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MODEL MANAGEMENT AS A COMPONENT OF A KNOWLEDGE MANAGEMENT SYSTEM: CAPTURING MODELING KNOWLEDGE IN THE ENTERPRISE

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Abstract

Models should be part of the organizational knowledge that is made available in a comprehensive knowledge management system. However, modeling knowledge entails some difficulties that differ from other forms of knowledge. We outline the requirements for a knowledge management system that includes support for modeling. We want to point out the differences between models and other forms of knowledge, put out an agenda for research based upon those differences, and solve at least one problem caused by the differences.

Introduction

Computer-based information systems can provide managers with a wealth of data. More than twenty years ago, John D. C. Little wrote, "The amount of data handled by a large company is staggering. Business runs on numbers." (Little 1979) With the spread of ever more computer applications, more data is generated internally than when Little wrote his paper. Additional data is available today from external sources (Curry 1993, Marshall 1996). Many questions that managers ask can be answered with straightforward information retrieval combined with such simple operations as addition, segregating numbers into groups, taking ratios, charting, sorting, and picking out exceptional cases. These kinds of simple operations require so little effort with today's software that there is little point in managing them beyond enabling people to do them as needed on an *ad hoc* basis.

Other questions that managers ask concern data that is not to be found. For example, "How many widgets will we need to order from our suppliers next month?" or "What was the impact of the competition's reduction of prices in the Kansas City market?" or "Where is the most cost-effective place to locate a new plant to minimize our logistics costs?" The common thread among these is that they concern data that does not exist in the transaction database, nor the data warehouse, nor the data the firm can buy from outside suppliers. In each case, the question calls for analysis. Answering the question requires a model.

It is well-known that models are important. Occasionally, models have a large financial impact. According to Robert Crandall, former CEO of AMR and American Airlines, "We estimate that yield management has generated $1.4 billion in incremental revenue in the last three years alone. This is not a one-time benefit. We expect yield management to generate at least $500 million annually for the foreseeable future. As we continue to invest in the enhancement of DINAMO [dynamic inventory and maintenance optimizer -- the yield management system] we expect to capture an even larger revenue premium." (Smith et al. 1992). Although this system is exemplary rather than typical, modeling and analysis are knowledge activities with significant potential impacts on costs and revenues. It is not isolated. Recently documented in the literature are:

- models to support truck scheduling, harvesting, location of machinery and roads, and forest planning, resulting in gains estimated to exceed US$20 million per year for the Chilean forestry industry (Epstein et al. 1999)
- models to schedule field engineers at British Telecommunications save $150 million per year (Lesaint et al. 2000)
- models to construct portfolios to reduce the annual cost of trading at Van Otterloo and Company by at least $4 million (Bertsimas et al. 1999)

Most models will not save their companies millions of dollars. However, they can serve as a basis for new policies and procedures, recommend operational action, or just provide insight. In each of these roles, models serve as vehicles of understanding and offer value to the knowledge worker.

Although not all organizations employ models, models are a part of many organizations' knowledge. The knowledge that a firm possesses takes many forms. Some knowledge, like patents and operating procedures, is explicit. Other knowledge is tacit. Modeling knowledge takes both forms.

Models are an intellectual asset of the enterprise. Models represent explicit knowledge. Also, the knowledge about the model is (unless documentation practices are exemplary) tacit. This tacit knowledge is difficult to share beyond the immediate work group of the model creator. This can result in unnecessary duplications of effort. For example, one author of this paper has direct knowledge of a series of similar budgeting models that were developed in many sales offices of a major pharmaceutical company. At the same time, the difficulty in sharing resulted in some applications of the model being overlooked. Not every sales office in that pharmaceutical company used a budgeting model; those that went without were controlled inefficiently. At the same time, those offices which used a budgeting model were also inefficient because they failed to use an already-created model and instead built one from scratch.

The knowledge management literature has largely overlooked modeling knowledge *per se*. Many articles and books in the area do not mention models at all. Others make statements that could be interpreted to include models. Bohn (1994), for example, does not mention models explicitly, but does mention algorithms as one of his stages of knowledge growth. We believe that some aspects of models and modeling processes require some differences in how the knowledge about them should be managed from how other kinds of knowledge should be managed.

Models are also different from most software. Modeling knowledge should typically be differentiated from other forms of algorithmic knowledge such as might be embedded in the organization's transaction processing systems. Most software that an organization possesses is embedded into the organization's procedures. That can be the case with modeling knowledge. However, it is our observation that most models are used by an individual or a workgroup to analyze a situation, or to provide insight for a decision. Some models are used once and discarded. Others are used routinely by their workgroup, but fail to be available across the organization. According to Wright et al. (1998), "Models are most likely to be managed at the departmental level rather than centrally in an organization . . . [and] within department interactions (e.g., model sharing) are the most frequent and interactions across departments are the least frequent."

