# A Knowledge Management Approach Oriented to Improve Strategic Decisions in Pavement Management Practices

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## ABSTRACT

The success in fulfilling target objectives in any organization largely depends on making sound strategic decisions. Strategic decisions are inherent to the entire management process and impact all management and functional areas across the organization. Strategic decisions are made during the formulation of strategic plans and as a response to key management questions. Management questions regarding what objectives the organization wants to achieve, how to respond to changing scenarios, how to allocate resources among competing needs, how to compete in the areas in which the organization has business activities, and how to manage functional areas, are just some of the questions that arise during the management process. Addressing these questions properly involves making sound strategic decisions that should be oriented to achieve the agency's desired outcome.

Pavement management practices imply complex trade-offs among many factors involved in the process including the availability of data, interpretation of data, prediction of future pavement performance, effectiveness of treatments, level of funding available to invest in pavement assets, agency's maintenance and rehabilitation pavement strategy, and political and social influence. Unfortunately, many of the factors that influence decisions in pavement management practices and affect outcomes are unknown or too complex to be easily defined. Unexpected events introduce uncertainty increasing the likelihood of failure. To handle uncertainty during the decision making process, systematic procedures and tools should be available to the decision-maker.

Pavement management systems are intended to assist agencies in the decision making process to allocate resources efficiently. However, experiences over the last several years have shown that engineering tools and business principles do not always fulfill this purpose. It is proposed that a knowledge management approach applied to pavement management practices can make a significant difference.

This paper discusses how a knowledge management approach can be integrated with pavement management practices to better accomplish agency's goals by reducing the uncertainty inherent in the decision making process due to the lack of knowledge.

## THE CHALLENGE

Road infrastructure is one of the major assets managed by an agency. Large investments in time and money are required to sustain maintenance and rehabilitation programs. However, the limitation of funds combined with the deterioration of pavement condition over time due to environmental factors and increasing traffic loads creates a complex management problem to the agency.

Pavement management is intended to assist agencies in the decision-making process of allocating funds to pavement assets efficiently. The ultimate purpose of pavement management is to get the most of the available resources by investing the least. To accomplish this goal, keen decisions are needed at different management levels, more especially at the strategic management level where treatment strategies and funding policies are established.

There are many variables and chance events involves in the different phases of the strategic management process that makes difficult to handle. Figure 1 shows the different phases of the ongoing process of strategic management *(1)*.

The complexity of the on-going process of strategic management makes hard to define the problem, to set alternatives, and to forecast the potential payoffs for each alternative. Furthermore, the dynamics of the management process makes even more difficult to identify potential course of actions. Making sound and effective strategic decisions under these conditions is the great challenge that agencies face.

## THE DECISION MAKING PROCESS

A decision is "the act or process of choosing one course of action among several alternatives" *(2)*. Decisions may be the result of a rational thinking process, subjective judgment, or a combination of both. In the management field, decisions are intended to lead an organization to the fulfillment of its goals and objectives.

Some decisions have a short term impact, while others have a long term impact. Decisions that involve strategy or policy changes will usually have a long term impact in the organization. Due to the negative long-term impact of unwise decisions, the decision making process deserves a careful thought.

### Modeling Strategic Decisions

Modeling strategic decisions is not an easy task. Several factors contribute to this difficulty. The factors go from personal preferences and perspectives to information technology issues.

Four main sources of difficulty regarding modeling decisions are considered: complexity of the problem, uncertainty of the situation, objectives set by decision-makers, and decision-maker's perspectives. All these sources of difficulty should be taken into account while modeling *(3)*.

Complexity arises from the nature of the problem itself. Most of the problems involve so many issues that need to be decomposed for analysis. For example, the selection of a rehabilitation pavement treatment may require considering not only technical aspects, but also environmental, social, and economic impacts. Each of these areas deserves attention in the analysis, and the interrelations among them should also be considered in the modeling.

Uncertainty comes along with any decision. The level of inherent uncertainty depends on the situation. For example, if a new revolutionary pavement rehabilitation treatment technique is under consideration, the effectiveness of the treatment in the long-term and its environmental impact is uncertain, but if a conventional rehabilitation treatment is chosen the level of uncertainty is less.

Objectives set by decision-makers influence the analysis and the model itself. When multiple objectives are pursued, there may be conflicts and trade offs among them may be needed. Benefits in one area may cause a negative impact in another area. The model should be able to handle these situations.

The background and previous experiences of decision-makers play an important role in the decision making process. Each team member that participates in the decision analysis may have a different perspective. Different perspectives may lead to different conclusions. The definition of the problem and the identification of clear objectives at the beginning of the process are vital to overcome these differences.

*Types of Models*

In terms of requirements, the objective is to develop a model that contains everything that is essential for solving the problem. This type of model is called a requisite model. "A model can be considered requisite only when no new intuitions emerge about the problem" *(4)*. This implies that a model is called a requisite model only when the decision-makers' thoughts, beliefs, and preferences have been considered in the model formulation.

