints, and Reactions

Table 4[1,2] contains the essential steps of Stage (4). In step <4a>, two aspects of the example problem environment are identified as influential on the acceptability, namely, the Bureau of Traffic of the State Department of Transportation (BTDOT) and the Division of Highway

Table 4. Identify the decision maker(s) who may have a significant influence on the acceptability of the set of possible outcomes.

<4a> Identify the aspects of the problem environment that may affect the acceptability of the set of possible outcomes.

<4b> Identify all the relevant decision makers who influence the controlling of those aspects.

<4c> Determine the range of control open to each decision maker.

<4d> Determine the degree of influence each decision maker may have on the acceptability of the set of possible outcomes.

<4e> Determine the means and channels through which each decision maker may exercise this influence.

<4f> Identify those decision makers who can significantly influence the acceptability of the set of possible outcomes. Go to Table 5.

Construction (DOHC). Three persons in the BTDOT and two in the DOHC are identified as the influential decision makers. The BTDOT individuals are also the initiators of the study, and they have full control over the operation of the intersection. The DOHC personnel have significant influence if constructional changes are required. The BTDOT and DOHC decision makers have authoritative power to exercise their influence and are identified in <4f>.

The decision makers identified in <4f> examine the postulated set of possible outcomes in step <5a> in Table 5[1,16]. As a result, we find

Table 5. Determine the relevant objective(s) of the decision maker(s) and the associated constraint(s).

<5a> Examine the possible outcomes with the decision maker to assess support for particular courses of action.

<5b> Depending upon the response, identify the decision maker's choices related to goals that can be affected by the solution of the problem.

<5c> Identify the objective (factual) and the subjective (value) elements within each of the decision maker's choices.

<5d> Define the objective(s) by using the element(s) identified.

<5e> Define the constraint(s) by using the element(s) identified within the choices in connection with the decision maker's goals.

<5f> If the set of possible outcomes is unacceptable to any one of the decision makers, go to <7e>; otherwise go to Table 6.

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that neither BTDOT nor DOHC desires constructional changes due to the high cost. In step <5d>, the main objective is determined: to minimize the total average vehicle waiting times. Three constraints are associated with this objective: (1) average vehicle waiting time in each direction should not exceed two minutes, (2) average pedestrian waiting time in each crossing direction should not exceed one minute, and (3) no constructional changes.

We now go to Stage (6), shown in Table 6. The users' aspect of the example problem environment is identified in <6a> as potentially in

Table 6. Identify the decision maker(s) who may object or counteract the acceptance of the set of possible outcomes.

<6a> Identify aspects of the problem environment beyond the decision maker's range of control but from which may come opposition to acceptance of the possible outcomes.

<6b> Identify all the relevant decision makers who influence the controlling of those aspects and who may oppose to acceptance of the possible outcomes.

<6c> Determine the range of control each decision maker is able to exercise.

<6d> Estimate the strength of objections or counteractions by each decision maker against acceptance of the possible outcomes.

<6e> Determine the means and channels through which each decision maker may exercise these objections or counteractions.

<6f> Identify those decision makers who may raise objections or initiate counteractions that could affect acceptance of the possible outcomes. Go to Table 7.

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opposition to acceptance of the possible outcomes. The drivers and pedestrians using the intersection and route are identified as the decision makers in <6b>.

Implementation of a different operating policy at the intersection may stimulate undesirable conditions elsewhere in the road network, causing opposition to acceptance of the outcomes. Hence, the effect of any change on other intersections should be considered within the study. The drivers and pedestrians may exercise their influence through political channels and are the decision makers identified in <6f>. Discussing the possible outcomes in <7a>, we find that any outcome is acceptable to them as long as the constraints (1) and (2) defined in <5e> are satisfied. Thus, expecting no opposition we go to step <7e>.

2.1.3 Stages 8-9: Performance Measures and Solution Credibility

Table 7. Determine what objections, reservations, or counteractions are likely to arise from those decision makers and why.

<7a> With each of the decision makers identified in <6f>, examine the set of possible outcomes and assess the strength of opposition to acceptance of those outcomes. If no significant opposition exists, go to <7e>.

