A Methodology for Evaluating
Potential KBS Applications

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SUMMARY

It is often difficult to assess how well Knowledge-Based Systems (KBS) techniques and paradigms may be applied to automating various tasks. This report describes the approach and organization of an assessment procedure that involves two levels of analysis. Level One can be performed by individuals with little technical expertise relative to KBS development, while Level Two is intended to be used by experienced KBS developers. The two levels review four groups of issues: goals, appropriateness, resources, and non-technical considerations. Those criteria are identified which are important at each step in the assessment. A qualitative methodology for scoring the task relative to the assessment criteria is provided to allow analysts to make better-informed decisions with regard to the potential effectiveness of applying KBS technology.

In addition to this documentation, the assessment methodology has been implemented for personal computers use using HYPERCARD™* software on a Macintosh™* computer. This interactive mode facilitates small group analysis of potential KBS applications and permits a non-sequential appraisal with provisions for automated note-keeping and question scoring.

This work was performed for DOE/OAC/S&T under Advanced Concept Funding. The results provide a useful tool for assessing the feasibility of using KBS techniques in performing tasks in support of treaty verification or IC functions. The points of contact for further information are Mr. Doug Downen, DOE-HQ, FTS 896-2123, Dr. Lou Martucci, PNL/ONST, FTS/Commercial 509-375-2112, or Dr. Ronald B. Melton, PNL, FTS/Commercial 509-375-2932.

* HYPERCARD and Macintosh are trademarks of Apple Computer, Inc.

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A METHODOLOGY FOR EVALUATING POTENTIAL KBS APPLICATIONS

1.0 INTRODUCTION

It is often difficult, in analyzing potential KBS applications, to assess the match between the task or tasks involved in a particular application and the current state of the art in KBS development paradigms and techniques. It is not unusual for KBS practitioners to invest significant time discussing a potential application before discovering properties that make it an undesirable candidate for the application of KBS technologies.

Artificial intelligence literature contains little advice to assist in identifying those tasks with a high potential for successful KBS solutions. The bulk of this information typically is reported in short lists of "tips" for analyzing KBS applicability or for expediting KBS development. Prerau (1985) provides a more organized approach by grouping lists of questions, with a short paragraph of discussion for each, such that an organization selecting among several potential expert system applications may choose the one or ones that offer the greatest potential for success. Also of interest is Kline and Dolins (1985), who present a series of "Probing Questions" intended to assist KBS developers in relating task characteristics to specific KBS techniques, representations, and methodologies.

This report describes a two-phase technique for assessing potential KBS applications. It may be used by individuals with various levels of technical competence in KBS technologies. For example, higher level managers might use this procedure prior to discussing applications with their development staff, or technical development staff might use it to make a detailed assessment of the important issues for a given problem task. Suggestions for using this procedure are given in section 1.4.

1.1 APPROACH

This report takes a slightly broader view than most of the referenced literature, in looking at the more general topic of KBS. It provides two levels of questions, designed to identify and elucidate the characteristics of a task that are important in deciding whether to initiate a development effort.

This procedure assumes a primarily end-product orientation to the KBS application analysis. Any ultimate success or failure is therefore defined in terms that may be reduced to production end-use, such as productivity, speed, efficiency, accuracy, consistency, and

related measures. The goal of the KBS development effort is assumed to be a viable system for production use.

The procedure is based on criteria and "tips" described in the artificial intelligence (AI) literature. Some of these are mentioned explicitly and are referenced to their sources. Others are indirectly mentioned or are strongly implied. Issues that are salient at more than one point in the decision process are mentioned more than once. It should be noted that on some issues the literature offers conflicting advice. In such cases suggestions are given based on the authors' experience about which view might be most appropriate to the particular assumptions made herein about KBS goals.

Many of the information in the literature is oriented specifically toward the development of expert systems. Since this report takes the somewhat broader view of knowledge-based systems, some of the referenced advice has been generalized when appropriate. For example, discussions about the accessibility of experts may reasonably be generalized to the accessibility of other knowledge sources (KSs) as well.

The organization of topics presented here is intended to provide a roughly sequential procedure that may be used in assessing potential tasks for KBS applications. This sequence enables the analyst to make early determinations about whether KBS techniques are inappropriate and disadvantageous in solving the task under consideration.

1.2 OUTLINE

This paper is organized in four sections. The first includes the introduction and describes the approach, outline, terminology, and directions for using the procedure. The second and third sections form the core of the analysis procedure, with one section for each of the two levels of analysis. The final section includes material on scoring and interpreting the results of the analysis, a description of the next steps to be taken in a KBS development effort, and conclusions.

1.3 TERMINOLOGY

The term *expert systems* appears frequently in both the AI literature and in common use. However, this term has very different meanings to different people. It is often understood by non-technical management, for instance, to indicate a level of intelligent performance for a special type of computer technology. Within the context of this report,

the term "expert" will refer only to one of the possible sources of problem-solving knowledge, rather than indicating any level or quality of performance or intelligence.

The term *knowledge-based systems*, on the other hand, is used here to describe the technologies associated with systems that draw their power from their (mostly) explicit representation of problem-solving knowledge. While *expert systems* and *knowledge-based systems* are often used synonymously, KBS may be viewed as a super-class of expert systems. For example, an expert system would typically involve the capture of a human expert's behavior, frequently in the form of inference rules, while a KBS might include many other forms of knowledge, such as knowledge about the physical or functional behavior of objects in a model. The scope of this work is the applicability of KBS.

KBS technologies are generally applied to automate some form of human problem-solving behavior or task. Throughout this report the terms *task*, *problem*, and *problem-solving task* are used interchangeably to refer to this target behavior rather than the work involved in implementing the automated KBS solution. Capturing this target behavior is referred to as the *solution* or *development effort*, as opposed to the *result* which is used herein to mean the set of decisions, inferences, or results of applying the problem-solving behavior to a specific case or set of data.

1.4 SUGGESTIONS FOR USE

This procedure leads the analyst through many salient issues. The majority of these issues are designed to identify task characteristics that indicate an inappropriate or unwarranted use of KBS techniques. Several issues, however, lend positive support to the use of a KBS approach. In addition, some indicators should be given greater import than others. The indicators therefore require orientation (positive or negative) and strength (weak or strong).

A scoring box is associated with each issue. The scoring boxes have five sections, with "++" being the strongest positive indication, "--" the strongest negative indication, and "." indicating that the evidence is inconclusive. Each of the questions may have a different potential for affecting the final outcome, and some scoring indications may be inapplicable. These inapplicable sections are "grayed out". The use of graying for individual issues is largely judgmental and therefore may be altered by the user to meet specific organizational goals. An empty weight box enables the analyst to assign weights to the criteria based on organization-specific goals and any known constraints.

For example, there is no possible response to the following question (from section 2.4) that will lend strong positive support for KBS development.

- *Are there any situations that are expected to impede solutions?*

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Since no strong positive indication is possible, the “++” indicator box is grayed out. In a typical case, where no problem situations are foreseen or expected even after thorough study and soul-searching, the response here would be “+”. The same conclusion after less analysis, might yield a response of “•”; i.e., inconclusive.

Although a weight box has been included with each scoring box, the use of weights generally is not recommended. Rigorously applying quantitative methods to fuzzy and ill-defined concepts, such as those presented here, can lead to misleading results. The individual weight boxes should be used only in unusual circumstances, and only when the analyst has a fair amount of experience with the checklist procedure. For example, when the goal of the analysis is to identify the best among a number of possible KBS applications and the first pass through the analysis procedure has proven inconclusive, the weights may provide an additional means for differentiating between various candidates.

2.0 LEVEL ONE - MANAGEMENT ANALYSIS

The top-level analysis should be performed by a management or resource allocation team, with the consultation of an experienced KBS developer or technical manager. The goal of the analysis at this level is to initially examine those factors that would indicate the appropriateness of using KBS technology in solving the particular problem.

In analyzing any potential KBS application, there exists one fundamental question which must be answered before proceeding with any development effort:

- *What is the probability of success for a KBS solution to the problem task?*

This is essentially the same fundamental question asked in analyzing the potential for any "traditional" computer systems approach to a problem. Answering this question involves the intelligent merging of the answers to four additional questions:

- *What is the definition of success?*
- *Is the KBS approach appropriate for the task?*
- *Are the necessary resources available?*
- *Are there any non-technical impediments to the development of a KBS solution?*

Each of these questions is addressed in the following sections.

2.1 DEFINITION OF SUCCESS

The first of these questions is easiest to answer, and should not be overlooked. The management team must be able to define what constitutes a successful solution to the problem task. The definition of success may be viewed in terms of several additional questions.

- *Are the goals of the activity clearly defined and are the objectives of the KBS development effort clearly stated?*

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The absence of well-defined goals and objectives often leads to failure. The existence of well-defined goals and objectives enhances the likelihood of achieving success.

- *Has a clear definition of success been delineated?*

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The lack of a workable definition of success creates an environment conducive to failure. System developers, users, and management do not know exactly what to expect the KBS to do, and will not know when it is "done". The better the workable definition of success, the better the likelihood of achieving success.