Models currently used in decision analysis can be divided in two major groups: deterministic and probabilistic models *(5)*. Both models are in practice. The selection of a particular model mainly depends on the nature of the problem, and the availability of information. Factors related to the sources of difficulty in modeling decisions also need to be considered in selecting a model.

Deterministic models are used when the outcomes are determined by certain rules that do not change. They are static models since the rules that govern the relationships among the model's parameters remain stable over the analysis horizon. Models used in physics, or chemistry to explain certain phenomena can be classified as deterministic models. Deterministic models are found on science disciplines.

Deterministic models are mostly used to model processes which outcomes depend directly on the input parameters, and the outcomes can be anticipated using the rules governing the model. On the other hand, there are other disciplines which are not considered exact sciences such as economics, sociology, or psychology. Predicting outcomes in these disciplines is hard since they do not follow "deterministic rules".

In the case of engineering, it really depends on the nature of the problem. In general, deterministic models are not exact representations of the real world. Although, rules can be set to explain engineering processes, using physics or chemistry laws, there are external factors that affect the outcome and need to be considered in the model. The number of combinations of the parameters affecting the outcome could be very difficult to handle in practice by a deterministic model.

Probabilistic models are an alternative to deterministic models. Probabilistic models are largely based on the application of statistics for probability assessment. In probabilistic models actions are based on expected outcomes. The input parameters and predicting variables to be used in the model are defined following statistical principles. These principles involved risk assessment techniques. The strength of a probabilistic model approach is that they can consider not only uncertainty, but also decision-makers' preferences, or past experiences. The weakness of probabilistic models comes from the availability and accuracy of information needed to develop the probability distributions to run the model. However, it is worth to highlight the issue that lack of information is a general weakness in modeling. Therefore, the main strength of probabilistic models resides in encouraging decision makers to think about all the factors that affect outcomes either objective or subjective.

## STRATEGIC DECISIONS, UNCERTAINTY AND KNOWLEDGE

Strategic decisions are made under certain level of uncertainty. To deal with uncertainty or future unknown events in the decision making process, risk assessment techniques are used. Great efforts are done toward making uncertainty explicit by estimating the level of risk.

Risk is defined as an uncertain event for which the probability distribution is known. To make uncertainty explicitly, it is assumed that outcomes follow a probability distribution. The final resolution of an uncertain event is an outcome. Risk assessment is a study conducted to determine the potential outcomes along with their probabilities. At the strategic management level, risk assessment becomes more challenging since multiple objectives are involved in the decision context.

Decision analysis techniques have been developed to cope with uncertainty. The higher the level of uncertainty, the higher the level of risk involved in a decision. The fear to make decisions under uncertainty must be confronted by bringing knowledge into the process. Uncertainty comes from the absence of knowledge. Depending on the amount and degree of knowledge, the decision context falls under one of these three scenarios:

a. Decisions made under pure uncertainty
b. Decisions made under risk
c. Decisions made under complete knowledge

None of the extreme scenarios are realistic. Decisions are always made under risk and knowledge is always desired to reduce uncertainty. Knowledge is required to define the problem properly, to gather the right information and distinguish relevant information to the problem, to incorporate lessons learned from the past into the decision model, to choose the appropriate probability function for risk assessment analysis, and at last to make a decision. Figure 2 shows the relationship between uncertainty and knowledge growth.

Knowledge evolves from data. The evolution process goes from data to information, information to facts, and facts to knowledge. Figure 3 shows the evolution from crude data to knowledge.

Crude data is usefulness. When data is relevant to the decision problem becomes information, and information becomes a fact when there is data to support it. When facts are interpreted and used in the solution of a problem, facts become knowledge. The level of exactness increases as data evolves to knowledge.

Sound decisions can not be made without knowledge. However, knowledge is not cost free. Methods to create, capture, store, and disseminate knowledge are needed to minimize this cost. Knowledge takes effort, time, and money, and it must be clear that the quest for knowledge is really an on going process that requires a deep level of commitment across the entire organization.

**Decision Support Systems for Strategic Decisions**

Decision support systems are conceived as a tool to assist decision-makers make decisions. Pavement management systems and asset management systems are decision support tools. The degree of complexity of a decision support system depends on the agency's objectives and the resources available for the development and maintenance of the system.

One approach followed by decision support systems is the development of knowledge-based expert systems. Knowledge expert systems use human knowledge to solve problems that normally require human intelligence. The expertise knowledge is represented by rules and data within the computer system. These rules and data are used by the system to solve problems *(6)*.

Knowledge-based expert systems are considered a branch of artificial intelligence (AI) which is defined as the capability of a device to perform tasks or functions qualified as intelligent. Since 1970s knowledge-based systems have been used in medicine, financial analysis, teaching, computer software development, robotics, traffic control, and military applications. These systems assist in diagnosis, monitoring, repair, instruction, interpretation, design, and almost in any activity in which a human expert is needed.

The main difference between a conventional computer program and an expert system is that an expert system has the capability to collect human know-how into a knowledge-based and apply this knowledge to reason through the solution of a problem without the need to reprogram its source code.