<7b> Attempt to have the decision maker identify and fully explain any objections, reservations, or counteractions.

<7c> Examining the response further with the decision maker, determine the rationale, competitive goals, and conflicting objectives causing the objections.

<7d> Determine new objectives and constraints. Revise the alternative if possible or generate new alternatives to avoid the factors causing the opposition.

<7e> If there is a need for more alternatives, go to Table 3; otherwise go to Table 8.

Generally speaking, at the end of stage (7) the objectives are identified. However, a great deal of work may remain in the definition of appropriate measures to reflect the attainment of the objectives[1]. Consider, for example, the objective of obtaining the highest productivity in problem A3 of Figure 1. Such an objective requires the definition of functional relationships for measuring productivity and the composition of a synthesizing function acceptable for producing an acceptable composite measure of productivity. Such functional relationships are usually called "performance measures," and the composite function, an "objective function." Determination of the objective function can be extremely difficult especially when there are multiple objectives[7]. In these situations, decisions are based upon the values of the performance measure(s). The steps in Table 8 can be used to define acceptable performance measure(s) and objective function(s). However, these definitions in some circumstances cannot be prescribed in detail.

Sources have suggested that the credibility of model results be judged by an institution for certification[12,15], either as a government agency or an independent third party. Certification requirements are identified in Table 9. For the example problem considered, the certification requirement may be the satisfaction of all traffic rules and regulations.

3. FORMULATED PROBLEM VERIFICATION

A concept of problem formulation is illustrated in Figure 4. The communicated problem and its boundary are rarely clear, specific, or organized. This is illustrated by irregularly shaped dashed curves. After completing the problem formulation process, the problem is expected to be well structured and defined to contain the actual problem in its entirety.

Three types of errors may be committed in solving a formulated problem by using modeling as depicted in Figure 5. Type I error is committed when the model results are rejected when in fact they are sufficiently credible. Rejection could be the action of a certification agency or the original decision makers.

Type II error is committed when the model results are accepted although in fact they are insufficiently credible. Type III error is committed when the formulated problem does not completely contain the actual problem. The probability of committing type I error is called *model builder's risk* and type II, *model user's risk* [5]. Under type III error, the problem solution becomes irrelevant, for the outcome must either be unsuccessful or an error of type II. Therefore, type III error is extremely important and its probability of occurrence must be kept as small as possible.

Table 8. Define performance measure(s) and objective function(s) which are acceptable to the decision maker(s).

<8a> List all the objectives named.

<8b> Identify the controllable variables associated with each alternative set of possible outcomes.

<8c> Identify the uncontrollable variables (parameters) which affect the performance.

<8d> Define a functional relationship or logical procedure that produces values of performance measures observed under all alternatives.

<8e> Define an objective function to obtain a composite value.

<8f> If the performance measure(s) and the objective function(s) are acceptable to the decision maker(s), go to Table 9; otherwise go to <8b>.

Table 9. Identify the decision maker(s) who will certify the credibility of the results and determine their requirements.

<9a> Determine if certification of the results is intended. If not, go to <9f>.

<9b> Identify the certifying institution.

<9c> Identify the decision maker(s) in that institution who are to evaluate the results for certification.

<9d> Determine the standards, regulations, and precision requirements which affect all alternative outcomes.

<9e> Incorporate all requirements identified within the formulated problem.

<9f> Prepare a report containing a detailed description of the formulated problem. Terminate.

Substantiation that the formulated problem contains the *actual* problem in its entirety and is sufficiently well structured to permit the derivation of a sufficiently credible solution is called *formulated problem verification*. For this substantiation, the formulated problem must

