# Applying Systems Thinking to Knowledge Management Systems:
# The Case of Pratt-Whitney Rocketdyne

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**Abstract.** This paper describes Pratt-Whitney Rocketdyne's use of a systems thinking methodology to define and improve knowledge management (KM) within the firm. Using systems thinking, the company identified and changed key behaviors within the KM environment and effectively established a generative learning environment. The study sheds light on how organizations can improve KM practices.

**Keywords:** Knowledge management systems; systems theory; systems thinking; aerospace industry.

# INTRODUCTION

Despite the importance of knowledge as an asset, few organizations truly understand what it means to be a knowledge-based firm and how to manage knowledge to achieve their goals (Yu, 2005). Knowledge management (KM) is the process of identifying and leveraging the collective knowledge in an organization to help the organization compete (von Krogh, 1998; Alavi and Leidner 2001). For most firms KM is achieved through a series of initiatives that seek to build a culture and infrastructure that connects people and processes (Davenport and Prusak, 1998). Frequently these initiatives rely on KM information systems, such as knowledge repositories and expert databases, to manage organizational knowledge (Alavi and Leidner, 2001). However, while many managers embrace KM initiatives as the solution, few understand the problem KM initiatives are meant to address. The result is often KM solutions that are expensive, frustrate employees, and lack the focus needed to provide tangible value to the organization (Cohen, 2006; Gilmour, 2003).

This reality is particularly striking in the face of significant research in the last decade directed at better understanding knowledge and improving KM practices (e.g., Davenport and Prusak, 1998; Hansen, et al., 1999; Majchrzak, et al., 2005). Alavi and Leidner (2001) propose a framework that breaks down KM in organizations into four core processes: the creation, the storage, the transfer, and the application of knowledge. However, increasingly researchers are recognizing that multiple processes, structures and resources within a firm interact to affect KM efforts (Sambamurthy and Subramani, 2006). KM is not a one-time project or even a set of projects, but rather a dynamic set of processes and practices, embedded in both people and structures (Alavi and Leidner, 2001). In this paper we build on this emerging perspective and suggest that organizational knowledge is best managed when viewed holistically as a set of people, processes, and technology, not merely as a set of individual knowledge processes or technology-based systems. We examine the following research question: What steps can an organization take to effectively implement KM as an integrated set of processes, people, and technology?

To answer this question, we performed an in-depth case study of a KM initiative at Pratt-Whitney Rocketdyne (PWR). Faced with the harsh reality that 50% of the engineers in the aerospace industry were eligible for retirement as of 2007, PWR tried to retain and use the knowledge that otherwise would have been lost. However, the company experienced only marginal benefits. Therefore, in 2001, PWR embarked on a major initiative to revamp its KM using a *systems thinking* methodology, which assumes an integrative, holistic view of KM. As a result, PWR enjoyed tangible cost and opportunity savings of about $25 million.

This paper makes two fundamental contributions. First, we examine the five steps that PWR took to use the systems thinking methodology for KM, and document them for potential application by others. This is one of the first papers that analyzes and reports a real-world application of the systems thinking methodology to improve KM practices. Second, we use an inductive approach based on the results of the case study to propose how systems thinking can improve KM practices. In particular, we discuss how firms can move toward generating new knowledge, which is a critical component in creating and retaining a knowledge-based competitive advantage.

In the next two sections, we review the theoretical link between knowledge management and systems thinking. In the fourth section we describe the use of KM systems thinking at PWR. Finally, in the last two sections we discuss the findings, develop some propositions, and conclude with contributions and limitations.

## KNOWLEDGE MANAGEMENT IN ORGANIZATIONS

A knowledge-based view of the firm characterizes knowledge as a source of competitive advantage (Grant, 1996). That advantage is derived from the knowledge embedded in a mix of the firm's organizational resources, including its people, processes, and technologies (Kogut and Zander, 1996). Knowledge management can be broken down into four core processes: knowledge creation (Pentland, 1995), knowledge storage (Argote, 1999), knowledge transfer (Gupta and Govindarajan, 2000), and knowledge application (Chun and Montealegre, 2007; Grant, 1996). Alavi and Leidner (2001) suggest that it is by actualizing, supporting and reinforcing these processes that information technology can improve KM.