The basic components of a knowledge-based expert system are a knowledge database, an interface engine and control mechanism, a user interface, and computer hardware. Figure 4 shows the basic components of a knowledge-base expert system *(6).*

The knowledge database is the repository where the expertise domain resides. There are two basic types of entities in the knowledge base: facts and rules. A fact is “simply an assertion that a relationship on a set of objects is true”, and a rule is “an assertion that some fact(s) are true provided that another set of facts is true” *(7)*. The knowledge base is the heart of the system and defines the knowledge presentation scheme which determines the relationship between rules and facts.

The inference engine and control mechanism is the problem processor component of the knowledge-based expert system. The inference engine is the brain of the system and its role is to use the available facts and rules stored in the knowledge base to solve the problem. The tasks of the inference engine involves selecting rules from the knowledge-base, evaluating the selected rules, generating new facts, retrieving facts from the knowledge-base and the user, and finally generating the problem solution *(8)*.

The user interface allows the user to monitor the performance of the system, and to interact with the expert system to request an explanation of the reasoning followed in solving a problem. To summarize, the distinguishing characteristics of knowledge-based systems are that they *(6)*:

- Contain symbolic programming and reasoning capabilities
- Contain a knowledge base about a specific domain or situation
- Contain an inferential reasoning capability
- Can explain their advise or reasoning process
- If-then rules, heuristics, are used extensively but not necessarily exclusively

Some attempts have been done to utilize a knowledge based expert system approach in pavement management practices. Knowledge-based expert systems have been used to forecast pavement performance and to select treatment strategies in Iowa DOT’s pavement management system. The approach was used in combination with a dynamic programming technique for project selection and resource allocation over a five year period. The study concludes that by following this approach, a lower level of investment is needed to achieve a desired network pavement condition *(8)*. Although a five year period is considered as a short term to assess the impact of pavement maintenance and rehabilitation strategies, there are certain boundaries within findings are valid. The results are valid within the domain of expertise of the knowledge-based system, and the performance forecasting model is constraint to the limitations of a deterministic model. Therefore, setting facts and rules for a knowledge base system seems to be an unfeasible task, and without a knowledge base component no inference engine can take place.

Knowledge based expert systems are powerful decision support systems, but they can not handle the complex needs at the strategic management level. A broader approach is needed to address these needs.

## WHAT IS KNOWLEDGE MANAGEMENT?

What is defined as knowledge management today has emerged from diverse disciplines over at least three decades. Some of the disciplines having the most profound effect on the development of knowledge management concepts are organizational science and human resource management, computer science and management information systems, management science, psychology, and sociology. This diverse legacy has resulted in various approaches to knowledge management, but there is no unique, universally accepted method of implementing knowledge management.

The growing importance of managing organizational or corporate knowledge was emphasized in Massachusetts Institute of Technology (MIT) and Carnegie Mellon research in the 1970s. However, these efforts were oriented toward the development of automated machine processes and artificial intelligence rather than toward integrating human resources as a unifying corporate goal. In the 1990s, the idea of better utilizing human resource knowledge began to be considered as a new organizational approach.

### Historical Overview of Knowledge Management

The historical development of knowledge management goes from isolated data applications before the 1970s to knowledge management in the late-1990s. Before the 1970s, at the beginning of information technology (IT) development, no special attention was given to data management. The first step in the historical development of knowledge management started with technical integration of isolated data with the implementation of database management systems (DBMS) in the mid-1970s. The second stage, in the mid-1980s, involved conceptual data integration, data modeling, and data handling. The need for enterprise-wide horizontal integration led to very large database systems (DBS) in the late 1980s. This step is considered the third stage in the historical development of knowledge management. In the 1990s, information was considered as a production factor and object oriented database management systems (OODBMS) were implemented for data warehousing, data mining, and document management. This advance is considered the fourth stage in the evolution. Finally, knowledge management emerged as a business approach in the late-1990s with new technological tools including information and communication technology (ICT), knowledge management systems (KMS), customer relation management (CRM), web portals supported by “intelligent technologies”, and a new model to structure data called extensible markup language (XML). Now, in the 2000s, the ability to deploy and exploit knowledge is recognized as being crucial to corporate survival.

### The Nature of Knowledge

The complexity of knowledge management is compounded because optimal mechanisms for acquiring knowledge are related to the type of knowledge. Tacit and explicit knowledge are the two primary categories of knowledge, as identified or supported by Polanyi in 1966 *(9)*, Nonaka in 1991 *(10)*, Koulopoulos and Frappaolo in 1999 *(11)*, Tiwana in 2000 *(12)*, and Gamble and Blackwell in 2001 *(13)*.

The nature of knowledge itself must be considered as a knowledge management system is developed. Knowledge can be classified into two broad categories: tacit and explicit *(10)*. Tacit and explicit knowledge are different in nature, and only by understanding their nature, components, and differences is it possible to select or develop the right tools to capture and transfer knowledge efficiently.