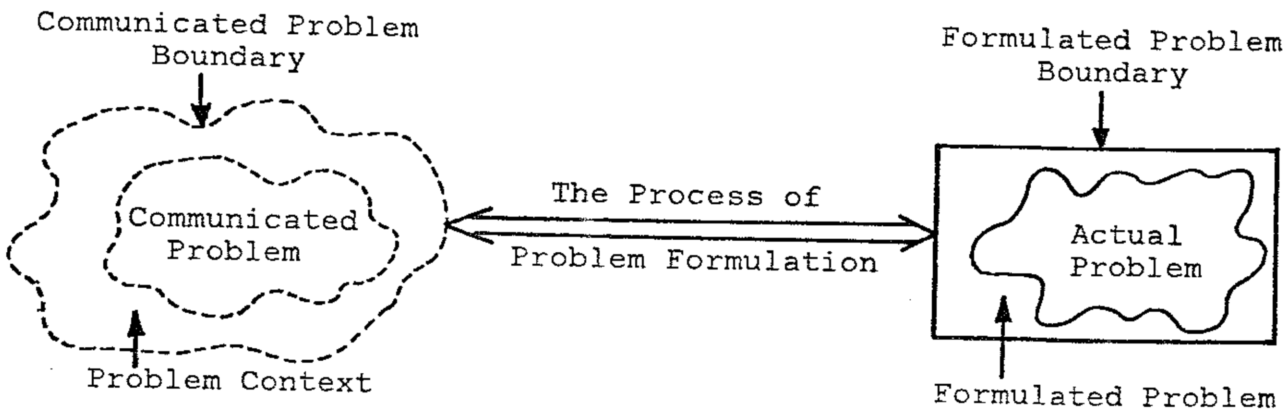

Figure 4. A diagrammatic illustration of problem formulation.

be evaluated by the people who are intimately knowledgeable of the problem(s) based on experience and training. The analyst who formulated the problem is not qualified to make this evaluation since the analyst is also subject to evaluation.

3.1 The Measurement of the Formulated Problem

The formulated problem is viewed as an extant concept to be measured using indicators (also called measures, scales, or factors). An *indicator* is an indirect measure of a concept that can be measured directly[3,8,11]. Thus, we can measure indicators to affect the evaluation necessary for formulated problem verification.

Indicators should be developed to measure: (1) the probability of committing type III error, (2) the probability that an alternative set of possible outcomes can be rejected due to the formulation of the problem, and (3) how well the formulated problem is structured.

The following 20 indicators are designed to measure the probability of committing type III error:

1. *People personalize problems* [18].