Recent research has largely focused on each of the four KM processes, in order to understand how they affect the ability to manage knowledge (e.g. Cross et al., 2001; Gray and Meister, 2004). Much of this literature treats each individual process as separate from the others, even though they complement and support each other (Venkatraman and Tanriverdi, 2004). The interaction between knowledge processes is captured by Alavi and Leidner's depiction of knowledge transfer (2001, pg 123). Their diagram shows interaction between knowledge application and creation, between application and storage, and between creation and storage. However, prior work has often failed to consider how each of the processes may negatively impact the other and how those relationships may actually hinder organizational KM systems from achieving their goals (Shultze and Leidner, 2002). Ciabuschi (2005) reports that in one company employees often failed to encode and store their knowledge due to fear of losing the unit's competitive advantage. When knowledge *was* stored, only high level specifications were provided. Concerns about knowledge transfer impeded knowledge storage and knowledge creation. In other organizations, pressure on employees to store knowledge electronically can decrease the quality of the knowledge stored and in one case, employees created “more than they knew” (Garud and Kumaraswamy, 2005, pg 26). In another company employees were under such time pressure to store knowledge that they had no time to look for existing knowledge (Gallivan et al., 2003), which meant that existing knowledge was not applied and redundant knowledge was created.

We contend that understanding both the positive and negative consequences of organizational knowledge management requires a holistic perspective. Leveraging KM initiatives to achieve organizational goals requires a deep understanding of how knowledge processes relate to each other, what factors influence knowledge processes and knowledge workers, and how all of these factors relate to the environment (Massey, et al., 2002). Through an integrative understanding both the positive and negative consequences of KM can be explored and the drivers of a successful KM system implementation can be identified. In addition, this holistic perspective must be theoretically sound. Many KM initiatives and the KM literature have lacked a theoretical foundation that can inform the process of KM system development, and in particular the process of KM information systems development (Alavi and Leidner, 2001; Linden et al, 2007). We posit that systems theory and systems thinking provide a foundation that can facilitate such an integrative understanding and can enhance organizational KM practice.

## SYSTEMS THEORY AND SYSTEMS THINKING

Systems theory focuses on the relationships between parts and the properties of a whole, rather than reducing a whole to its parts and studying their individual properties (Ackoff, 1971; Katz and Kahn, 1996; Senge, 1990). Systems theory has been applied to a wide variety of organizational and management issues including innovation (Shen et al 2009), information systems change (Lyytinen and Newman, 2008) and supply chain management (Helou and Caddy, 2006). Recently researchers have suggested that business in general and knowledge management in particular could benefit from leveraging a systems perspective (Atwater et al, 2008; Linden et al, 2007). A system is defined as *"an entity which maintains its existence through the mutual interaction of its parts"* (von Bertalanffy, 1976, pg. 298). Ackoff (1971) translated von Bertalanffy's original definition of a system to the organizational context. Table 1 contains an overview of key systems theory concepts used in this paper. A system is composed of at least two elements and a relation that holds between them. At any given time, a system or one of its elements exhibits a *state*, defined as its relevant properties, values or characteristics. A change in the state of a system is called an *event.* In more common terms, an event is an occurrence, something that happens.

**Table 1. Systems Theory: Concepts and Definitions**

| Concept | Definition | References |
|---|---|---|
| *System* | An entity which maintains its existence through the mutual interaction of its parts. A system is composed of at least two elements and a relation that holds between them. | von Bertalanffy, 1976; Ackoff, 1971 |
| *State* | The relevant properties, values or characteristics of a system element or an entire system. | Ackoff, 1971 |
| *Event* | A change in the state of the system or parts of a system. | Ackoff, 1971 |
| *Behavior* | A system event which initiates other events. | Ackoff, 1971 |
| *Process* | A sequence of behavior that constitutes a system and has a goal producing function. | Ackoff, 1971 |
| *Systemic Approach* | Viewing and interpreting processes from a holistic viewpoint and over time. | Angell, 1990 |
| *System Environment* | A set of elements and their relevant properties that are not part of the system, but a change in any of which can produce a change in the system. | Ackoff, 1971 |
| *Closed Systems* | A self-contained system that is not influenced by elements outside of the system. The system does not have to interact with the environment or another system to maintain its existence. | Ackoff, 1971; Senge, 1990 |
| *Open Systems* | A system that is influenced by elements outside of the declared boundaries. An open system exchanges information, energy, or material with its environment. | Ackoff, 1971; Kast & Rosenzweig, 1972; Senge, 1990 |
| *Dynamic System* | A system whose structural state changes over time. Dynamic systems can be either open or closed. | Ackoff, 1971 |
| *Reinforcing Process* | A relationship where an action produces a result that influences more of the same action, resulting in an outcome of growth or decline. | Anderson and Johnson, 1997 |
| *Generative Learning* | The process of leveraging and customizing existing information to suit individual user's needs and generate new knowledge. It enables innovative rather than reactionary approaches to new problems. | Senge, 1990; Wittrock (1990, 1992) |