*Tacit Knowledge*

Tacit knowledge resides in the minds of people. The acquisition of tacit knowledge is usually developed through a process of trial and error during practical experience. This is the reason tacit knowledge is so difficult to articulate, formalize, and encode. If knowledge gained from practice remains only in the minds of people who had the experiences, then this knowledge is lost when the experienced employees retire or change employment. To turn personal knowledge into corporate knowledge, subjective tacit knowledge must be externalized to an explicit form of representation. Once the knowledge is externalized, it is easier to move across communication networks. Three challenges are faced by an organization in this process. The first challenge is to capture and formulate tacit knowledge in a communicable form. The second challenge is to make the knowledge easily available to the entire organization. The third and ultimate challenge is to develop an organizational culture for seeking and using tacit knowledge.

Knowledge that comes from experiences accumulated by a field engineer over the years is an example of tacit knowledge. The lessons learned by this engineer are not written in any book or manual and will be usually transferred to other engineers by mentoring

*Explicit Knowledge*

Explicit knowledge is formal knowledge or information. The acquisition of explicit knowledge is usually achieved by formal study through some type of education process. Since explicit knowledge can be articulated in formal language, it is much easier to convey and capture than tacit knowledge. An example of explicit knowledge is knowledge that is in the manuals, books, and articles, or any other written document.

**Knowledge Transfer**

What really distinguishes an organization from another is not its explicit knowledge. The key to its competitiveness resides in tacit knowledge, and one of the core objectives of knowledge management is to expand the understanding and application of tacit knowledge throughout an organization. Preserving this knowledge and maintaining security checks through the transferring process is an additional challenge for practitioners.

To transfer knowledge through codification, tacit knowledge has to be made explicit. However, as shown in Figure 5, tacit knowledge cannot be fully transformed into explicit form. Further, explicit knowledge can only rarely be fully personalized or internalized by an individual. Thorough transfer and personalization of knowledge is the goal of knowledge management, and personalization allows a more thorough transfer of both types of knowledge *(14)*.

The limits of knowledge explicability or externalization are difficult to establish in a practical sense. There are usually trade-offs between explicit and tacit knowledge that make establishing limits difficult. Codification of explicit knowledge usually involves less cost than personalization of tacit knowledge. On the other hand, an effort to convert tacit knowledge into explicit knowledge through codification, without losing personalization, is a real challenge. The goal is to move the limit of explicability from explicit knowledge toward tacit knowledge, finding a point of equilibrium between codification and personalization. Accomplishing this reduces the gap between explicit and tacit knowledge.

### Knowledge Management Systems

Knowledge management systems are defined as the integration of technologies and mechanisms to support knowledge management processes that help in discovering, capturing, sharing, and applying knowledge *(15)*.

To support each of the four processes there are structural means used by a knowledge management culture within the organization. These means are called “mechanisms of knowledge management”. A mechanism involves some kind of organizational arrangement to achieve certain objective. Examples include face to face meetings, mentoring programs, and employee rotation. Mechanism does not necessarily involved technological tools, although mechanisms are very limited in their scope without technology.

Technologies indeed, constitute a key element in knowledge management systems. No matter the complexity of the technology in practice, from database management systems to artificial intelligence expert systems, a common interface to connect knowledge is needed.

## KNOWLEDGE MANAGEMENT FOR PAVEMENT MANAGEMENT PRACTICES

AASHTO states that the purpose of a pavement management system is “to improve the efficiency of decision making, expand its scope, provide feedback on the consequences of decisions, facilitate the coordination of activities within the agency, and ensure the consistency of decisions made at different management levels within the same organization” *(16)*.

Experiences in the last years have shown that engineering tools and business principles are not sufficient to fulfill the purpose of pavement management systems. A knowledge management approach integrated to pavement management practices can make the difference. The knowledge management approach proposed for pavement management practices emphasizes the importance of the human factor and how to get the best outcomes from human assets.

From this perspective, pavement management systems are seen as a tool for knowledge discovery rather than as a mean to provide final answers. As a matter of fact, the process of knowledge discovery is envisioned as an iterative loop cycle which is completed only when the decision-maker is satisfied with the information generated by the system.

### A Case-Based Knowledge Management System

A case-based knowledge management system working in conjunction with technological tools is proposed for pavement management practices due to its many advantages. A case-based knowledge management system facilitates knowledge acquisition and maintenance of the system. It is also expected to perform better than rule-based systems which are hard to develop because of the broad nature of the domain of pavement management practices. Furthermore, it can directly contain knowledge from different experts in a variety of fields, bringing the user of the system access to broad knowledge domain.

This case-based knowledge management system will be organized in knowledge categories for easy storage and retrieval. Knowledge will be expressed as cases which will be used to explain certain approach or methodology, to present results from previous studies, communicate agency’s policies, or to introduce unique tools for pavement management practices. This knowledge cases will be stored in a repository system at which each member of the community of practice can access. The repository system will not exclude traditional sources of information including books, research reports, presentations, newsletters, and technical papers among others.

## Components of the Knowledge Management System

Due to the combination of factors and extends of the approach, it is hard to list the components of a knowledge management system explicitly. However, the components can be identified by the knowledge process that they support. Some components may share a common mechanism or technology.