The root problems may be hidden by people who see them as personal

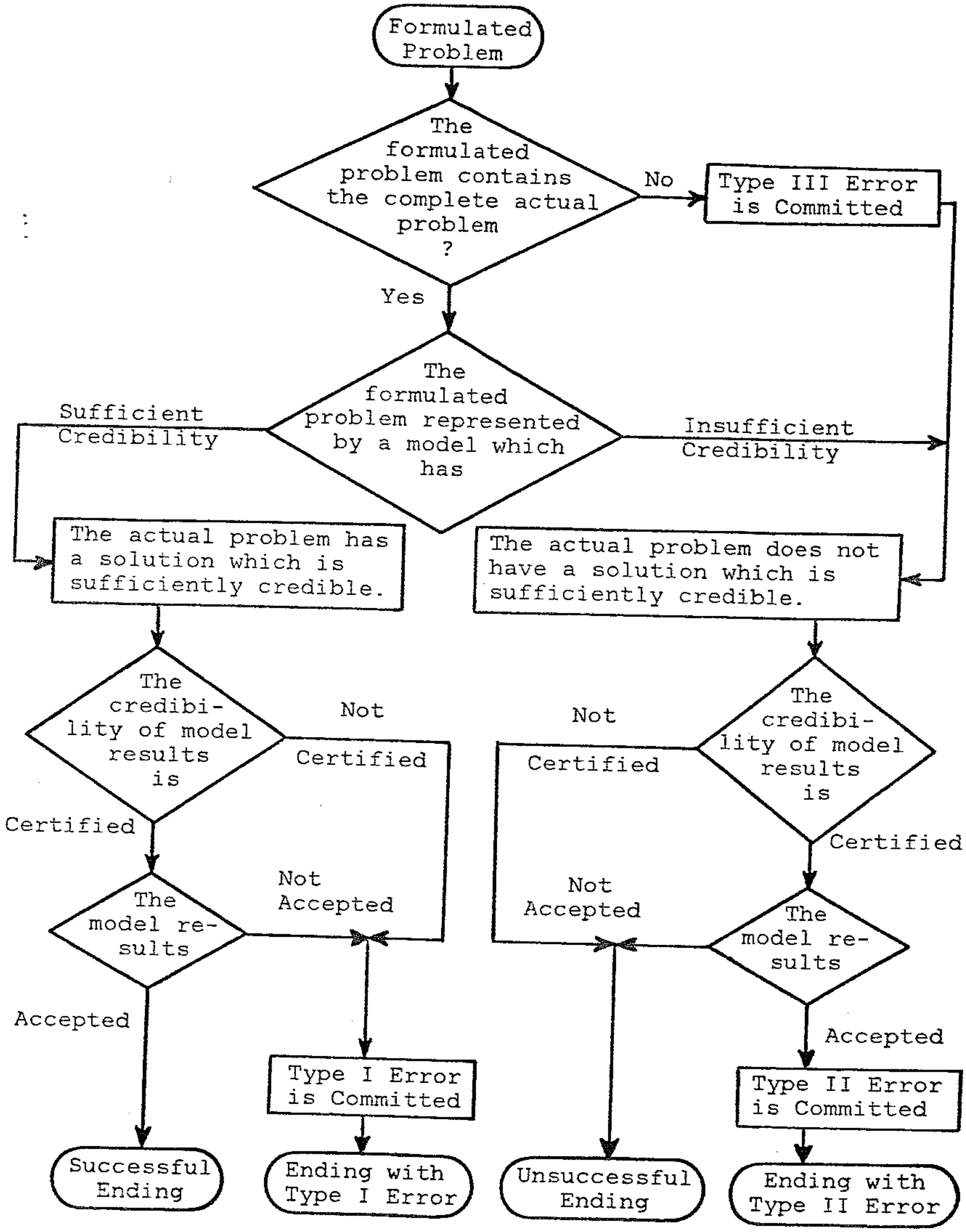

Figure 5. The occurrence of errors in the model life cycle.

failings. People may distort information indicating the existence of a problem to protect their positions and pride or become defensive at the suggestion that a problem exists.

2. *Information showing that a problem exists is not revealed* [18].

Subordinates may hide information to keep their manager(s) happy or to avoid political disputes.

3. *The problem context is too complex for the analyst to comprehend* [18].

This indicator often occurs when the analyst is an external consultant or unfamiliar with the problem context. Under binding time pressure an analyst might forego the necessary time for distinguishing among causes and symptoms and treat the definition superficially.

4. *Root problems arise in contexts with which people have had no experience* [18].

Root problems cannot be identified correctly when they occur under conditions that are unfamiliar to people. Due to the lack of experience, people may not even recognize the existence of a problem.

5. *Cause and effect are not closely related within the problem context.*

Determining the interactions present in Figure 3 may not be easy; the problem context may be counterintuitive. Problems and their root causes may not be closely related in time or space. Problem recognition may surface long after the emergence of the primary root causes.

6. *The analyst cannot distinguish between facts and opinions* [16].

During the processes of observing, interviewing, analyzing, participating and examining documentations, the analyst may accept opinions as facts rather than only personal views. The analyst may also be biased by his own opinions and experience, leading to incorrect inferences or hasty conclusions.

7. *The analyst may be misguided deliberately or accidentally.*

People may misguide the analyst believing the solution of the problem is not to their benefit. Inaccurate or incomplete knowledge can cause people accidentally to mislead the analyst.

8. *The level of extraction of problem context is insufficiently detailed.*

An artful balance is required in extracting the proper level of description of the problem context in formulating the problem. Extraction of unimportant elements may create unnecessary complications; while exclusion of a crucial element may hide a significant root problem.

9. *The problem boundary is insufficient to include the entire problem.*

An important root problem may be ignored through the analyst's inappropriate definition of problem boundary.

10. *Inadequate standards or definition of desired conditions exist* [18].

A root problem may not be identified when the deviation cannot be perceived due to inadequate documentation or inaccurate understanding of standards or the desired set of conditions.

11. *The root causes are time dependent.*

At the time the analyst is formulating the problem, the root causes may not be observable due to time dependencies.