- *How well are the activity goals aligned with organizational goals?*

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Attempting to solve a problem that is not well aligned with organizational goals often leads to failure. Over time, many of the essential personnel will assign low priority to any task that is recognized as not in tune with organizational goals. Attempting to solve a problem that is well aligned with organizational goals enhances the likelihood of achieving success. Considerations such as organizational or activity goals, task requirements, and resource constraints have a significant impact on the decision to invest in the development of a KBS. These same considerations are also important in problem solutions involving traditional software engineering.

- *To what extent are the advantages associated with the KBS technologies compatible with the project goals?*

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Any such advantages should be related to the definition of success and contribute directly to the project goals. Several of the benefits typically associated with successful KBS application development are as follows:

- rapid prototyping, with related benefits of early testing of conceptual design and early feedback from users
 - “explicit” knowledge encoding
 - ease of modification
 - availability of dynamic, efficient development tools
 - explanation capabilities within the KBS, for development and validation as well as for fielded operations
 - capability for rapid inclusion (present or future) of newer technologies, such as learning techniques.
- *Is the objective of the KBS system clearly defined as either:*
 - actual use (a production system), or*
 - major new advances in the state of the art for KBS (a research system)?*

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Either objective a) or b) is acceptable, but not both a) and b) at the same time (Prerau 1985; Smith 1984). Attempting to do both will tend to defocus the effort while adding complexities that impede progress. A clear tendency toward either of these objectives will indicate strong positive support, while uncertainty or attempting to do both will indicate negative support.

- *Is the motivation for using computer automation, and the motivation for considering a KBS approach, well-formed and defensible?*

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Since this study is directed primarily toward practical use of KBS applications, success is defined in terms that may be reduced to return on investment. In practice, success or favorable return on investment may be measured by comparison to conventional computer-based solutions, or to manual, non-computer based techniques. Measures of success may include financial, technical, educational, research, or political criteria. For a KBS project to succeed, the organizational concern must be the proper application of KBS technology to appropriate problems. The measures of success selected by the organization should form the basis for answering this question. KBS managers tend to push for KBS solutions and KBS staff tend to look for "interesting" problems. These motives may conflict with the organizational goal of cost-effective solutions to important problems

- *To what extent do conventional computing techniques appear to be unsuitable or inadequate for solving the problem?*

++	+	•	-	--	
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Have such techniques been tried? If so, and the effort was unsuccessful, what caused the failure? Can a KBS approach overcome the causes of the failure? If the problem can be solved successfully using conventional techniques, then a KBS approach is not generally recommended.

- *To what extent is there a need to capture the expertise?*

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This may be due to the scarcity or expense of human expertise or knowledge, or to a perceived over-dependence on overworked experts. The need may be current or projected (Prerau 1985). Obviously, the greater the perceived need for capturing the problem-solving knowledge, the more committed the organization will be to supplying the resources required for the development effort.

- *Is the beneficial outcome important enough to warrant the cost of the KBS solution?*

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In other words, is the cost of using KBS technology going to exceed any potential benefits? This is the standard cost/benefit question. If the objective of the KBS development effort is a practical use system, this is a crucial question.

2.2 APPROPRIATENESS OF KBS TECHNOLOGY

Determination of appropriateness involves analysis and characterization of the particular task under consideration. An analysis or characterization process may not be well understood by the user. Current techniques are typically empirical in nature, although there are some formal task characterization approaches. Another difficulty faced in assessing appropriateness of the KBS technology is identifying when the KBS is "completed". Without an end point, the analyst cannot adequately define success, determine the best problem-solving approach, nor estimate the resources required for the development effort.

While "appropriateness" is a difficult issue to address without a detailed technical analysis, several questions may be asked at this level to roughly determine a measure of appropriateness.

- *How necessary is the KBS approach?*

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Are conventional programming techniques adequate? Have they been tried in previous attempts to solve the problem? Conventional techniques are preferred whenever they are adequate to solve the problem, because they are better understood, easier to manage, and entail a generally lower risk. However, if the problem task is characterized largely by the use of expert knowledge, judgement, and experience, the KBS approach may be appropriate for further study (Prerau 1985).

- *How sufficient is the KBS approach?*

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Is the problem too difficult for the current state of KBS technology, or does it involve a problem that is not well suited to KBS techniques? Although this question may require good technical understanding of KBS, it is useful to determine whether any parts of the task have caused difficulties for KBS development efforts in the past (Buchanan et al. 1983). Tasks such as natural language processing, spatial modeling, causal relations, commonsense reasoning, and image understanding are generally regarded within the KBS community as "hard" problems, for which no fully adequate techniques or solutions are known.

The answers to both of these questions can be roughly determined by asking two related questions.

- *How "similar" is the task to another task for which a successful KBS solution exists?*

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Research into the similarities between the candidate task and other tasks addressed by previous KBS efforts, together with an estimation of the success of those efforts, will provide additional insight into the appropriateness of KBS techniques for the candidate task. The difficulties occur in defining the concept of similarity and understanding the task at this point in the checklist. The Level Two analysis will address this question in more technical detail. In general, when the candidate task exhibits the same basic characteristics as another task which has a previous, successfully developed KBS, the Level One analyst may assume that the candidate task is appropriate for a KBS solution.

- *How "similar" is the task to another task that has caused problems for previous KBS?*

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Another important clue in assessing appropriateness is similarity to previously unsuccessful KBS efforts. While unsuccessful attempts are difficult to find in the

literature, there are several general types of problems that are known to be difficult. These problems are discussed in the sufficiency question above and are further discussed in sections below. Negative support is indicated to the extent the task can be recognized as fundamentally similar to a previously unsuccessful KBS effort. For example, two different tasks from the medical field may be similar only in their terminology, while the problem-solving techniques required may differ significantly.

2.3 AVAILABILITY OF RESOURCES

Fundamental questions must be asked before proceeding to the detailed analysis. Each resource necessary to the development effort must be estimated.

- *How available is the necessary knowledge from the user group?*

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- *How available is the necessary knowledge engineering expertise from the KBS development group?*

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- *How available is the necessary technical and management manpower from both user and development groups?*

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- *To what extent is the necessary funding available, for hardware and software tools and related support, for training staff as necessary, and for building, validating, and fielding the final product (if required)?*

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These questions imply that the required resources are known. While complete information is not known at this point in the analysis, some estimation can reveal whether to proceed with KBS development or another option.

2.4 NON-TECHNICAL CONSIDERATIONS

It is possible for a candidate task to be technically appropriate for the application of KBS methodologies, but decidedly inappropriate due to other considerations such as funding or legal implications. Other questions common in traditional decision-making also must be asked.

- *How prepared is the organization to develop KBS?*

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Negative support is indicated if the project is the development organization's first venture into KBS application building. Stronger negative support is indicated if the project is also the user organization's first venture into KBS application building. If the development organization has extensive KBS experience, the user organizations' lack of KBS experience is not critical. Consider how successful previous KBS development efforts have been in assessing the development organizations' preparedness, and the user organization's enthusiasm. It is important to measure the probability for success in view of past history. A development team's first attempt at applying KBS techniques is less likely to succeed than subsequent attempts. In addition, management may choose to view a single unsuccessful attempt as an asset rather than a liability, since it provided a learning experience.

- *How important is this problem?*

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Do experts agree on the importance of the problem? Does management agree on the importance of the problem? Would experts, management, and end users support the KBS development and fielding efforts? The definition of *important* must be closely related to the definition of success, as discussed above. For research-oriented problems, there should be a consensus among task experts that the candidate task is important. For practical use applications, the management view of the problem is very critical. Establishing management support inherently stems from the continuity of the problem's importance over time.

- *Are there any situations that are expected to impede solutions?*

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For example, a commonly occurring situation is related to political turf battles within the organization.

- *Are the assumptions and constraints of the project well-formed, realistic, and defensible?*

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It is important that project assumptions and constraints be made explicit. Look for unrealistically optimistic assumptions, which can negatively impact success, and “artificial” constraints, which can positively impact the development project when clearly identified *and removed*. An example of a common, unrealistic assumption is that the KBS project can be managed using conventional top-down analysis techniques. Due to the generally ill-defined nature of the problems that are commonly solved using KBS, a more flexible approach is required with regular review of project scope, objectives, and budgets. An example of an artificial constraint is that the development of the KBS on a personal computer could require that it be fielded on a like computer.

- *How realistic and defensible are the economic, ethical, and legal considerations of the project?*

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Each of these considerations may indicate an inappropriate business or legal environment for further consideration of the candidate task. While a detailed discussion of these factors is beyond the scope of this report, it is important to include them in the analysis. For example, return on investment would be a major consideration for an industrial corporation, while legal and ethical considerations might be more important for a medical laboratory.