There is an important classification of events called *behaviors.* Behaviors are events that initiate other events. For example, an announcement of quarterly earnings may result in changes in the stock price and subsequent strategic actions by the firm. A *process* is a sequence of behaviors that constitutes a system and has a goal producing function. In a process, each behavior brings the system closer to its goal, although goals are not always reached and are sometimes accompanied by other unintended goals. Thus behaviors and processes can lead to either *desirable* or *un-*

*desirable* system states. Viewing and interpreting processes from this holistic perspective and over time is the essence of the *systemic approach* to analysis (Angell, 1990).

A system's *environment* consists of the elements and their relevant properties that are not part of the system. Systems that interact with their environment are called *open systems*. Open systems exchange information, energy or material with their environments (Kast and Rosenzweig, 1972; Senge, 1990). Systems that do not interact with their environment are called *closed systems.* A *dynamic system* is one in which events occur and whose state changes over time. If the elements within a dynamic system only change in response to each other, it is a *closed dynamic system.* If the elements respond to the environment, it is an *open dynamic system.*

One of the building blocks of many dynamic systems is the *reinforcing process.* Reinforcing processes compound change in one direction with even more change in the same direction, and thus they can cause either growth or decline (Anderson and Johnson, 1997). An example of a reinforcing process is the relationship between principle and interest in a bank account. Each time the interest rate is calculated, it is applied to a greater principle, resulting in more interest and ever increasing higher principle.

*Systems thinking* was derived from systems theory and is the basis for the learning organization (Senge, 1990). In relation to knowledge, an important concept in systems thinking is *generative learning.* Generative learning is the process of leveraging, integrating and customizing existing knowledge for new uses (Senge, 1990). In generative learning the focus is not on storing and relisting information, but rather on generating relations and creating meanings that increase understanding (Wittrock, 1992). Generative learning enables innovative approaches to new problems rather than the mere reactionary, and often ill-suited, re-application of old ideas to new problems.

A systems thinking approach to KM recognizes that each time one of the key knowledge processes is enacted, there may be a ripple effect of events and behaviors that may change the state of other sub-systems. Events may be part of reinforcing processes that lead to either desirable or undesirable outcomes. Each knowledge process may lead to reactionary solutions or true generative learning. We define an environment that supports this holistic perspective as a *systemic KM environment*.

Research has just begun to examine how systems thinking may relate to KM (see Gallivan et al., 2003; Gao et al., 2002; Massey et al., 2005; Garud and Kumaraswamy, 2005). These studies have discussed how, at a general level, KM subsystems relate to the whole. For the most part these studies have only posited how systems concepts might be applied to a KM environment. In this paper, we take a next step and examine the explicit use of a systems thinking methodology for KM, which we call *KM systems thinking*. We define *KM systems thinking* as a perspective that integrates the overall events, behaviors, processes, and states associated with knowledge and its management in an organization KM. Rather than applying system theory post-hoc to a firm's KM initiatives, we add to the literature by describing how one company, PWR, actively applied systems concepts to specific KM processes, developed a KM systems thinking methodology and used it to inform the development of KM information systems. Based on analysis of that effort, we offer a set of systems thinking concepts that are adapted to suit the KM context. We also put forth a set of propositions as to how systemic thinking can help organizations achieve KM process maturity, realize desirable KM outcomes and encourage generative learning. In the next sections we describe the research methodology and case study of PWR, which will allow us to develop a framework for KM systems thinking.

## RESEARCH DESIGN AND METHODOLOGY

Consistent with the goal of better understanding the development of KM initiatives over time, this research was designed as a single longitudinal case study. The study focuses on *how* systems thinking was used at PWR, an approach for which case study methodology is appropriate (Yin, 1994). The longitudinal design enabled us to examine the phenomenon over time in a natural setting to engage in theory-building (Miles and Huberman, 1984).