12. *A root cause is masked by the emphasis on another.*

A root problem may be overemphasized because of political disputes, personal conflicts, conflicts of interests, etc. The analyst's attention can thus be diverted from a more significant problem.

13. *Invalid information is used.*

A root problem may not be identified due to incorrect inferences made because of the use of invalid information.

14. *Invalid data is used.*

Incorrect derivations, transformations, and conclusions can be caused by invalid data. This may cause a root problem to be ignored.

15. *Assumptions may conceal root causes.*

Root causes may be hidden by assumptions, especially those justifying approximations and simplifications.

16. *People suspicious of change may show resistance.*

Strong resistance may come from people who oppose any changes or who perceive no benefit in solving the problem. Determined actions by such people complicate the identification of root causes.

17. *The problem is formulated under the influence of a solution technique.*

The problem formulation may be influenced by a solution technique familiar to the analyst, creating gross approximations resulting in a formulated problem somewhat removed from the real one. For example, under the influence of linear programming, a problem may be formulated by approximating all the constraints and the objective function as linear; while the nonlinear characteristics of some constraints may be crucial for solving the *actual* problem.

18. *The real objectives are hidden accidentally, unconsciously, or deliberately.*

The formulated problem may deviate substantially from the actual if the real objectives are incorrectly identified. Different objectives result in different problem formulations.

19. *Root causes arise in other unidentified systems, frameworks or structures.*

The definition of the problem context may be too narrow. No matter how detailed the analysis of the problem context, root causes may not be recognized if their effects arise beyond the defined problem boundary.

20. *The formulated problem is out of date.*

The time interval between the problem formulation and the solution presentation may be several months or even years. Over such an extended period the problem context and objectives can change. Failure to incorporate these changes and revise the formulated problem accordingly may result in a solution to a past problem that is no longer applicable.

Eight indicators are developed to measure the probability that an alternative set of possible outcomes is rejected due to the formulation of the problem (see Appendix, questions 12.1 to 12.8). Several other indicators are developed to measure how well the formulated problem is structured. All of the indicators are presented in the Appendix in the format of an evaluation questionnaire.

3.2 The Evaluation of the Formulated Problem

The questionnaire in the Appendix must be completed by the people (evaluators) who are intimately involved in the problematic situation. An evaluator should have expert knowledge of and experience with the operations and characteristics of at least one problem area. Evaluators should be selected so that their areas of expertise and experience cover all areas of the problematic situation. Here, the situation must be defined as broadly as possible.

The accuracy of the formulated problem verification is dependent upon the quality of the measurement. Measurement quality depends on the validity and reliability of the measures[11], and the quality of the evaluators.

4. MODEL CREDIBILITY

A recent literature review[6] revealed the use of 16 terms: *acceptability, accuracy, analysis, assessment, calibration, certification, confidence, credibility, evaluation, performance, qualification, quality assurance, reliability, testing, validation,* and *verification*. We find that the published research dealing with these terms does not cover the problem formulation and its verification in sufficient detail. The actual story below perhaps places the formulated problem verification in the correct perspective:

> In a country, the name of which is not important, the Department of Energy (DoE) gave a project to a research institution to determine the best location for building a nuclear power plant. Following an extensive study, location x was proposed and accepted by the DoE. However, during the implementation phase, the Department of Defense (DoD) rejected the location for the reason that it can easily be attacked by the enemy. The study was reinitiated.

In the above scenario fault must be attributed to the research institution for failing to identify the DoD as a key influential decision maker. By following the steps of Tables 4 and 5, they would have realized the unacceptability of location x.

In a modeling and simulation study, we must recognize the formulated problem verification as an explicit requirement of model credibility. Otherwise, a loss in credibility of the modeling agency is a likely outcome.

5. CONCLUSIONS

A procedure is presented to guide the analyst in formulating a problem requiring prescriptive and/or descriptive solutions that are decision-aiding. The procedure structures the verification of the formulated problem and seeks to increase the likelihood that the results are utilized by decision makers.