- *What is the match among the overall goals between project payoff and the risk of failure?*

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Another economic consideration is the relationship between expected payoff (success) and the projected risk of failure. In assessing the applicability of KBS technology to candidate problems, KBS applications analysts must carefully consider the risks involved in undertaking a KBS development effort. When the potential for failure is high, based on the criteria described in this report, and the expected payoff in the event of success is not correspondingly high, the candidate task may not be an appropriate choice.

- *Will the KBS meet a real need?*

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If a goal of the KBS development effort is an operational system, and it is not clearly identified to satisfy a real need, there is a high probability that the system will produce a low payoff. This is not consistent with the assumed goal of favorable return on investment.

- *To what extent is the system politically sensitive or controversial?*

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Will the introduction of the system, the knowledge contained in the system, or the system's results be politically sensitive or controversial? Sensitivity and controversy issues can cloud the success of the KBS effort, often as late as during the fielding phase. It is therefore necessary to consider these issues before development begins. Sensitivity and controversy can be related to the systems users, experts, lower or middle management, and upper management. KBS development efforts open the expert's thinking to outside scrutiny and possible attack. Users may fear that their jobs and/or their status are in jeopardy. Management may fear exposure of proprietary data, results, and/or decision-making methods. Management may also fear that they will lose control of the decision-making process, and thereby reduce the quality of decisions. Finally, users, experts, and management may all be concerned that the KBS will be unable to adequately consider political or other similar subtleties in formulating decisions. While it will not be possible to

avoid these issues completely, KBS efforts faced with potentially serious problems in any of these areas may be poor candidates.

3.0 LEVEL TWO - DETAILED ANALYSIS

If no overwhelmingly negative responses have been identified during the Level One analysis, the next step is Level Two, a more detailed technical analysis of the candidate task. The four major topics discussed above provide the foundation for this analysis as well.

The Level Two analysis should be performed by an experienced KBS project leader and a project team consisting of appropriate technical staff with a range of skills and expertise covering KBS development, the application domain, software engineering, and project management.

3.1 TASK APPROPRIATENESS

Given the preliminary inclinations toward necessity and sufficiency, as determined in the Level One analysis, the basic question of appropriateness remains to be answered definitively:

- *Is the candidate task an appropriate one for the use of KBS technologies?*

Appropriateness issues must be addressed on several fronts. The nature and source(s) of the problem-solving knowledge used in performing the task and the case-specific data related to the task (Buchanan et al. 1983) are critical. The characteristics of the task itself are fundamentally important. These topics are discussed in greater detail below.

3.1.1 Problem-Solving Knowledge

Assessing the appropriateness of the problem-solving knowledge involved in a task involves analysis of both the source of the knowledge and the nature of the knowledge itself.

3.1.1.1 The Source of the Knowledge

Knowledge is the essential source of problem-solving power in KBS programs (Davis 1984). The process of constructing a KBS program, commonly known as knowledge engineering, involves an iterative technique of acquiring knowledge from one or more sources and representing it so that it may be processed by a computer. This effort includes isolating, identifying, obtaining, understanding, and organizing the knowledge

prior to encoding. A knowledge source (KS) may be a human expert, but this is not always the case. For some applications problem solving knowledge is developed through systematic analysis of the problem domain. In the following, we use the term KS when it is not clear that the source of knowledge is necessarily a human. The term expert is used to indicate that the source of knowledge is a human.

Knowledge acquisition is critical to the success or failure of a KBS project. Thus, the ease with which knowledge may be acquired and subsequently represented is a key issue. The issues described below will help to determine the availability, accessibility, and quality of the knowledge required for the task under consideration.

- *Does the knowledge exist?*

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If the knowledge required in the problem-solving behavior is non-trivial, and it does not yet exist in any form, the development effort necessarily must include the generation and formulation of this requisite knowledge. This will add significantly to the overall magnitude of the KBS effort, and can reduce the chances of success if major uncertainties exist.

- *Have the knowledge sources been explicitly identified?*

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Knowledge may come from a number of different sources. Most commonly discussed in the AI literature is knowledge derived from a human expert. Other sources may include textbooks (a special case of expert knowledge) and related documents; also, automated data analysis, learning, and discovery programs. Many projects will involve knowledge from a combination of these sources. In any case, it is critical to identify the location(s) of the knowledge prior to beginning any development efforts.

- *Does at least one recognized expert exist today?*

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If there are no current experts, i.e. human knowledge repositories with self-modifying explanation and teaching capabilities, the success possibility for any KBS or

expert system is highly questionable. The expertise, experience, and energy provided to the development effort by the interaction and constructive critique of a human with recognized problem-solving skills are practically indispensable.

- *Is the expert's level of expertise and base of experience sufficient?*

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The prevailing view in the literature is that the knowledge source, or expert, must exhibit a high level of expertise in performing the problem task. Expertise is generally related to the difficulty of the task, the ability of the expert to effectively solve the problem, and the amount of experience brought to the task by the expert. An adequate period of experience may be measured in tens of years. For tasks more oriented toward analytical reasoning, an adequate period may be measured in tens of months. The underlying point is that the knowledge source must have whatever degree of practical experience is necessary to efficiently handle the intricacies of real-world problems in typically noisy or otherwise difficult environments. Without this experience, the KBS may be improperly biased or ineffective in performing the problem-solving task.

- *Are the experts provably better than beginners in performing the task?*

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If not, the candidate task may be trivially simple, and therefore not appropriate for a KBS approach. In general, if the "expert" is no better at performing the task than are amateurs and novices, the KBS technology may be inappropriate or the chances of success may be reduced greatly.

- *Is the expert currently practicing in the selected task?*

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The expert (source of knowledge) should be currently active in the field. If not, he may be out of touch with current practice.

- *Does the KS have a reputation within the field that will lend credibility and authority to the KBS, even if it is able to capture only a portion of the knowledge?*

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If the KS lacks credibility or authority within the field, the resulting KBS similarly will lack credibility and authority. Without these, the results produced by the KBS will be viewed by the users with greater suspicion, and the possibilities for any success within a production use environment will be seriously compromised.

- *Does the expertise for each task or subtask come from a single expert?*

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The number of experts that will be involved in the KBS development effort is an important factor. The “traditional wisdom” is that a single expert or KS should be used to avoid inconsistencies, incompatibilities, and disagreements (Prerau 1985). However, some researchers and practitioners have reported that success is *best* served by including as many experts as possible, at least at the initial stages of KBS development (Mittal and Dym 1985; Smith 1984). Sorting out the arguments on each side of this issue requires several additional questions. Scoring this question, therefore, should wait until the following questions have been evaluated to help determine which of these two approaches would be best-suited to the task at hand.

- *Is the knowledge resident in individuals or is it a community involvement?*

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In many situations, multiple experts are required to solve the overall task. In such cases the KBS development also must use more than one KS. The traditional wisdom suggests that one of the KSs (typically a human expert) should be given the final authority for decision-making in order to resolve conflicts among the KSs (Prerau 1985). If a multiple expert requirement is indicated, this question should be scored negatively when numerous individuals are needed, when the requisite number of experts is not available to the KBS effort, or when the available experts and KSs do not work well together.

- *Do various KSs use essentially the same approach, or is there a significant difference or idiosyncratic variability?*

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Usually, the existence of multiple approaches will indicate negatively, but this is not always true. For example, when multiple experts solve the same essential problem, but with varying specializations or goals, it is advantageous for the KBS developers to include an initial review of each approach in order to gain a broader understanding of the problem. This should effectively reduce the possibilities of taking an overly-narrow view of the problem task or of missing the most efficient problem-solving approach, due to using a KS with a single perspective and approach. It is important to determine if the different approaches are equally valid. On the other hand, it indicates positively when the initial analysis determines that all the KSs use very similar approaches. In such cases, the KBS developers may choose to focus on just one KS in order to reduce the costs of the development effort.

- *At the outset of the project, is the expert able to specify many of the important concepts?*

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If the expert has difficulty in specifying important initial concepts, he might have difficulty in analyzing or communicating his/her problem-solving knowledge during later knowledge acquisition efforts. That is, the expert must be able to communicate his expertise at conceptual and detailed stages. However, a negative score for this question can be generated inappropriately from too casual initial contact. Some highly skilled experts will not react gracefully to interruptions from (what they consider) fools, novices and rank amateurs who are unable to ask pertinent questions. If the score indicates negatively, consider how the initial contact with the expert was arranged and conducted.

- *Is the KS cooperative, analytical by nature, and effective in communicating knowledge, judgment, experience, and methodology?*

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Unless the KS can effectively communicate, is cooperative, and easy to work with, a successful KBS development effort will be difficult to achieve. In addition, an expert with an analytical nature can prove valuable when the development effort requires improvisation relative to the expertise. The analysis team must assess the candidate expert(s) for these factors as a part of the process. Typically, this will involve a review of the individuals' past performance and work record, and preliminary interviews. Each of these factors impacts the knowledge engineering work, which accordingly impacts the overall KBS development effort. It is important, however, to judge these characteristics cautiously, since early impressions are not always accurate. Also, problems with the expert can sometimes be attributed to a lack of appropriate training on the part of the knowledge engineer (Forsythe 1987).