Data were collected in two phases during a 21-month time period. Data collection involved multiple sources of historical data, which were triangulated to establish construct validity and reliability. In the first phase (Nov-Dec 2006), the lead author collected both public and confidential corporate archival data related to KM. Primary sources included internal reports, organizational charts, strategic KM planning documents, minutes of meetings, internal correspondence, memos, and e-mails. Secondary sources included industry reports, public disclosures, media publications, and Internet articles. While collecting archival data, the authors together documented the general direction of the KM initiative, the primary actors involved, and the major decisions made over time.

In the second phase of data collection, the second author of this manuscript and the 15 members of PWR's KM team together spent two months (Jan-Feb 2007) conducting formal interviews with individuals who sponsored, supported, or participated in the KM system implementations. Forty top executives from the firm's eight product groups and six program teams were interviewed. These interviews provided detailed data on how the initiative was perceived and experienced. It also provided details on how KM practices changed during the initiative. To ensure accuracy and to promote triangulation, case data were reviewed and verified by members of the KM department and interviewees. Observation activities were conducted, which culminated in field notes and journal reflections. Covered were activities such as informal hallway conversations with employees, status report meetings, and planning meetings. A database was generated to store the data.

The data extracted from these multiple sources was coded to reflect the themes addressed by the interviewees. The researchers first independently coded the data and then compared coding results to eliminate concerns of bias and to improve inter-rater reliability. The analytical codes and sources of evidence were then grouped into logical categories in order to segment the data. The data were then ordered as a series of sequentially interconnected events and interactions. Key data points (e.g. antecedent conditions, forces affecting decision making, implementation procedures, key players affecting the direction of the implementation, and outcomes over the course of the KM integration efforts) were arranged to document the chronological sequence and to identify patterns. Coding the data and grouping the evidence by dimensions also enabled discovery through a process of inquiry and search for answers. This process also helped to expand and tease out the data in order to formulate new questions and levels of interpretation.

Once coding was completed, the lead author examined the data to generate meanings (Coffey and Atkinson, 1996). The data was put into a temporal process model which was used to identify gaps in the literature and to compare trends in the observed data with those predicted by theory (Yin, 1994). The technique of pattern matching was used to move back and forth between the empirical data and possible theoretical conceptualizations (Eisenhardt, 1989; Yin, 1994). Existing literature was used to provide theoretical guidance to explain the interplay between behaviors, states, and KM processes that existed at PWR.

## KM AT PRATT-WHITNEY ROCKETDYNE

Founded in 1925 in Hartford, Connecticut, Pratt & Whitney became one of the world's leaders in the design, manufacture, and service of aircraft engines, industrial gas turbines, and space propulsion engines. In 2005 the company had an operating profit of $1.4 billion on revenues of $9.3 billion. The firm employs over 40,000 employees and supports more than 9,000 customers in 180 countries. Since its origins, Pratt & Whitney has diversified its product offerings from small engines that power corporate jets, regional aircraft, and helicopters, to commercial airline engines that power more than 40% of the world's passenger aircraft fleet.

PWR is a subsidiary of Pratt & Whitney that focuses on the manufacturing of rocket propulsion and space exploration engines. Engineers are typically hired into process groups and are assigned to product groups. Assignments to a product group can last anywhere from six months to five years, depending on the scope of the project. Throughout their careers, engineers—called *scientists*—are encouraged to switch among six programs and eight product teams to diversify their skills. In the past, scientists were evaluated mainly based on the success of projects in which they participated, so they had little incentive to share their knowledge with other groups. On the contrary, this structure motivated them to hoard knowledge within their own program or product team.

Prior to 2001, each scientist in a program or product team had her own idea of how knowledge was to be managed, which resulted in knowledge silos and an unnecessary duplication of knowledge. In a diagnosis study, the firm found that of the knowledge generated, 30% was duplicated somewhere else within the firm. Further, there was a distinct generational gap between the more seasoned and the newly hired employees, which contributed to an unwillingness to share knowledge. Hence, the ability to learn from existing knowledge was limited.