The formulation of a problem to which a "modeling solution" is applied greatly affects the credibility and acceptability of model results. The formulated problem verification employs the use of indicators developed to measure (1) the probability of committing type III error, (2) the probability that an alternative set of possible outcomes will be rejected due to the formulation of the problem, and (3) how well the formulated problem is structured. The precision of the verification is dependent upon the measurement quality. Assessment of measurement validity and indicator reliability are difficult and highly problem dependent. Consequently, the indicators proposed in this paper should be considered as examples or candidates for application to a specific problem area, and the measurement validity and reliability should be established with regard to that specific area.

APPENDIX
Formulated Problem Evaluation Questionnaire

The following questions (indicators) are designed to measure how well the problem is formulated. Do not start answering these questions unless you have studied the report on the formulated problem and understood its content in detail. There are no right or wrong answers. Answer the questions to reflect your expert knowledge. If a question is not appropriate simply mark NA. If you are unsure of the answer to a question, simply indicate so and do not guess. You may be asked to defend your answers if necessary.

1. The potential benefits of solving the formulated problem are

   a) over estimated a lot
   b) over estimated
   c) estimated close enough
   d) under estimated
   e) under estimated a lot

2. The cost of solving the formulated problem is

   a) over estimated a lot
   b) over estimated
   c) estimated close enough
   d) under estimated
   e) under estimated a lot

3. Do you agree with the analyst's justification that the formulated problem is worthwhile to solve?

   a) Strongly agree b) Agree c) Disagree d) Strongly disagree

4. What are the chances (in terms of a percentage, i.e. 5%, or a range of percentages, i.e. 4% - 6%) that the *actual* problem is not completely identified due to the possibility that

   % or % range
   of chance

4.1 people might have personalized problems: __________

4.2 information showing that a problem exists might have not been revealed: __________

4.3 the problem context is too complex for the analyst to comprehend: __________

4.4 root problems might have arisen in contexts with which people have had no experience: __________

4.5 cause and effect may not be closely related within the problem context: __________

4.6 the analyst might have not been able to distinguish between facts and opinions: __________

4.7 the analyst might have been misguided deliberately or accidentally: __________

4.8 the level of extraction of problem context was insufficiently detailed: __________

4.9 the problem boundary was insufficient to include the entire problem: __________

4.10 inadequate standards or definition of desired conditions exist: __________

4.11 the root causes might be time dependent: __________

4.12 a root cause might have been masked by the emphasis on another: __________

4.13 invalid information might have been used: __________

4.14 invalid data might have been used: __________

4.15 assumptions might have concealed root causes: __________

4.16 resistance might have occured from people suspicious of change: __________

4.17 the problem was formulated under the influence of a solution technique: __________

4.18 the *real* objectives might have been hidden accidentally, unconsciously, or deliberately: __________

4.19 root causes might be present in other unidentified systems, frameworks, or structures: __________

4.20 the formulated problem may be out of date: __________

If results are prescriptive, skip to question 8.

5. Do you know or can you think of any decision makers, other than the ones identified by the analyst, who might be aided by the solution of the problem?

   a) Yes b) No If yes, list them.

6. Do you agree that the decisions to be made by the decision makers are correctly identified?

   a) Strongly agree b) Agree c) Disagree d) Strongly disagree

7. Do you agree that the decision makers' needs for making the decisions are completely and correctly identified?

   a) Strongly agree b) Agree c) Disagree d) Strongly disagree

   Skip to question 19.

8. Are there any alternative sets of possible outcomes generated by the analyst that, you believe, are unacceptable to the decision makers or cannot be implemented?

   a) Yes b) No If yes, list them and give a rationale for each of them.

9. Do you know or can you think of any other alternative sets of possible outcomes which would be acceptable to the decision makers?

   a) Yes b) No If yes, list them and explain each in detail.

10. Do you know or can you think of any relevant decision makers, other than the ones identified by the analyst, who may influence the acceptability of any one of the alternative sets of possible outcomes?

   a) Yes b) No If yes, list them.

11. Do you know or can you think of any relevant decision makers, other than the ones identified by the analyst, who may cause the rejection of any one of the alternative sets of possible outcomes by way of strong objections or counteractions against its implementation?

   a) Yes b) No If yes, list them.