The entire knowledge management system can be visualized as being composed by four primary components which are integrated under one common framework. The four components are: knowledge discovery, knowledge capture, knowledge sharing, and knowledge application. These components are shown in Figure 6 *(15).*

Some knowledge management systems are focused just in one of the four knowledge processes discovering, capturing, sharing, or applying, even though all of them need attention. However, the four processes must be addressed in some way by the system to fully implement a knowledge management system.

### *Knowledge Discovery*

Knowledge discovery supports knowledge creation by combining existing sources of explicit knowledge or by enabling the formation of new tacit knowledge through socialization. Mechanisms used to foster knowledge creation include meetings, conference calls, telephone conversations, cooperative team work, employee rotation, and others. Among the technologies available for knowledge discovery are web-based access to knowledge databases, electronic mail communication, peer network, and video conference.

### *Knowledge Capture*

Knowledge capture supports knowledge retrieving from people or from organizational entities. Lessons learned records, mentoring program, face to face meetings, models, and prototypes are some of the mechanisms used to capture knowledge. Knowledge technologies for capturing knowledge involves chat groups, best practices and lessons learned databases, expert based systems, computer-based simulations, and artificial intelligence. In pavement management practices, knowledge capture can be enhanced through the use of a case-based system. This case-based system offers a repository knowledge database that the decision-maker can use as a reference to set input parameters, to adjust prediction models, to learn about strengths and weaknesses of new methodologies and techniques, to review treatment costs, and to be aware of the results of maintenance and rehabilitation strategies implemented by other agencies.

### *Knowledge Sharing*

Knowledge sharing assists in communicating knowledge. Sharing knowledge implies that the receiver understands the knowledge well enough to apply it and solve problems. Mechanisms to support knowledge sharing are similar to the other systems. Technologies are well-developed in this area with emphasis in using web-based systems to gain access to databases containing best practices and lessons learn records, and expertise locator systems. Knowledge sharing involves mechanisms to ensure that knowledge is distributed to the right person and being understood and correctly applied. A web-based platform is recommended as a supporting tool for knowledge sharing. A peer-network can be developed among members of the community of practice to share experiences and bulleting boards can be used to encourage knowledge sharing.

*Knowledge Application*

Knowledge application assists individuals to utilize knowledge without really acquiring, or learning that knowledge. Some of the mechanisms used to support knowledge application are organizational policies, standards, work practices, and support centers. Technologies vary from expert systems, case-based reasoning systems, decision support systems, to simple directions or instructions or a most frequency asked question section.

## CONCLUDING REMARKS

This paper is a first step in developing a model for a knowledge management approach for pavement management practices. However, much remains to be done in this complex field of research since practitioners need effective tools to help them make decisions.

The following step in this research is to assess how the proposed knowledge management approach can assist practitioners to improve the strategic decision making process in pavement management practices. This second stage of the research will involve:

- Discussion on the capabilities and limitations of the tools proposed to capture, store, and distribute knowledge.
- Results of the research on the applicability and usefulness of the integration of a knowledge management approach to pavement management practices.
- Recommendations on the type of reports needed in pavement management to convey knowledge at the strategic level.

Case studies will be used to assess the applicability of the proposed knowledge management approach. Particular attention will be given to evaluate the usefulness of the approach in identifying the stream of investments needed to achieve multiple agencies' objectives set by pavement management policies. The efficiency of the tools to convey knowledge will be also discussed. Examples will be presented to illustrate the applicability of these tools with emphasis on the types of reports needed at the strategic level.

Three basic goals for implementing a knowledge management system are to strengthen existing communities of practice and promote the development of new communities of practice; to improve information accessibility; and on-going capture of new knowledge and resources. An intimate relation between agency's goals and the benefits from a knowledge management system exists. Benefits are consequences of this relationship, the stronger the relation the greater the benefits. Many benefits are expected from the integration of a knowledge management approach to pavement management practices. According to previous experiences, benefits can be foreseen on an improvement of employees' performance and their level of satisfaction as well as on an overall improvement of organizational performance directly or indirectly. Direct benefits on revenues or costs are expected which are translated into a higher return of investment. Competitive advantage is also mentioned as an indirect benefit, which is the difference between the organization and other organizations. To achieve these benefits, knowledge management systems must support organizational growth through on-going improvement of existing organizational processes in three major areas: effectiveness, efficiency, and degree of innovation.