- *Is the expert and his/her management willing to commit the necessary resources to KBS development?*

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A commonly reported difficulty in the development of KBS involves the availability of the KS. Demands upon a human expert's time are frequently overwhelming. This tends to keep the expert overworked and effectively unavailable at critical points in the KBS development effort. Often, when conflicts or questions arise during development, the expert is not available for consultation, thereby hampering progress. Adequate commitments should be obtained from experts and his/her management as a pre-condition for a KBS development effort.

3.1.1.2 The Nature of the Knowledge

- *How much knowledge is involved?*

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It has been suggested that the amount of knowledge involved should be enough to make an “interesting” knowledge base (Prerau 1985; Stefik et al. 1983). Although the definition of “interesting” is ambiguous, the quantity of knowledge present must clearly indicate that the problem task exceeds the threshold of using sophisticated techniques to solve trivial problems. However, there are some types of data-intensive problems where the degree of interest depends more on the type and amount of data involved in the task than on the amount of knowledge required. In such cases, a relatively small amount of knowledge can be both very useful and very profitable (Laufmann 1988). Section 3.1.3 and Figure 3.1 discuss this in more detail. Thus, either too much or too little knowledge can indicate a negative score, while a moderate amount is more appropriate.

This raises the question of how to quantify knowledge. Some subjective techniques that can reasonably be performed at this point in the analysis, include measuring the amount of time or the amount of training and experience that a human problem-solver requires to perform the task.

- *To what extent is the knowledge diverse, incomplete, fragmented, inexact, ill-specified, unreliable, or in flux?*

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Each of these characteristics can adversely impact a KBS development effort. In general, any condition that reduces the quality, the consistency, or the accessibility of the knowledge will create difficulties in the KBS development effort. In addition, problems such as incomplete knowledge typically require relatively expensive solution techniques (Kline and Dolins 1985). If none of these attributes are found to any appreciable degree, a strong positive indication is warranted. However, such a finding should prompt a review of the need for a KBS approach.

3.1.2 Case-Specific Data

The nature of the data that is specific to any particular case over which the task must be performed is likewise a critical part of the overall analysis of task appropriateness. This is a common software engineering issue, and the interested reader is referred to the software engineering literature for additional information. However, a few of the most critical issues must be addressed here. In general, the analyst must undertake some effort to characterize the data, especially with regard to its reliability, variability, and amount.

- *How reliable is the data?*

Noisy or unreliable data can significantly complicate testing, tuning, validation, and fielding efforts.

- *To what extent does the data vary with time?*

The additional dimension of time can complicate the development process. Time variability can indicate instability in either the data or the task, and frequently necessitates the addition of temporal reasoning techniques to the KBS.

- *How much data is involved?*

The bulk of data involved in heavily data-intensive tasks may make otherwise simple KBS efforts more difficult, due to the requirements for reviewing, compressing, or summarizing. However, data-intensive tasks are typically those that humans have the greatest difficulty solving effectively. The potential for a successful KBS therefore may be higher for some tasks involving a large quantity of data (Laufmann 1988).

3.1.3 Knowledge/Data Comparison

- *What are the relative quantities of problem-solving knowledge and case-specific data involved in the task?*

Quantifying the case-specific data and the problem-solving knowledge required for the candidate task can be difficult. A rough determination of each can enable a qualitative comparison of the relative amounts of data and knowledge involved in solving the problem task. KBS developed for problems involving relatively small amounts of knowledge applied to large amounts of data may provide an attractive opportunity for near-term success. Figure 3.1 shows a qualitative comparison of these two task characteristics (Laufmann 1988). The measures for knowledge and data used in Figure 3.1 serve only to promote understanding. The measure for knowledge is suggested as the simple conditions in the antecedent clauses of a rule-based system. Highly complex consequent clauses or significant amounts of knowledge in other forms will tend to invalidate this measure. The measure of data is suggested as the number of bytes of stored data. If, as in many database systems, only a small portion of this data is actually processed in problem resolution, then this is not a good measure. Therefore, these units of measure are not suggested as valid metrics to determine the amount of knowledge or the amount of data for knowledge-based problems in general. Instead, appropriate units of measure must be determined for each specific problem. It is the relative amount of appropriately measured knowledge and data that permits insight into the potential for exploiting KBS technology.

3.1.4 Task Characterization

This section specifies a two-step process for identifying salient task characteristics and assessing their impact on KBS applicability to the task under consideration.

1. Define and bound the problem-solving task to be considered.
2. Determine the nature and complexity of the task.

FIGURE 3.1. A Qualitative Comparison of Case-Specific Data vs. Problem-Solving Knowledge

At each step a series of questions are given to assist in determining task appropriateness. Each step requires a considerable degree of study, so organizations with a large number of candidate tasks may wish to identify just a few by more strictly applying the criteria discussed in Level One, or using the other criteria identified in sections 2 and 3 of Level Two.

3.1.4.1 Task Definition and Bounding

The first step in task characterization is to carefully define and adequately bound the specific task under consideration. Development efforts that fail to adequately address this definition and bounding step can be expected to experience difficulties.

The task must be of the right basic type, size, and difficulty level for KBS technology. The task must be neither too easy for KBS technology, nor too difficult. The basic issues of necessity and sufficiency must once again be addressed, this time in greater detail. These include issues such as:

Have conventional, algorithmic programming approaches alone proven unsatisfactory?

How long does it take a human to perform the task?

How much specialized training differentiates the human expert or KS from a non-expert?

While it is not easy to gauge the difficulty or complexity level of a task, especially before a solution is developed, several questions may provide insights into these issues.

- *Is the task defined clearly and unambiguously, with a precise definition of the inputs and outputs?*

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While the definition of the task may be refined over the course of the development effort, if the task cannot be defined clearly, including inputs and outputs, during this analysis phase, a major element of confusion is introduced. Related questions, that may help to determine if the task is well-defined, are as follows:

- *Is the skill required by the task taught to novices, or is the field or task discussed in books or other written materials?*

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Whenever a candidate task has been either discussed in textbooks or taught to novices, the problem-solving task is probably well understood. While this does not indicate that the KBS development effort will be trivial, it does reduce the likelihood of serious unforeseen problems later in the KBS development process.

- *How stable is the task definition?*

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If elements of the task or the task domain are in a state of rapid growth or change, whereby the task definition is likely to be modified during or immediately following the development effort, the task may be a poor candidate for KBS development.

- *How well-bounded and narrowly defined is the task?*

Although these issues seem obvious, they are often neglected because KBS clients and management often have unrealistic expectations. In practice, the candidate task must be both narrowly defined and adequately bounded before development efforts begin. Otherwise the scope of the KBS development project will be difficult to control and success will be similarly difficult to achieve. A practical rule-of-thumb is that the number of concepts or rules involved in the problem-solving should be limited to several hundreds at most (Buchanan et al. 1983; Prerau 1985).

- *Is the task largely and effectively separable from its contextual tasks?*

This is directed at the separability of the candidate task from other “adjacent” tasks in the overall context of the problem. This may include either the processing context, the human problem-solving context, or both. If the candidate task is intricately linked to other kinds of knowledge and problem-solving behaviors which are not part of the candidate task, the opportunity to effectively and efficiently implement and field the KBS solution will be severely reduced. However, if the candidate task can be described as self-contained, there is a reasonable chance for success (Mittal and Dym 1985; Prerau 1985; Stefik et al. 1983).

- *How decomposable is the task?*

If the task can be decomposed into a number of component subtasks, each task may be prototyped individually. This will normally increase development efficiency by reducing the overall task complexity. If the task is large and cannot be decomposed in a relatively straightforward manner, the chances of success will be slightly reduced, depending on other factors. One rule of thumb, used by many software engineers, is to target decomposition toward units of tens of rules and/or one-page units of code.

3.1.4.2 Task Complexity and Characterization

Once the task is well-defined and well-bounded, the developers must determine the degree of difficulty involved in the problem-solving behavior. This is difficult because there are frequently hidden subtasks or skills that won't be identified in the initial analysis. However, to isolate and identify these difficulties before the development effort begins, developers must determine to what extent the task can be done with current technology as opposed to requiring research and development of new techniques. This is difficult to answer during the analysis phase, prior to initiation of development efforts. However, several other questions may provide additional insights.

- *To what extent are either potential or pre-existing "conventional" programming tasks involved?*

In general, an eclectic approach to KBS development is highly recommended, merging the best of KBS techniques with the best of "conventional" software development techniques. To whatever extent soundly constructed, "conventional" programming is used, the development effort may benefit from existing software engineering methodologies. This tends to reduce the level of uncertainty associated with the use of KBS programming techniques. In many cases this software already exists, further reducing the amount of development effort required for the total KBS solution.