12. What are the chances (in terms of a percentage, i.e. 5%, or a range of percentages, i.e. 4% - 6%) that the ith (i = 1,2,...,I) alternative set of possible outcomes is rejected due to the possibility

% or % range of chance for the ith alternative

12.1 that a key decision maker to whom the ith alternative is not acceptable might have not been identified: ____________

12.2 that the ith alternative might have been unacceptable due to the substantial changes occured in the problem context: ____________

12.3 that the analyst might have failed to interact with the decision makers during the process of problem formulation: ____________

12.4 that an important element of the problem context might have been excluded from the ith alternative: ____________

12.5 that an important alternative set of possible outcomes might have been ignored: ____________

12.6 of strong objections or counteractions against its implementation: ____________

12.7 of its high cost of implementation: ____________

12.8 of its unacceptability to a key decision maker: ____________

13. Do you know or can you think of any other constraints which should have been identified by the analyst?

a) Yes b) No If yes, list them.

14. Are there any incorrect or irrelevant constraints?

a) Yes b) No If yes, list them.

15. Are there any constraints which make the formulated problem infeasible to solve?

a) Yes b) No If yes, list them.

16. How well do the objective function values represent the attainment of the objectives?

a) Excellent b) Good c) Fair d) Poor

17. Do you know or can you think of any relevant decision makers, other than the ones identified by the analyst, who would not accept the objective function(s)?

a) Yes b) No If yes, list them.

18. Do all the decision makers involved accept the objective function(s)?

a) Yes b) No If no, list the ones unacceptable with respective decision makers.

19. How clearly are the objectives stated?

    a) Very clearly b) Clearly c) Unclearly d) Very unclearly

20. Do you believe any objectives to be inconsistent, ambiguous, or conflicting in any way?

    a) Yes b) No If yes, list them and explain in detail.

21. How realistic are the objectives?

    a) Very realistic b) Realistic
    c) Unrealistic d) Very unrealistic

22. Are there any priorities specified for the case where only some of the objectives are achievable?

    a) Yes b) No

23. Do you know or can you think of any relevant decision makers whose objectives are conflicting with any one of those specified?

    a) Yes b) No If yes, list them.

24. In case of multiple objectives, do you agree with the way the objectives are weighted?

    a) Strongly agree b) Agree c) Disagree d) Strongly disagree

25. Do you agree that the stated objectives are the *real* objectives of the decision makers involved?

    a) Strongly agree b) Agree c) Disagree d) Strongly disagree

26. Do you know or can you think of any associated objective which is disguised or hidden either accidentally, unconsciously, or deliberately?

    a) Yes b) No If yes, list them.

27. How often could the stated objectives change?

    a) Always b) Usually c) Sometimes d) Seldom e) Never

28. How sufficient are the stated performance measures for attaining the objectives or for making the decisions?

    a) Very sufficient b) Sufficient
    c) Insufficient d) Very insufficient

29. Do all the decision makers involved accept the performance

measure(s)?

a) Yes b) No If no, list the ones unacceptable with respective decision makers.

30. Do you know or can you think of any relevant decision makers, other than the ones identified by the analyst, who would not accept the performance measure(s)?

a) Yes b) No If yes, list them.

31. Are there any sources of data and information used by the analyst that you believe to be unreliable?

a) Yes b) No If yes, list them.

32. Are there any data and information used by the analyst that you believe to be out of date or need to be updated?

a) Yes b) No If yes, list them.

33. Are there any data and information which you believe to be not sufficiently accurate?

a) Yes b) No If yes, list them.

34. Are there any invalid assumptions?

a) Yes b) No If yes, list them and give a rationale for each of them.

35. Are there any invalid inferences or conclusions drawn by the analyst?

a) Yes b) No If yes, list them and give a rationale for each of them.

36. How clearly are the requirements for the certification of credibility of the results stated?

a) Very clearly b) Clearly c) Unclearly d) Very unclearly

37. Do you know or can you think of any relevant people, other than the ones identified by the analyst, who may influence the certification of the credibility of the results?

a) Yes b) No If yes, list them.

38. Do you know or can you think of any other certification requirements appropriate to specify in the formulated problem?

a) Yes b) No If yes, list them.

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