## Applying Systems Thinking to KM at PWR

In 2001, the executives at PWR realized that the firm faced a significant threat of knowledge loss, as more than 50% of their scientists were scheduled to retire in the following years. The inability to retain and leverage its knowledge led executives to investigate whether they could effectively transform KM practices. For that purpose, they named Kiho Sohn project manager for Knowledge Management and Chief Knowledge Management Officer. He had been with the company for 21 years and had managed several other KM implementation projects. Kiho recalled the KM problem at PWR:

> “*We dealt with very proud ‘rocket scientists’ who did not want to ask questions. Many of them had their means of managing their own knowledge, which resulted in thousands of knowledge silos.… Documents were located all over the firm and it was a challenge to identify, locate, or use them…We are good at capturing lessons learned, but perform poorly when attempting to learn from these.*”

Kiho had extensive training in systems thinking and embarked on tackling the KM problem using this perspective. Given his experience, he believed that a piece-meal approach to KM was not the answer. In February 2001, he formed a new KM team with a dozen employees and tasked them to develop a vision for their KM efforts. Their task was established as follows:

> *“The vision of PWR Knowledge Management is to strive for the wisdom to understand what knowledge is needed and available, based on accurate information and supported by validated data. The mission of the PWR Knowledge Management Team is to facilitate the interactive sharing of knowledge and skills by providing enablers and promoting behaviors that reduce risk in the product life cycle, allowing us to consistently deliver competitive, high quality products to our customers.*”

Figure 1 presents an overview of the steps that the KM team took to establish a systemic KM environment at PWR. The main goal in steps 1-4 was to identify the overarching reasons for behaviors that were leading to undesired states. These reasons or *themes* were uncovered by first examining the states of KM processes, and then tracking the underlying behaviors and reinforcing processes that led to these states. Finally, in step 5 reinforcing processes that led to undesirable states were mitigated, and behaviors that led to desirable states were promoted.

--- *Insert Figure 1 about here* ---

**Step 1: Determine State of Knowledge Processes.**

During the first month of the project, the KM team's first task was to learn about existing KM practices from scientists. Assessing existing stores of knowledge, sometimes called a *knowledge audit,* is the first step of many knowledge management strategies (Debenham and Clark, 1994; Liebowitz, et. al, 2000). Multiple methodologies have been suggested for conducting a knowledge audit. However many of the methodologies published either have not been widely tested (e.g. Burnett et al, 2004; Cheung, C.F. et al, 2005; Jackson, 2005; Perez-Soltero et al 2006) or are primarily technology-oriented (e.g. Schreiber et al, 2000). For PWR a systemic thinking approach offered a methodology that had been used successfully applied in multiple organizational contexts and could encompass both technology and socially oriented processes. Leveraging systemic thinking, the main objective of Step 1 was to identify existing desirable and undesirable states related to the four basic knowledge processes. The processes and related states are listed in the first two columns of Table 2. A second objective was to begin to understand how the KM processes were related to each other. For example, regarding knowledge creation, a *desirable state* was defined as when *true* new knowledge was created. True new knowledge was characterized as not previously existing. Another desired state for KM practices was to store new

**Table 2. Sample of Desirable States, Undesirable States and Behaviors**

| KM Process | Desirable State | Associated Behaviors |
|---|---|---|
| **Creation** | True new knowledge is created through innovation and customization of existing knowledge. | Scientists easily find existing knowledge and associated contact sources. |
| **Storage** | New knowledge is stored in a place and manner that is accessible to others. | Scientists periodically store knowledge if it aids personal job performance. |
| **Transfer** | Encoded knowledge is transferred through an information system. | Scientists share knowledge if they are recognized within the organization as domain experts. |
|  | Individual knowledge is transferred through person-to-person interaction. | Scientists share knowledge with others if given an opportunity to showcase their work. |
|  | Existing knowledge is widely known and readily transferable to others. | Scientists share their knowledge and expertise if asked or approached. |
| **Application** | Existing knowledge is applied to solve new problems. | Scientists can easily identify and locate knowledge across multiple knowledge sources. |

|  | Undesirable State | Associated Behaviors |
|---|---|---|
| **Creation** | Knowledge created is redundant. | Scientists cannot locate existing knowledge within the firm. |
| **Storage** | Knowledge is stored in silos that are inaccessible to others. | Scientists hoard knowledge in a transition from a project or product group to another. |
|  | New knowledge created is not always stored, or it is stored in a way that is not searchable. | Scientists are not recognized for their knowledge and not asked to store or share it. |
|  | Knowledge stored and its location not known to others. | Scientists cannot identify domain experts. |
| **Transfer** | Transfer is limited particularly across project and departments. | An ‘us versus them’ attitude creates resistance to learning from others and to sharing with others. |
|  | Existing knowledge that is transferred can be hard to understand and customize. | Scientists are unwilling to take the time to educate other competitive project groups. |