Some of the "conventional" programming requirements frequently encountered in KBS development efforts are listed below:

- networking & communications
- database access
- signal processing
- pattern recognition
- system level operations
- user interface
- support functions
- numeric processing

- modeling and simulation
- *To what extent are normally "human" faculties or skills involved in the task?*

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In general, the greater the number and complexity of the "human" skills involved in the problem-solving behavior and the degree to which the problem-solving behavior is dependent upon them, the greater the "research" flavor of the task and the more difficult the development effort will be. Several of these "hard" problems are listed below:

- vision
- tactile sensing
- natural language processing
- speech understanding
- analytic reasoning
- reasoning from first principles
- reasoning by analogy
- commonsense reasoning.

Each of these skills represents a major research topic in the field of artificial intelligence. While currently there are no general solutions to these problems, limited solutions to restricted forms of these problems do exist. Whenever the limited solution is adequate for the specific problem-solving ability required for the candidate task, the KBS may be reasonably achievable. However, if the actual problem exceeds the bounds of any limited solutions, the task is a poor candidate for a KBS development effort.

- *Does the task require expertise?*

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An affirmative answer to this question is a positive indicator for the appropriateness of KBS, since it is difficult with conventional techniques, and there are examples of successful KBS applications.

- *Is the task primarily cognitive?*

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An affirmative answer to this question is a positive indicator for the appropriateness of KBS, since it is difficult with conventional techniques, and there are examples of successful KBS applications.

- *Is the task concerned primarily with reasoning about symbolic information?*

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An affirmative answer to this question is a positive indicator for the appropriateness of KBS, since it is difficult with conventional techniques, and there are examples of successful KBS applications.

- *Does the task require "guessing"?*

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An affirmative answer to this question is a positive indicator for the appropriateness of KBS, since it is difficult with conventional techniques, and there are examples of successful KBS applications.

- *Does the task require reasoning about the status or abilities of the problem-solver himself (self-referencing)?*

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An affirmative answer to this question is a positive indicator for the appropriateness of KBS, since it is difficult with conventional techniques, and there are examples of successful KBS applications.

- *Does the task require the use of heuristics for handling large numbers of possibilities, incomplete or uncertain information?*

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An affirmative answer to this question is a positive indicator for the appropriateness of KBS, since it is difficult with conventional techniques, and there are examples of successful KBS applications.

- *Does the task require a significant level of explanation or justification of results?*

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An affirmative answer to this question is a positive indicator for the appropriateness of KBS, since it is difficult with conventional techniques, and there are examples of successful KBS applications.

- *Is the task characterized by the use of expert knowledge, judgment, and experience?*

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An affirmative answer to this question is a positive indicator for the appropriateness of KBS, since it is difficult with conventional techniques, and there are examples of successful KBS applications.

- *To what extent does the task involve mostly task-specific knowledge, as opposed to a more fundamental, general type of knowledge, such as common sense or generic knowledge, or general problem-solving abilities?*

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If the task primarily involves knowledge that is specific to the task under consideration, the development will have a higher probability for success. General knowledge and problem-solving ability, such as understanding the nature, properties, and

normal functions of common physical objects, knowledge about simple physical laws and relationships, and reasoning by analogy all involve skills and knowledge that are not necessarily specific to the candidate task. Such skills are common among human problem solvers, and typically will be used by the human problem-solver whenever unusual circumstances arise or other methods are inadequate. This behavior is difficult to replicate in computers, and is generally regarded as a research topic. As such, tasks requiring this behavior are poor candidates when the goal of the KBS is directly related to economic return. If the task requires any significant use of knowledge that is more fundamental or general, such as first principles or common sense, the KBS solution will be much more difficult to implement.

- *How many different areas of knowledge or fields of expertise are required in order to perform the task?*

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In general, the greater the number of diverse (and potentially conflicting) areas of knowledge are involved in performing the task, the greater the complexity of the task, and the more difficult the KBS development effort will be.

- *Is the general character or class of the problem described in Figure 3.2?*

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The general nature of the problem will help to identify other potentially similar problems for which other KBS solutions have already been implemented. It will also assist in identifying those types of problems that have proven difficult for KBS techniques in the past. Figure 3.2 shows the breakdown of generic operations given by Clancey (Clancey 1985).

FIGURE 3.2. Breakdown of Generic System Operations

In this breakdown, the operations that have yielded most readily to current KBS technologies are *identify*, with its sub-operations, and *design*, with its sub-operations. Other operations have typically proven more difficult.

- *Is it unusual for the task to involve novel situations or faults that the expert(s) have never seen before?*

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If the task requires reasoning about situations or faults that the practicing experts have never seen before, it is probably a candidate for “deep reasoning” or “model-based reasoning” techniques (Kline and Dolins 1985). These approaches are typically expensive, so these tasks may be poorly suited for KBS solutions where economic return is a primary factor in defining the success of the KBS effort.

- *Does the problem-solving task involve subtasks that are understood in widely varying levels of detail?*

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If so, the KBS will probably require several different levels of description, which also is expensive (Kline and Dolins 1985).

- *Are multiple types of problem-solving behavior or lines of reasoning involved in the overall task?*

Although multiple lines of reasoning may give the appearance of increased task complexity, this is not necessarily the case. Such problems may have a higher level of problem decomposability that counterbalances any increased complexity in control issues.

- *Must the task find either an optimal solution or all plausible solutions?*

If an optimal solution is necessary or all solutions are required, the KBS will be required to do considerably more work at run time, and will require different search techniques, such as exhaustive search or generate-and-test. Both of these alternatives are considered to be expensive (Kline and Dolins 1985).

- *To what extent does this task involve selecting among alternative, pre-enumerable solutions, as opposed to constructing a complex, non-enumerable solution?*

Tasks for which all possible solutions may be enumerated generally require simpler reasoning strategies and techniques. Frequently a simple, rule-based approach is adequate (Kline and Dolins 1985). Constructive solutions, however, may necessitate more complex reasoning processes, and consequently a more complex KBS solution.

- *To what extent is the interaction mode for the task conversational, consulting, or query-response, as opposed to being transparent to users, i.e., unassisted decision-making and/or control?*

The types of interactions required from the user are important in assessing the level of effort required in applying KBS technology to a candidate task. Interactions will have a

direct bearing on the types of interfaces required, the quality of acceptable decisions, and the types of knowledge representation and management required. For example, a user-transparent control KBS would need only to interface to databases (a source for case-specific data) and the appropriate hardware (the system being controlled). The user interface could be rather simple, consisting only of initialization switches and explanation facilities, in addition to some sort of development and testing interface. In contrast, a highly interactive consultation-type KBS would minimally require a robust query-response mechanism and dynamic explanation facilities, and probably a graphic or symbolic display mechanism for showing system status and intermediate results. Additionally, when KBS decision-making is unassisted by humans, a higher level of decision quality more likely will be necessary. Further, when both approaches to interaction are involved in various stages or at different times, an appropriate combination of these requirements may be necessary.

- *Will KBS results be reviewed for each case, or automatically trigger other actions or events?*

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While these issues are closely related to those discussed above, the emphasis here is on the degree to which the fielded KBS will be able to cause damage. Often the candidate task involves a number of checks and reviews at various points in the overall problem-solving process, as in a typical consultative diagnostic KBS. It may be easier to field a KBS in such cases because the KBS may be designed to feed results directly into the existing review process. In cases where such a review process does not pre-exist the KBS development effort, and especially when other actions or events are triggered without outside review, the KBS fielding effort will be more difficult. These cases may require an extensive analysis of the economic constraints of the candidate task.

- *To what extent is the task all or nothing, as opposed to making use of occasional or partial results, or tolerating some potential errors?*

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In situations where the task can provide useful results without solving the entire problem, or where the results would be useful even if they could not be generated for all cases, the probability for success in implementing a KBS solution would be significantly

higher than if this were not the case. Such situations enable greater decomposability of the problem, more rapid prototyping of subtasks, and potentially quicker testing and fielding cycles, than problems for which solutions are all or nothing. This situation occurs often when the nature of the task is primarily in constructing results dynamically from predefined elements or concepts rather than simply choosing from among a predefined set of static, alternative results.

- *To what extent are task decisions or solutions generally evaluated as either right or wrong, as opposed to being normally made from among very "close" alternatives, or being frequently made on the basis of levels of belief??*

These issues help determine the nature of the decisions made during the problem-solving behavior. Decision types can range from being discrete, where decisions are grouped with clear, well-defined boundaries, to being continuous, where decisions can be anywhere in between and boundaries are indistinct. In general, the less distinct the boundaries between decisions or answers are, the more difficult the job of tuning the KBS to provide correct results. In addition, tasks in which decisions are heavily based on levels of belief, are likely to be characterized by broad disagreement among experts about which solutions are correct. This will cause difficulties in KBS validation and fielding efforts.

- *To what extent does the task involve significant real-time interaction with other programs or devices?*

KBS implementations that are significantly constrained in timing generally involve an additional layer of development complexity. While this by itself may not disqualify a candidate task from further consideration, it does introduce an additional complication to the development effort, and should therefore be considered very carefully. In some situations these constraints are closely related to highly profitable production use opportunities, such as in manufacturing automation, where human operators may be unable to make quality decisions quickly enough.