There are several advantages to a firm from systematically managing their knowledge about modeling. Making models available across the organization would reduce duplication of effort or would permit application of the modeling to a situation to which it could apply. Typically, the expertise needed to run a model and interpret its output leaves the firm with the model's creator, even though the modeling data and software remain with the firm. The need to capture this expertise for firm is typical of the type of problem that knowledge management initiatives address.

In trying to classify models in terms of existing knowledge management frameworks, we find an interesting contradiction. On one hand, the knowledge embedded within the model itself is explicit and at a high stage of knowledge (Bohn, 1994). On the other hand, knowledge about the model -- *metaknowledge* -- is usually tacit and at a low stage of knowledge. We propose codification of this metaknowledge.

The problem this paper addresses is the application of frameworks from the knowledge management literature to the problem of model management. We will explain that this offers insights about modeling beyond those found in the model management literature alone.

Theory of Organizational Knowledge About Models

One problem is that when a model is created, much of the knowledge within it has been embedded in a tacit way.

To illustrate how knowledge about models might be managed, we follow a framework from Nonaka and Takeuchi (1995) which posits four modes of conversion of knowledge through a firm. Their framework, illustrated in Figure 1, assumes that knowledge is created via conversions in form. The conversions involve movement among tacit and explicit forms. There are four possible modalities: tacit to tacit, tacit to explicit, explicit to tacit, and explicit to explicit. They suggest that knowledge creation is a repeating cycle among the four quadrants in Figure 1.

From/To	Tacit Knowledge	Explicit Knowledge
Tacit Knowledge	Socialization: Sympathized Knowledge	Externalization: Conceptual Knowledge
Explicit Knowledge	Internalization: Operational Knowledge	Combination: Systemic Knowledge

Figure 1. Nonaka and Takeuchi's Knowledge Conversion Framework

To illustrate how this cycle might operate with modeling knowledge, consider models of airport operations. We begin with a model of a single aspect of the airport. The model might, for example, simulate the flow of passenger foot traffic among gates at a hub. The simulation would serve to suggest how much time an airline must allow for its passengers to travel between gates to make a connection. The simulation might also be used to investigate the impact of facilities to speed passengers along, such as moving slidewalks or trams. That model includes information about facility layout that are applicable to other aspects of the airport, such as baggage handling. The approach to generating the original model is applicable to other airports. Eventually models about airports can be linked into an overall model of the air traffic system. However, before any of that spread can occur, the people who manage baggage operations must become aware that the original model exists, that the expertise to create the model exists, and that expertise must be available. (Our discussion of creating the model and conversions among them is oversimplified to conserve space. A realistic discussion of model creation has appeared in (Pidd 1999)). Let us examine all four quadrants of Nonaka's framework in turn.

Externalization concerns movement of knowledge from tacit to explicit. Model formulation, the building of the model itself for a particular application, is an example of knowledge externalization. The modelers come to the situation with tacit knowledge of the application and modeling technology and transforms some combination of those into a rigidly explicit model that can be run on the modeling software available. The process of building a model usually involves starting with a simple model of the situation that makes many assumptions to achieve parsimony. As modelers work with the model and gains understanding about the application, they add more and more details that complicate the model until it is realistic enough to answer the question(s) being asked. The modeler may be an individual or a workgroup. This is the typical work of the management science analyst. If supported by a knowledge management system, the externalization work would be captured as it occurs with a goal of making the knowledge available to others later. Alternatively, the model might already be finished, part of a legacy of existing models. The knowledge management system would need to provide access to this legacy knowledge.

During the externalization mode, the airport modeler must find sources of tacit knowledge in the application area domain to complement his tacit knowledge from the modeling domain. The modeler would use common techniques such as interviews or observations to gather appropriate knowledge. For simulation of passenger movements, the modeler would have to rely on the knowledge of airport operations staff and the gate agents of the airlines. Knowledge from other sources, such as facility layouts, flight schedules, and personnel schedules that may already be available in explicit fashion would also be gathered. The modeler then builds a simulation study of passenger movement, and uses that as an experimental platform to study the impact of possible new facilities or procedures.