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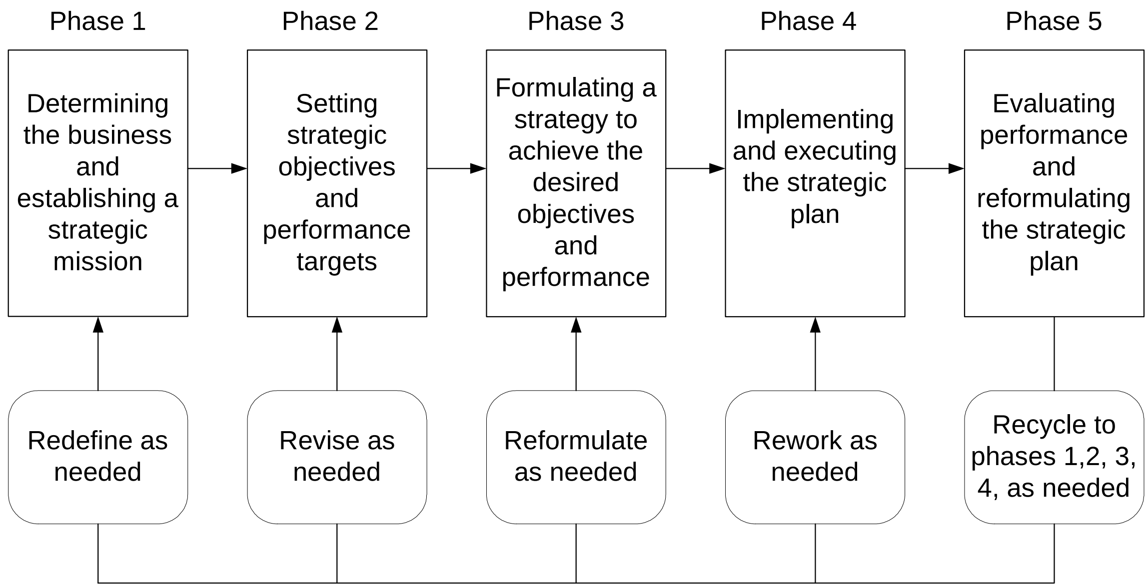