- *To what extent does the task require unusually large amounts of space or data storage?*

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KBS implementations that are large in terms of storage generally involve an additional layer of development complexity. While this by itself may not disqualify a candidate task from further consideration, it does introduce an additional complication to the development effort, and should therefore be considered very carefully. In some situations these constraints are closely related to highly profitable production use opportunities, such as in manufacturing automation, where human operators may be unable to make quality decisions quickly enough.

- *Does the task require unusually complex user presentation or interaction?*

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While all KBS should include an appropriate, highly usable interface, when the interface must be unusually large or complex, the level of development effort required for the interface may overwhelm the effort required for the KBS. However, in cases where the KBS is intended to add a capability to an existing, graphics-oriented program, the interface may be in place before the KBS effort begins, thereby *simplifying* the KBS effort.

- *Can an evaluator be developed for a partial solution or for each decomposable task?*

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When it is possible to develop an evaluator for partial solutions or decomposable tasks, the KBS can be given the means to check intermediate or final results before committing to them. When coupled with a utility for backtracking or otherwise obtaining alternative solutions, the KBS will be able to provide higher quality results more consistently.

3.2 ASSESSMENT OF REQUIREMENTS AND RESOURCES

KBS development typically requires well-trained computer professionals using specialized hardware/software development environments. While it is beyond the scope of this report to address such issues in detail, it is nonetheless important for technical KBS staff to review these issues and estimate resource requirements prior to beginning a development effort.

3.2.1 The Development Phase

- *To what extent are adequate human, hardware and software resources of known cost available to schedule for the development effort?*

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When the KBS development effort runs short of resources, either implementation and fielding will be delayed or the quality of the KBS will be reduced, due to factors such as reduced access to the KS. Each of the following resources must be available in adequate quantities and qualities, at the appropriate times, and in the appropriate locations:

- human experts and other KSs (Smith 1984)
- knowledge engineers (Smith 1984)
- tool designers (Smith 1984)
- programming support personnel (Smith 1984)
- managerial/support staff
- knowledge-processing hardware and software environment(s)
- *Are the resource personnel adequately trained for their roles in the KBS development effort?*

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This is especially important for the knowledge engineers. AI technology is maturing, hence it is vital that KBS developers remain current with the rapidly changing state of the technology. Remember that knowledge engineers with expertise in one area of

KBS development or technology may not have adequate training or experience in other equally important areas or technologies.

- *To what extent do available hardware and software environments exhibit appropriate properties for developing a KBS solution to the candidate task?*

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This is another difficult question. Two general requirements of KBS development, however, are flexibility related to representations and reasoning strategies, and power for rapid searching and inferencing. Low-cost tools and environments frequently limit representational possibilities and run only on less powerful hardware. On the other hand, highly flexible, power tools and environments are typically expensive and complex, requiring significant training for effective use. The trade-offs between these two ends of the continuum can affect the degree to which the KBS effort achieves success. In addition, each tool and environment will bring its own set of strengths and weaknesses to the effort, and must be evaluated for fit with the specific problem.

3.2.2 The Fielding Phase

For KBS that are intended to be fielded in some operational environment, the resources related to the fielding effort must also be considered. In general, fielding may be expected to add substantially to the resource requirements of the development effort.

- *Has a set of cooperative, patient users been explicitly identified, and will they commit the necessary resources to fielding the KBS?*

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Explicit identification of the KBS users is necessary for the requirements and task analysis process. The users must support the effort to develop and install a KBS solution to one or more of their problem-solving tasks.

- *To what extent will the users welcome the completed system?*

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KBS that are designed to assist the users, as opposed to those that replace the users or that are otherwise perceived as a threat, will better achieve success.

- *To what extent will KBS fielding disturb current operations and practice, as opposed to being phased into use gracefully, using progressive releases?*

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The problem-solving task must not be viewed as an independent task, but rather as a part of some greater process. In this view, the fielding effort must consider the overall process surrounding the candidate task and the transition between the existing system and the new KBS. Candidate tasks that can be divided into subtasks can often be fielded incrementally, thereby providing a more graceful, less threatening transition to the KBS solution.

- *Has ongoing maintenance been planned for?*

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Any system that will be fielded for operational use will require routine maintenance and updating. The organization and skills necessary to support this work must be identified and committed.

3.3 NON-TECHNICAL ISSUES AND CONCERNS

As with all forms of project development, there are a number of important non-technical issues that must be addressed before proceeding with a development effort. These issues are grouped into classes of related questions.

3.3.1 KBS Evaluation

- *Is a test available to determine the "correctness" of KBS results?*

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It is invaluable for the candidate task to have a test or procedure that can be applied to any given case to determine the correctness of the results for that case. For example, a statistical analysis of the data, or a similar independent check, can be used to corroborate the KBS results. This is especially useful when the independent check can be performed on a computer, and automatically compared to the KBS results.

- *To what extent can and will validation criteria and procedures be defined for the KBS, and will the final system be tested and evaluated?*

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Validation is critically important in demonstrating the success of a KBS. If the prospects for validation are poor, developing a KBS solution may not be a good idea. A correctness test, as described above, can be used in cases where one is available. Alternatively, a suite of test cases, with known solutions, can be used to develop and maintain a valid KBS. This requires that specific examples of problems and their solutions exist. While this is not as helpful as having a means for determining correctness of the KBS results for any and every specific problem, it will nevertheless reduce the level of effort required to perform debugging and tuning tasks.

- *Would experts agree on whether the results are correct?*

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In cases where experts might not agree on whether or not the system's results are correct, it may be inappropriate to apply KBS techniques. When this sort of general disagreement exists about specific problem cases, the task is probably poorly suited to solution using KBS methods.

3.3.2 Economics

- *Is the expected payoff measurable?*

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Unless the payoff of the KBS development effort can be measured in some quantitative way, its success or lack of success will be difficult to document. While this situation may be desirable in some situations, for most organizations it will be unacceptable.

- *Is the expected payoff reasonable?*

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The bottom line in most production use KBS development efforts will be the return on investment. While issues of this nature are beyond the scope of this report, most organizations will not pursue a development effort unless a reasonable return is expected. While the payoff may or may not be defined in economic terms, the concept of payoff is similar to the concept of success, as described in section 2.

- *To what extent can an "opportunity" measurement be made before the system is implemented, and an "opportunity capture" measurement be made after the system is fielded?*

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Opportunity is a measure of the potential for cost savings or increased profit and opportunity capture is a measure of how much of the opportunity has been achieved through the use of the system. The higher the quality of measurement, the more believable the argument for success following a KBS implementation and fielding effort. Technical staff may need to perform field tests to answer these questions.

- *To what extent is the cost of (frequency or severity of) wrong decisions projected to be reduced as a result of fielding the KBS?*

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The examination of this issue is intended to determine in greater detail the degree to which the problem-solving task lends itself to economic measurement. Technical staff may need to perform field tests to determine the current frequency and cost of wrong decisions. The cost of wrong decisions which are too conservative or cautious, as well as those which are too liberal or aggressive, may need to be considered. In many cases there are different penalties for different types of incorrect results. In other words, the cost of "overshooting" may be different than the cost of "undershooting". This must be considered in evaluating overall costs, as discussed above.

3.3.3 Expectations and Understanding

- *To what extent do all involved individuals have realistic expectations of the KBS development effort and solution?*

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Personnel at all levels must have realistic expectations, both positive and negative, in order to achieve an adequate measure of success. These expectations can be neither too high nor too low. Achieving reasonable expectations requires that each individual involved in the project, from development staff to upper management, understand both the scope of the system and the limitations even of a success (Prerau 1985).

- *Do all key management individuals support the KBS development goals and directions, agree that there is an organizational need to solve the problem, and has the KBS task been agreed upon jointly by the system developers and the using organization?*

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Support for the development must come from all of the key management individuals. This includes management from the using organization as well as from the KBS development side (Buchanan et al. 1983; Prerau 1985; Smith 1984).

- *To what extent is the project strongly supported by a senior manager, for protection and follow-up?*

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This is a potential problem common to all types of development projects, and is a fundamental issue that must not be overlooked due to infatuation with new technology. Without this support, the KBS development effort may lose momentum and eventually fail (Prerau 1985).

3.3.4 Business Environment

- *To what extent is the need for the task expected to continue for several more years, as opposed to disappear or significantly change in the foreseeable future?*

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Most often the definition of success for a project involves captured opportunity. When there is a real possibility that the opportunity is now or will in the future be changed significantly, the KBS development effort may run into trouble as the changes occur.

- *To what extent is the project on a critical path for any other development, or have absolute milestones for completion?*

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Because of the exploratory programming generally associated with developing a KBS, the ideal environment for developing them is a research-like atmosphere, where developers can experiment with various ideas and concepts. Unrealistic timetables and deadlines can force KBS developers to make technically complex decisions too early in the design and development process. Unfortunately this research-like atmosphere is not available in all user organizations. To avoid the negative impact of premature deadlines, plan carefully, allowing plenty of time for exploratory programming and experimentation in the development process. If possible a conservative approach which starts with a limited scope and expands incrementally is recommended.