The second mode of knowledge conversion is combination: movement of knowledge from explicit to explicit. In analytical modeling, combination occurs during model reuse and integration. Model reuse occurs when the explicit knowledge represented by the model is reapplied in a new context. Model integration occurs when a model is combined with other existing models to form a new overall model. Although model integration may sound esoteric to those unfamiliar with analytical modeling, it is not an uncommon requirement: some of the parameters in one model may be in turn estimated or forecast based upon other data. All but 12% of Wright et al's (1998) respondents reported some kind of model integration requirement. Although model integration today is often done manually, there have been several proposals for automating and supporting model integration. Muhanna and Pick (1994) viewed models as systems with subsystems that were combined to create new systems by linking their interfaces. Blanning (1985) viewed models as analogous to relational databases, and the combination of models as a join. Klein (1986) stringed models together to achieve a desired result. The point of this from a knowledge management view is that combination is an important stage of model use and that need is already recognized in the model management literature.

In our airport example, the simulation might have its layout-specific data changed and reapplied to model a different airport. Likewise, the departures and arrivals of airplanes at the gates might be included. Once we have gate management, we can examine servicing of aircraft and movement through ramp areas. These in turn might be combined with more global airport operations such as take-offs and landings in order to arrive at a simulation for the entire airport's operations. Some of these models may have already been available through previous efforts, and others may be recent developments. Even at this level, airport simulations could be combined with other airports to create an overall model of air traffic control for hub management at a regional, national, or international level.

The third mode of knowledge conversion is internalization, or a movement of knowledge from explicit to tacit. Internalization entails understanding of models in other workgroups or other application areas. Effectively, this applies the model to the problem setting so that productive decisions based upon the model can be made. Here, the operations group and management science analysts learn from application of the model. Internalization is strengthened through continued application or reuse of the simulation.

For the airport, the analysis of the simulation would result in new policies or practices. As the ground operations staff implements the policies and practices, they turn the explicit knowledge generated by the model analysis into the tacit knowledge required to practice their professions.

The fourth and final mode of knowledge conversion is known as socialization: movement of knowledge from tacit to tacit. This entails internalized understanding of modeling moving to appropriate groups in the firm. Socialization involves such informal things as sharing things around the coffee pot as well as formal things like mentoring relationships. This involves sharing tacit knowledge about the model that has been built. In modeling, socialization plays two low-key roles. The first is sharing across domains, and the analyst gathering tacit knowledge about the application domain. Socialization is also about the analyst communicating his knowledge about the model with others -- informal training about the model itself.

Socialization of the air transit model that has grown out of our continuing efforts may result in applying the model to a new, related domain such as simulation of railroad track utilization.

Requirements for Knowledge Management About Models

To fully support the creation of knowledge about models, a knowledge management system (KMS) will support the four modes of externalization, combination, internalization, and socialization.

Externalization is supported by existing modeling environments, modeling languages, and tools including such things as GAMS and spreadsheets. Many DSS tools and DSS generators, especially those intended for model-based DSS, support externalization. In many organizations, a wide variety of tools to support a variety of modeling approaches will be helpful (Dhar and Stein 1997).

Combination continues to be difficult, and several proposals (Blanning, 1985; Dolk and Konsynski 1985; Klein 1986; Muhanna and Pick 1994; Sharda and Steiger 1996) have been made to support it. These proposals can all be characterized as technical in nature, and the final word in this area has yet to be published.

Difficult though combination may be, in an organizational environment, especially that of a large organization, the more difficult problem may be finding that a model already exists in an organization or that modeling expertise already exists in an organization. Gordon and Fry (1989) have suggested an approach to organizing models to assist in later retrieval. Balasubramanian and Lenard (1998) have looked at capturing modeling knowledge from spreadsheets, and their approach shows promise for other types of knowledge. The need is for making people aware of a model rather than providing one modeling system that is able to manage all models (Wright et al. 1998). This is a portion of the issue of internalization. The remaining portion involves transferring the model or modeling expertise once they become aware of it.

The socialization of knowledge about models would involve sharing of tacit knowledge. This would be done not by storing the knowledge in a computer-based system, but by using technology to enable better interpersonal communications. Computers may support socialization via such communication tools as skill directories, presentation software, and e-mail.

To illustrate the requirements that models entail upon a knowledge management system, we propose the framework shown in Table 1. The framework puts Nonaka and Takeuchi's four modes of knowledge conversion along the vertical axis. Herbert

Simon's (1960) well-known model of decision-making makes the horizontal axis. (The irony that Nonaka and Takeuchi (1995, pages 37-39) criticize Simon's work is not lost on us. We do, however, believe that Simon's steps are a descriptive (but simplified) description of modeling activities and that integration of the two viewpoints is a crucial requirement for knowledge management support of modeling activity.) To populate the cells in this table, we found in the literature lists of activities that are part of either modeling or part of model management. For each such activity, we have classified in terms of both Simon's framework as well as Nonaka and Takeuchi. Although not all of the cells are occupied, each cell contains a type of model management activity which supports the given mode of knowledge conversion and the given phase of decision making.