**FIGURE 1 The Process of Strategic Management *(1)***

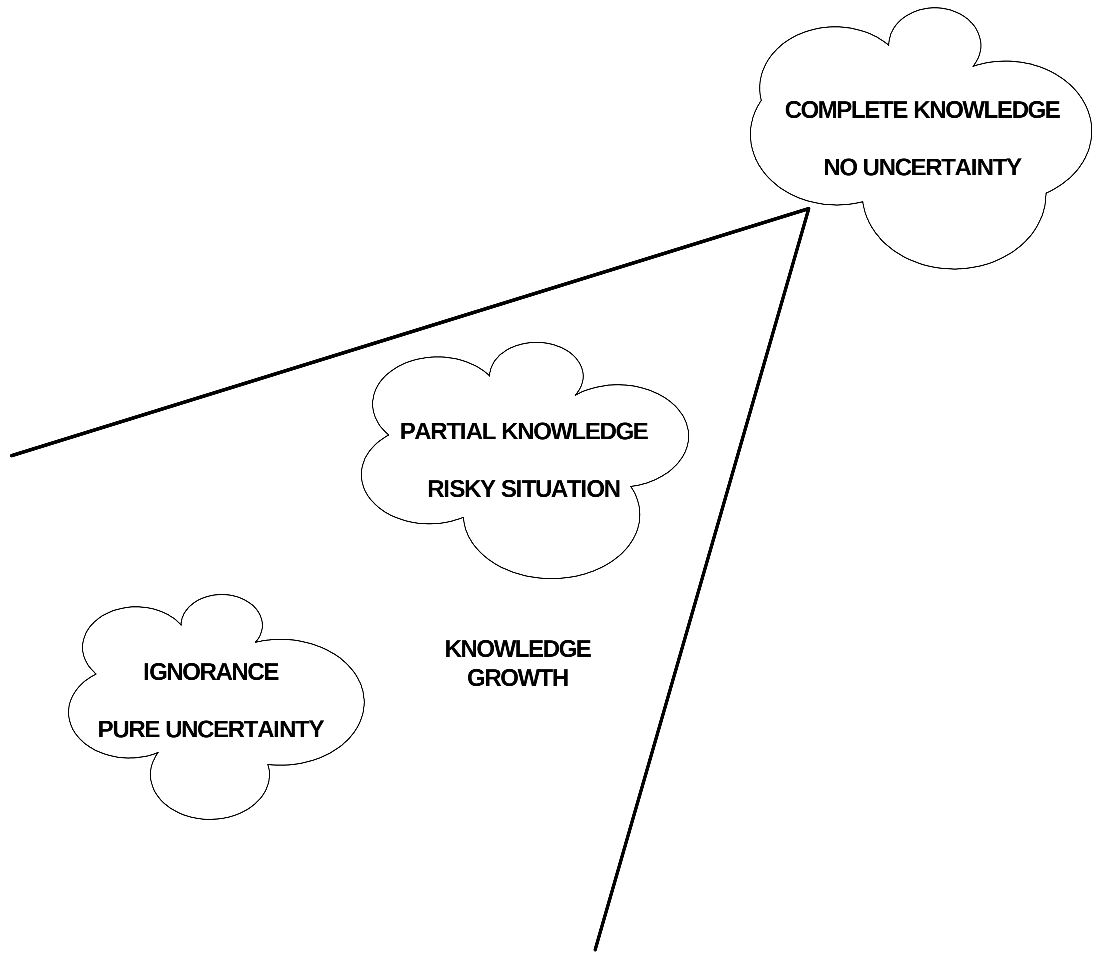


**FIGURE 2 Uncertainty and Knowledge Growth**

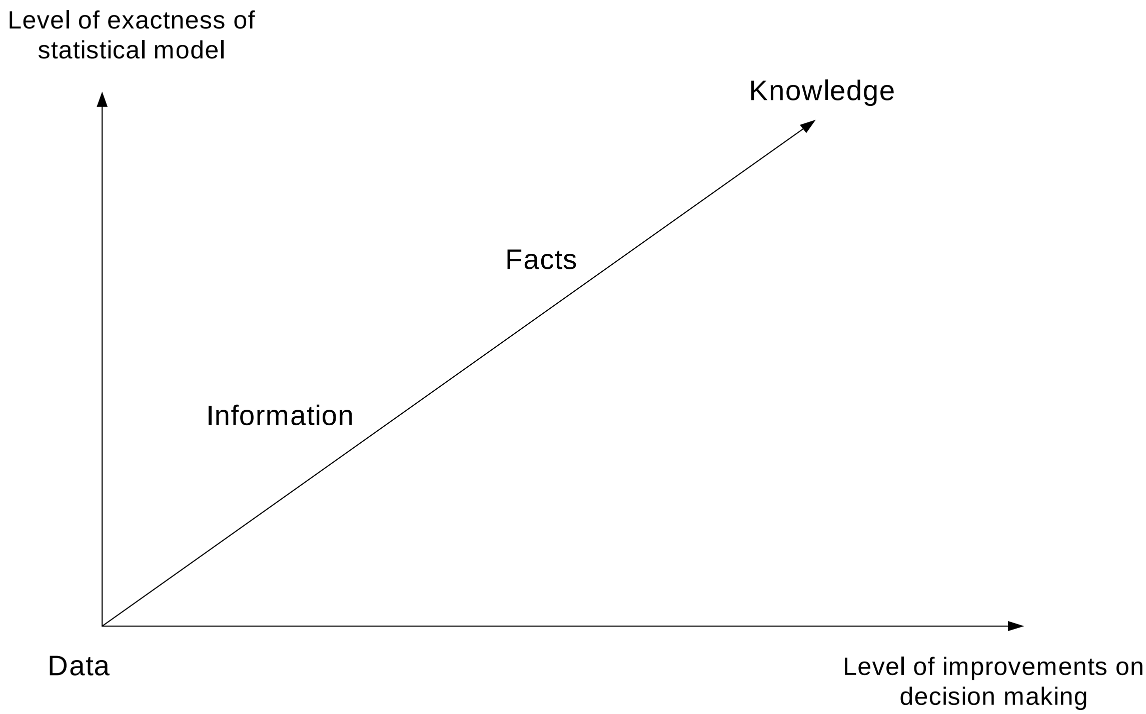


**FIGURE 3 Knowledge Evolution Process from Data *(5*)**

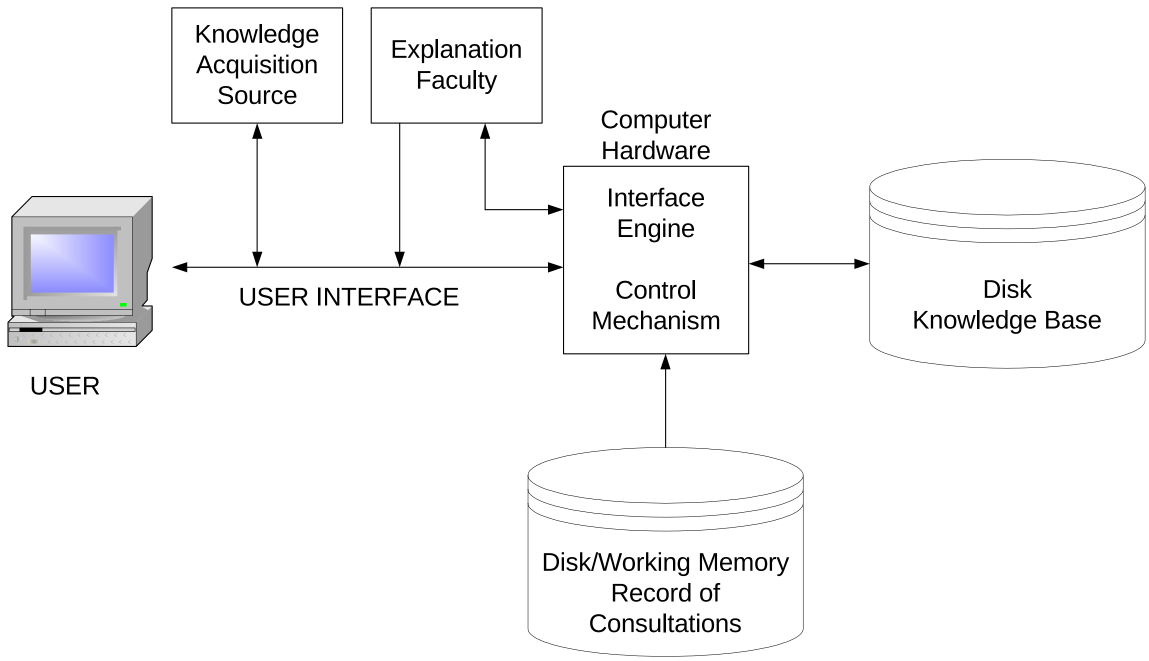