3.3.5 Timing

- *Is this the right time to be solving this task?*

There may be several reasons to postpone the development effort for an otherwise appropriate candidate task. In time the candidate task may become better understood, and the KBS technology will mature. This increases the opportunities for success, as KBS techniques become less expensive and easier to use, and development personnel become better trained and more experienced.

4.0 ASSESSMENT

4.1 SCORING

The process of reaching a final assessment requires that all of the "box scores" given to individual questions be considered together to provide some form of overall measure of the potential for success for a KBS development effort to solve the task. An informal, subjective approach is taken, wherein the task is considered as a whole, with total counts for each of the boxes, at each step in each level of the analysis. Thus, there will be a count for each box in the following grid shown in Figure 4.1.

	Level One						Level Two					
	++	+	•	-	--	wt.	++	+	•	-	--	wt.
Goals												
Appropriateness												
Resources												
Non-Technical												

FIGURE 4.1. Scoring Grid for the Candidate Task

4.2 INTERPRETING THE RESULTS

Interpreting the results of the analysis is based heavily on the definition of success, which is highly situation-specific. In actual use, the elimination of inappropriate KBS applications can be more attractive than identifying potential applications because of cost avoidance. For these reasons only some loosely-defined, qualitative rules are given here for interpreting the scoring for any specific candidate task. As was stated earlier, the underlying assumption in this interpretation is that the definition of success here is strongly related to economic return in production use. This includes the related assumption that the KBS will be fielded in some form of practical use environment.

We recommend that these general guidelines be followed:

- If there are even a few strongly negative indicators, regardless of the number or strength of any positive indicators, the candidate task is a poor choice. Reject the task *as stated*.
- When the scoring indicates mostly neutral indicators, with at most a few strongly positive indicators, the candidate task is probably not a good opportunity. Neutral indicators tend to identify areas where adequate information is lacking, indicating a high degree of uncertainty (i.e., risk) regarding important criteria. Reject the task *as stated* and work to better define the task.
- Many positive indicators, together with a few to several mildly negative indicators, signals a relatively good opportunity. Remember that no situation is perfect -- when the negative indicators are related to problems that can reasonably be expected to be overcome with the appropriate resources and effort, the development should probably proceed.

When using this procedure to compare the relative merit of more than one candidate task, consider the scoring order as follows:

1. When all else is equal, choose the task with the lowest negative indication.
2. When all else is equal, choose the task with the lowest neutral indication.
3. When all else is equal, choose the task with the highest positive indication.

The suggestions given above assume equal weights for all sections of the scoring grid. In general, the analyst must consider the particular organizational situation. In some cases it may be easier to overcome moderate technical difficulties than to overcome moderate political or economic difficulties. In other environments just the opposite may be true.

4. If the organizational situation complicates the selection process, weight the criteria based on the organizational situation, and choose the task with the resulting best score. Be cautioned, however, that rigorously applying quantitative methods to fuzzy and ill-defined concepts, such as those presented here, can lead to misleading results and is therefore generally ill-advised.

4.3 CAUTIONS

The bulk of the KBS techniques and approaches in current use is largely empirical in origin. Many lack the foundation of formal theory. The process of developing KBS solutions using these techniques remains similarly empirical. Development efforts are typically characterized by rapid prototyping, experimentation, and iterative modification, related to all areas of representation and reasoning strategies. It is important, then, for developers to remain flexible, both in the ways they think about the problem and in their approach to implementing the KBS solution.

Toward this end, developers should try to define the task before beginning the implementation, but should always allow for changes in specifications (Smith 1984). It is important for clients and management to similarly appreciate and accept this. A difficult KBS project that is appropriate to pursue has well-stated objectives, with stated intention to modify those objectives through experimentation and experience.

Another important pitfall to avoid is that of an apparently good fit between the candidate task and a production rule formalism. This appearance may be deceptive. The problem may actually be significantly more difficult to solve (Smith 1984). Developers are therefore advised to use caution when the problem appears to require only a simple, rule-based approach.

5.0 SUGGESTIONS FOR ADDITIONAL ASSISTANCE

Once a decision has been made to develop a KBS solution to the candidate task, there remain two critical questions before the development effort can get under way. While complete answers to these questions are beyond the scope of this report, other references can assist the reader in finding workable solutions.

- *Which KBS techniques are most appropriate for this particular candidate task?*

While the overall problem of mapping task characteristics into KBS techniques is not yet well understood, Kline and Dolins (1985) provide a series of "Probing Questions" that are designed to direct the analyst in the appropriate directions. These questions are both useful and effective.

- *Which KBS development environment is most appropriate for this particular candidate task?*

The selection of KBS development tools and environments is a similarly difficult question. Several references exist in the literature that describe the tool selection process for a particular problem. A recent report by Rothenberg et al. (1987) takes a more general view of tool selection, providing several insights that may be applied to any candidate problem.

While neither of these references provides the definitive word in answering these questions, each provides a useful starting point for analysts faced with making such decisions.

6.0 CONCLUSIONS

This report has presented three major topics for use by KBS analysts interested in assessing the potential for successful completion of a KBS development effort for some (one or more) candidate problem-solving tasks. The first topic is that of the approach and organization of the assessment procedure. The two levels of analysis provide a complete, robust procedure for the assessment process. The second major topic is the assessment criteria. At each step in the analysis, this report identifies those criteria which are important to the determination at that step. The third major topic is the scoring mechanism that is used. This is a subjective methodology for combining the assessment criteria into an overall score that can be used to make informed decisions with regard to KBS technology.

While this study has been prompted out of a need to make better decisions about pursuing a KBS solution for a candidate task, it has evolved into a more general tool that can be used to find the candidate task among several with the best potential for success. This procedure also provides a foundation upon which development staff can generate permanent documentation and justification of the assessment task and results. With use and experience, it is expected that the methodology will evolve to better accommodate user needs.

In addition, the evaluation procedure itself is amenable to automation in the form of a KBS, and may be included in future KBS environments and toolkits, and integrally linked to the knowledge acquisition and representation systems within those environments.

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APPENDIX A

APPLICATION EVALUATION SHEETS

APPENDIX A

APPLICATION EVALUATION SHEETS

This appendix provides a short form of the scoring boxes for evaluating a potential KBS application. The explanatory material has been removed leaving only the questions and scoring boxes followed by the scoring grid. We recommend that a copy of this appendix be used when scoring a potential application with the main body of the report being used as a reference. The numbering of the appendix corresponds to the sections in the main body of the document.

2.0 LEVEL ONE - MANAGEMENT ANALYSIS

2.1 DEFINITION OF SUCCESS

- *Are the goals of the activity clearly defined and are the objectives of the KBS development effort clearly stated?*

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- *Has a clear definition of success been delineated?*

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- *How well are the activity goals aligned with organizational goals?*

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- *To what extent are the advantages associated with the KBS technologies compatible with the project goals?*

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- *Is the objective of the KBS system clearly defined as either:*

a. *actual use (a production system), or*

b. *major new advances in the state of the art for KBS (a research system)?*

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- *Is the motivation for using computer automation, and the motivation for considering a KBS approach, well-formed and defensible?*

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- *To what extent do conventional computing techniques appear to be unsuitable or inadequate for solving the problem?*

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- *To what extent is there a need to capture the expertise?*

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- *Is the beneficial outcome important enough to warrant the cost of the KBS solution?*

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2.2 APPROPRIATENESS OF KBS TECHNOLOGY

- *How necessary is the KBS approach?*

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- *How sufficient is the KBS approach?*

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- *How "similar" is the task to another task for which a successful KBS solution exists?*

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- *How "similar" is the task to another task that has caused problems for previous KBS?*

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2.3 AVAILABILITY OF RESOURCES

- *How available is the necessary knowledge from the user group?*

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- *How available is the necessary knowledge engineering expertise from the KBS development group?*

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- *How available is the necessary technical and management manpower from both user and development groups?*

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- *To what extent is the necessary funding available, for hardware and software tools and related support, for training staff as necessary, and for building, validating, and fielding the final product (if required)?*

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2.4 NON-TECHNICAL CONSIDERATIONS

- *How prepared is the organization to develop KBS?*

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- *How important is this problem?*

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- *Are there any situations that are expected to impede solutions?*

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- *Are the assumptions and constraints of the project well-formed, realistic, and defensible?*

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- *How realistic and defensible are the economic, ethical, and legal considerations of the project?*

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- *What is the match among the overall goals between project payoff and the risk of failure?*

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- *Will the KBS meet a real need?*

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- *To what extent is the system politically sensitive or controversial?*

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3.0 LEVEL TWO - DETAILED ANALYSIS

3.1 TASK APPROPRIATENESS

3.1.1 Problem-Solving Knowledge

3.1.1.1 The Source of the Knowledge

- *Does the knowledge exist?*

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- *Have the knowledge sources been explicitly identified?*

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- *Does at least one recognized expert exist today?*

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- *Is the expert's level of expertise and base of experience sufficient?*

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- *Are the experts provably better than beginners in performing the task?*