Table 1. Knowledge Conversion Problem Solving Framework

	Intelligence	Design	Choice	Implementation
Externalization	Problem statement	Formulation; Data management; Model representation; Model base access	Execution of model;	
Combination	Model base access	Model evaluation (feasibility); Model base access; Model verification	Model selection; Model combination; Model modification	Data management; Model training
Internalization	Environmental scanning		Sensitivity analysis; Execution; Model interpretation	Application; Model training
Socialization	Problem identification			Implementation reviews

This table documents that a wide range of activities already documented as being part of modeling or model management activities can be classified as both a problem-solving activity as well as a knowledge conversion activity. As such, they can be used to create knowledge via the four steps of knowledge conversion.

An Architecture for Knowledge Management for Modeling

A Knowledge Management System (KMS) to support model management must be part of a comprehensive KMS for the organization or organizational unit. If it is isolated into a separate model management system, people who are ignorant of the applicability of the firm's modeling knowledge are likely to remain ignorant. Thus, if there is a yellow pages directory for people, it should include references to modeling experts. If the yellow pages includes pointers to such objects as best practices white papers, then it should include pointers to models or to white papers about them. Thus, the design for a KMS for modeling must also be an appropriate KMS for the organization. In this section, we will outline how the requirements of including modeling knowledge add to the requirements of the overall KMS.

We adopt a layered architecture which appeared in (Pick and Schell 2002) for the KMS as shown in Table 2. The top layer, dialog management, would reside upon a desktop client machine. We propose using an ordinary web browser for this purpose. Communications between the client and servers would use standard Internet protocols, as illustrated by the transport layer. The next layer, collaborative filtering and intelligence serves to reduce information overload. Below that is the heart of the knowledge management system, which we call the application layer. As we see it, applications would be further divided into three general areas. The first application area would be general knowledge such as yellow pages, lessons learned/best practices white papers, collaborative tools, and e-mail. The second application area would be meta-modeling knowledge. Meta-modeling includes model training, model selection, model integration, and model description (documentation/coding). The third application area would be modeling knowledge. This includes model formulation, model verification, model interpretation, data/model integration, sensitivity analysis, and model execution. Below the application layer are tools to import existing models into the application layer; for new models, it would be the identity. The bottom layer is a repository of data and models. In all likelihood, there would be additional transport layers between some or all of the layers. That is, various layers would exist of various servers interconnected by TCP/IP. This would be a multi-layer client-server architecture. However, the added transport layers are omitted for brevity.

Table 2. An Architecture for a Knowledge Management System to Support Modeling

Name of Layer	Items Within Layer
Dialog Management	Web browser
Transport	TCP/IP
Collaborative Filtering and Intelligence	Intelligent agent tools and knowledge portal
Application (knowledge management)	Skill directories, e-mail, model codification and documentation, search tools, model formulation, model representation, model integration, model base access
Legacy Integration	Import tools
Repository	Data Warehouses, Data Bases, and Model Bases

Due to the space limitations of this conference, this architecture is not sufficiently detailed to show how it would support every phase of modeling activity. We will illustrate with two short examples. One place where we see socialization of modeling occurring would be during the intelligence phase with problem identification. During that phase of modeling, we could use an organization-wide skills or "yellow pages" directory to find people with requisite skills or experience with that type of problem. By linking one person with the tacit knowledge to one who needs the knowledge, the skill directory would support conversion of knowledge from the tacit to the tacit. Access to such a directory would be part of the application layer of the architecture. The directory itself would be stored in the repository layer. A similar use of a skills directory could occur if a person had the explicit output of a model, but lacked the knowledge to interpret the output or apply it in the organization. That modeling activity is model interpretation, and would involve moving the explicit output into the tacit ability to apply it.

Conclusion

This paper ties together elements of the model management literature with elements of the knowledge management literature in order to propose the organizational and technical elements needed to build a system to extend modeling expertise throughout an organization. Models represent knowledge explicitly, yet the knowledge about the model and its application typically remains tacit. This simultaneous explicit and tacit character of model management makes it a suitable application for knowledge management techniques. We have put together a framework for analyzing modeling and model management activities into context with knowledge management, specifically, the knowledge conversion framework of Nonaka and Takeuchi. Future research will attempt to study the validity of our categorization of modeling into this framework and to make more specific proposals for capture of tacit modeling knowledge into explicit form.

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