**FIGURE 4 Basic Components of Knowledge Base Expert System *(after 6)***

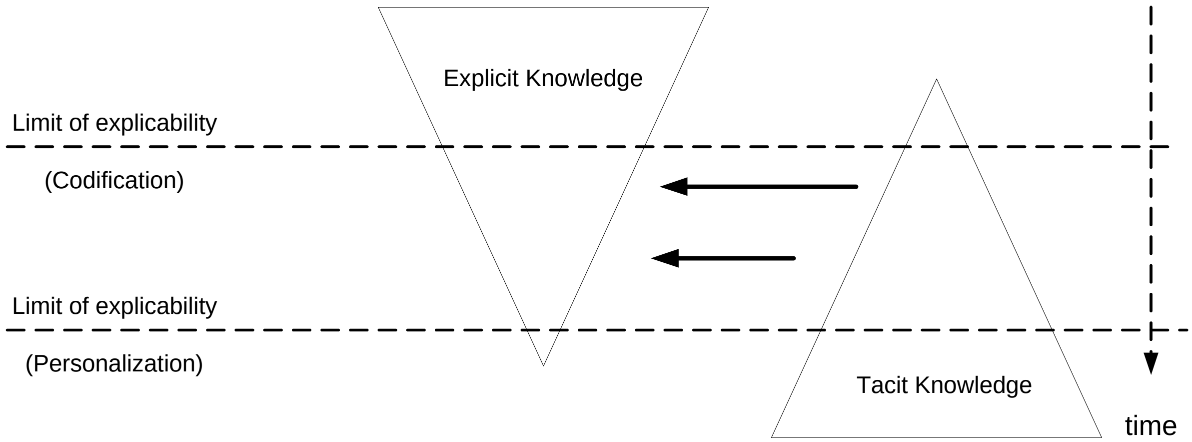


**FIGURE 5 Limits of Knowledge Explicability *(after 14)***

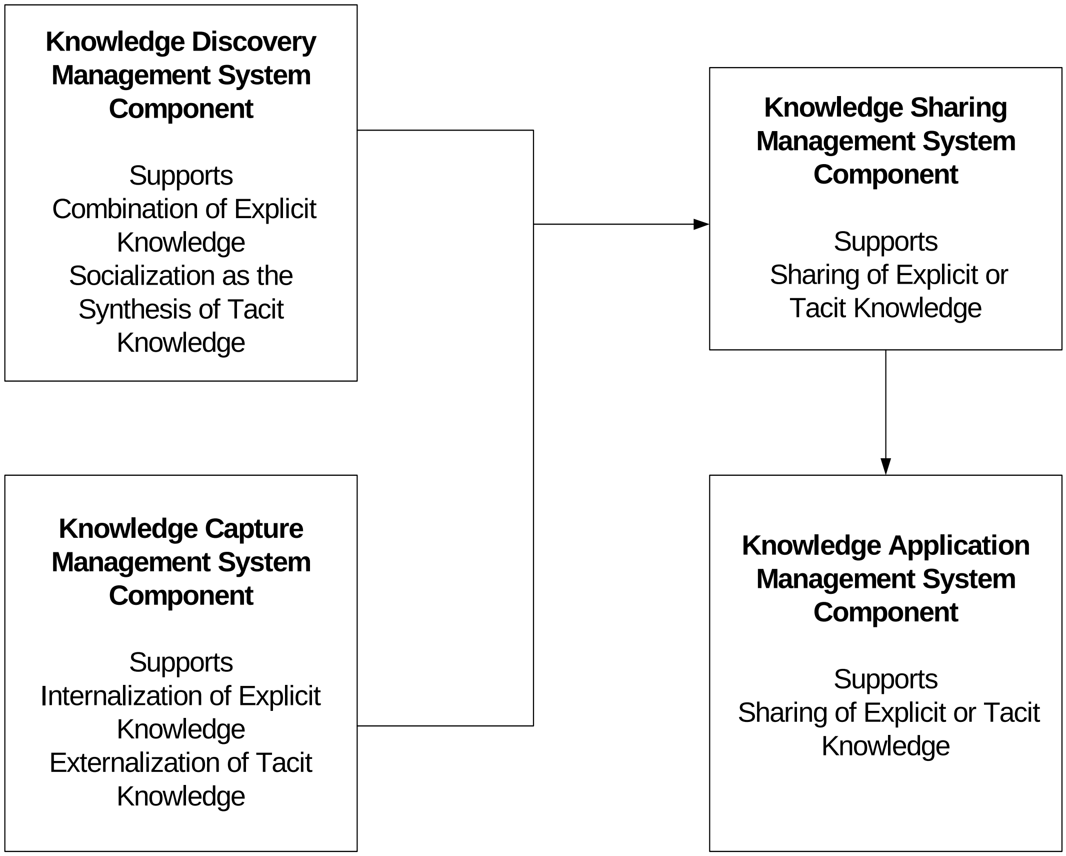


**FIGURE 6 Knowledge Management System Components *(after 15)***