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- *Is the expert currently practicing in the selected task?*

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- *Does the KS have a reputation within the field that will lend credibility and authority to the KBS, even if it is able to capture only a portion of the knowledge?*

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- *Does the expertise for each task or subtask come from a single expert?*

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- *Is the knowledge resident in individuals or is it a community involvement?*

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- *Do various KSs use essentially the same approach, or is there a significant difference or idiosyncratic variability?*

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- *At the outset of the project, is the expert able to specify many of the important concepts?*

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- *Is the KS cooperative, analytical by nature, and effective in communicating knowledge, judgment, experience, and methodology?*

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- *Is the expert and his/her management willing to commit the necessary resources to KBS development?*

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3.1.1.2 The Nature of the Knowledge

- *How much knowledge is involved?*

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- *To what extent is the knowledge diverse, incomplete, fragmented, inexact, ill-specified, unreliable, or in flux?*

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3.1.2 Case-Specific Data

- *How reliable is the data?*

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- *To what extent does the data vary with time?*

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- *How much data is involved?*

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3.1.3 Knowledge/Data Comparison

- *What are the relative quantities of problem-solving knowledge and case-specific data involved in the task?*

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3.1.4 Task Characterization

3.1.4.1 Task Definition and Bounding

- *Is the task defined clearly and unambiguously, with a precise definition of the inputs and outputs?*

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- *Is the skill required by the task taught to novices, or is the field or task discussed in books or other written materials?*

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- *How stable is the task definition?*

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- *How well-bounded and narrowly defined is the task?*

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- *Is the task largely and effectively separable from its contextual tasks?*

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- *How decomposable is the task?*

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3.1.4.2 Task Complexity and Characterization

- *To what extent are either potential or pre-existing "conventional" programming tasks involved?*

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- *To what extent are normally "human" faculties or skills involved in the task?*

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- *Does the task require expertise?*

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- *Is the task primarily cognitive?*

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- *Is the task concerned primarily with reasoning about symbolic information?*

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- *Does the task require "guessing"?*

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- Does the task require reasoning about the status or abilities of the problem-solver himself (self-referencing)?

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- Does the task require the use of heuristics for handling large numbers of possibilities, incomplete or uncertain information?

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- Does the task require a significant level of explanation or justification of results?

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- Is the task characterized by the use of expert knowledge, judgment, and experience?

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- To what extent does the task involve mostly task-specific knowledge, as opposed to a more fundamental, general type of knowledge, such as common sense or generic knowledge, or general problem-solving abilities?

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- *How many different areas of knowledge or fields of expertise are required in order to perform the task?*

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- *Is the general character or class of the problem described in Figure 3.2?*

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- *Is it unusual for the task to involve novel situations or faults that the expert(s) have never seen before?*

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- *Does the problem-solving task involve subtasks that are understood in widely varying levels of detail?*

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- *Are multiple types of problem-solving behavior or lines of reasoning involved in the overall task?*

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- *Must the task find either an optimal solution or all plausible solutions?*

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- *To what extent does this task involve selecting among alternative, pre-enumerable solutions, as opposed to constructing a complex, non-enumerable solution?*

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- *To what extent is the interaction mode for the task conversational, consulting, or query-response, as opposed to being transparent to users, i.e., unassisted decision-making and/or control?*

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- *Will KBS results be reviewed for each case, or automatically trigger other actions or events?*

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- *To what extent is the task all or nothing, as opposed to making use of occasional or partial results, or tolerating some potential errors?*

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- *To what extent are task decisions or solutions generally evaluated as either right or wrong, as opposed to being normally made from among very "close" alternatives, or being frequently made on the basis of levels of belief??*

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- *To what extent does the task involve significant real-time interaction with other programs or devices?*

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- *To what extent does the task require unusually large amounts of space or data storage?*

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- *Does the task require unusually complex user presentation or interaction?*

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- *Can an evaluator be developed for a partial solution or for each decomposable task?*

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3.2 ASSESSMENT OF REQUIREMENTS AND RESOURCES

3.2.1 The Development Phase

- *To what extent are adequate human, hardware and software resources of known cost available to schedule for the development effort?*

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- *Are the resource personnel adequately trained for their roles in the KBS development effort?*

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- *To what extent do available hardware and software environments exhibit appropriate properties for developing a KBS solution to the candidate task?*

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3.2.2 The Fielding Phase

- *Has a set of cooperative, patient users been explicitly identified, and will they commit the necessary resources to fielding the KBS?*

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- *To what extent will the users welcome the completed system?*

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- *To what extent will KBS fielding disturb current operations and practice, as opposed to being phased into use gracefully, using progressive releases?*

++	+	•	-	--	
----	---	---	---	----	--

- *Has ongoing maintenance been planned for?*

++	+	•	-	---	
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3.3 NON-TECHNICAL ISSUES AND CONCERNS

3.3.1 KBS Evaluation

- *Is a test available to determine the "correctness" of KBS results?*

++	+	•	-	---	
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- *To what extent can and will validation criteria and procedures be defined for the KBS, and will the final system be tested and evaluated?*

++	+	•	-	---	
----	---	---	---	-----	--

- *Would experts agree on whether the results are correct?*

++	+	•	-	---	
----	---	---	---	-----	--

3.3.2 Economics

- *Is the expected payoff measurable?*

++	+	•	-	---	
----	---	---	---	-----	--

- *Is the expected payoff reasonable?*

++	+	•	-	---	
----	---	---	---	-----	--

- *To what extent can an "opportunity" measurement be made before the system is implemented, and an "opportunity capture" measurement be made after the system is fielded?*

++	+	•	-	--	
----	---	---	---	----	--

- *To what extent is the cost of (frequency or severity of) wrong decisions projected to be reduced as a result of fielding the KBS?*

++	+	•	-	--	
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3.3.3 Expectations and Understanding

- *To what extent do all involved individuals have realistic expectations of the KBS development effort and solution?*

++	+	•	-	--	
----	---	---	---	----	--

- *Do all key management individuals support the KBS development goals and directions, agree that there is an organizational need to solve the problem, and has the KBS task been agreed upon jointly by the system developers and the using organization?*

++	+	•	-	--	
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- *To what extent is the project strongly supported by a senior manager, for protection and follow-up?*

++	+	•	-	--	
----	---	---	---	----	--

3.3.4 Business Environment

- *To what extent is the need for the task expected to continue for several more years, as opposed to disappear or significantly change in the foreseeable future?*

++	+	•	-	--	
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- *To what extent is the project on a critical path for any other development, or have absolute milestones for completion?*

++	+	•	-	--	
----	---	---	---	----	--

3.3.5 Timing

- *Is this the right time to be solving this task?*

++	+	•	-	--	
----	---	---	---	----	--

4.0 ASSESSMENT

4.1 SCORING

	Level One						Level Two					
	++	+	•	-	--	wt.	++	+	•	-	--	wt.
Goals												
Appropriateness												
Resources												
Non-Technical												

FIGURE 4.1. Scoring Grid for the Candidate Task

4.2 INTERPRETING THE RESULTS

Interpreting the results of the analysis is based heavily on the definition of success, which is highly situation-specific. In actual use, the elimination of inappropriate KBS applications can be more attractive than identifying potential applications because of cost avoidance. For these reasons only some loosely-defined, qualitative rules are given here for interpreting the scoring for any specific candidate task. As was stated earlier, the underlying assumption in this interpretation is that the definition of success here is strongly related to economic return in production use. This includes the related assumption that the KBS will be fielded in some form of practical use environment.

We recommend that these general guidelines be followed:

- If there are even a few strongly negative indicators, regardless of the number or strength of any positive indicators, the candidate task is a poor choice. Reject the task *as stated*.
- When the scoring indicates mostly neutral indicators, with at most a few strongly positive indicators, the candidate task is probably not a good opportunity. Neutral indicators tend to identify areas where adequate information is lacking, indicating a high degree of uncertainty (i.e., risk) regarding important criteria. Reject the task *as stated* and work to better define the task.
- Many positive indicators, together with a few to several mildly negative indicators, signals a relatively good opportunity. Remember that no situation is perfect -- when the negative indicators are related to problems that can reasonably be expected to be overcome with the appropriate resources and effort, the development should probably proceed.

When using this procedure to compare the relative merit of more than one candidate task, consider the scoring order as follows:

1. When all else is equal, choose the task with the lowest negative indication.

2. When all else is equal, choose the task with the lowest neutral indication.
3. When all else is equal, choose the task with the highest positive indication.

The suggestions given above assume equal weights for all sections of the scoring grid. In general, the analyst must consider the particular organizational situation. In some cases it may be easier to overcome moderate technical difficulties than to overcome moderate political or economic difficulties. In other environments just the opposite may be true.

4. If the organizational situation complicates the selection process, weight the criteria based on the organizational situation, and choose the task with the resulting best score. Be cautioned, however, that rigorously applying quantitative methods to fuzzy and ill-defined concepts, such as those presented here, can lead to misleading results and is therefore generally ill-advised.

END

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