**Source**: KM team interviews and preliminary findings document.
**Note**: See Step 3 on how the associated behaviors for each desired and undesired state were determined.

knowledge so that it was accessible to others. Examples of undesired states were knowledge duplication and new knowledge that was not shared. Once the desirable and undesirable states were determined, the KM team further investigated why the undesirable states existed, which led to Step 2.

**Step 2: Identify and classify existing KM systems.**

Using data that was gathered through their interviews and preliminary investigation, the team inventoried the existing KM systems and assessed whether they were closed or open. All KM systems were analyzed, both technology based and non-technology based systems. The objective was to gauge whether their properties contributed to either desirable or undesirable states. A sample of the inventory of systems is shown in Table 3.

**Table 3. Sample from Inventory of Existing KM systems**

| KM System | Closed System Characteristics | Open System Characteristics |
|---|---|---|
| **Scientist's Knowledge** | - Knowledge resides in scientist's brain.<br>- Knowledge is stored in personal filing cabinets or hard drives | - Input to the system is influenced by interpersonal interaction with colleagues.<br>- Output is sometimes shared through interpersonal interaction, white papers or CD's. |
| **One-to-one mentor meetings** | - Knowledge is not shared beyond the two scientists. | - Bring prior knowledge from other sources to the meeting. |
| **Departmental document storage and databases** | - System is not open to input from other departments. | - Other departments have access to documents and databases. |
| **Corporate library** | - Scientists were not aware of the information in the library. | - Scientists accessed and stored knowledge documents for other scientists to research. |
| **Expert Yellow Pages** | - System only practical for scientists who actively sought out other experts. | - System allowed scientists to identify knowledge experts and seek out available knowledge sources. |
| **Lunch brownbag KM sessions** | - Only scientists who attended session were exposed to additional knowledge sources. | - Attending scientists could engage in discussion and knowledge sharing. |
| **KM technical forum** | - Only scientists who attended sessions gained new knowledge. | - Numerous opportunities for scientists to exchange ideas, establish knowledge expert contacts, and build knowledge networks. |
| **Intra-company KM conference** | - Only scientists who focused on KM were invited. | - Knowledge could be attained by scientists from other firms. |

**Source:** KM team interviews and preliminary findings document.

The team found that many KM systems had characteristics of *closed* systems. For example, scientists were not using knowledge from other projects or departments and rarely received input from other scientists that had been exposed to similar problems. Also, since there was no formal procedure for storing or sharing knowledge, the scientists often kept information in personal filing cabinets or in their personal hard drives. The KM team determined these were closed system characteristics because only the employee had the ability to retain or discard the knowledge. These systems were individualized, departmental, or project team oriented, and did not allow cross-learning among scientists and project groups. These design features hindered the value of the KM systems to the organization, leading to undesirable states for knowledge sharing.

The team also found systems with *open* characteristics. For example, they identified brown bag knowledge sharing sessions, one-on-one mentoring relationships, intra-company technology conferences, and knowledge-sharing forums as having properties of open systems. While these systems were beneficial for knowledge exchange, the team felt that some were still contributing to undesirable states, because there was often a limited flow of knowledge. For example, knowledge exchanged or gained in the inter-company and intra-company KM forums was not formalized and shared throughout the organization.

### Step 3: Identify Behaviors Associated with States.

In Step 3 the objective was to identify the behaviors associated with desirable states and ensure that those behaviors were retained, and to identify behaviors associated with undesirable states, so that those behaviors could be discarded or discouraged. The behaviors associated with desirable and undesirable states are shown in the third column of Table 2. The team spent two months conducting interviews with scientists, gathering data and documenting behaviors. There were two salient behaviors related to desirable states. First, most of the scientists at PWR were willing to share their knowledge if they were asked. Second, scientists showcased and shared their knowledge if they had the opportunity. On the other hand, there were two salient behaviors associated with undesirable states. First, redundant knowledge was often created because scientists couldn't find existing knowledge or failed to search for it. Second, the work environment did not lend itself for knowledge sharing. An engineer commented:

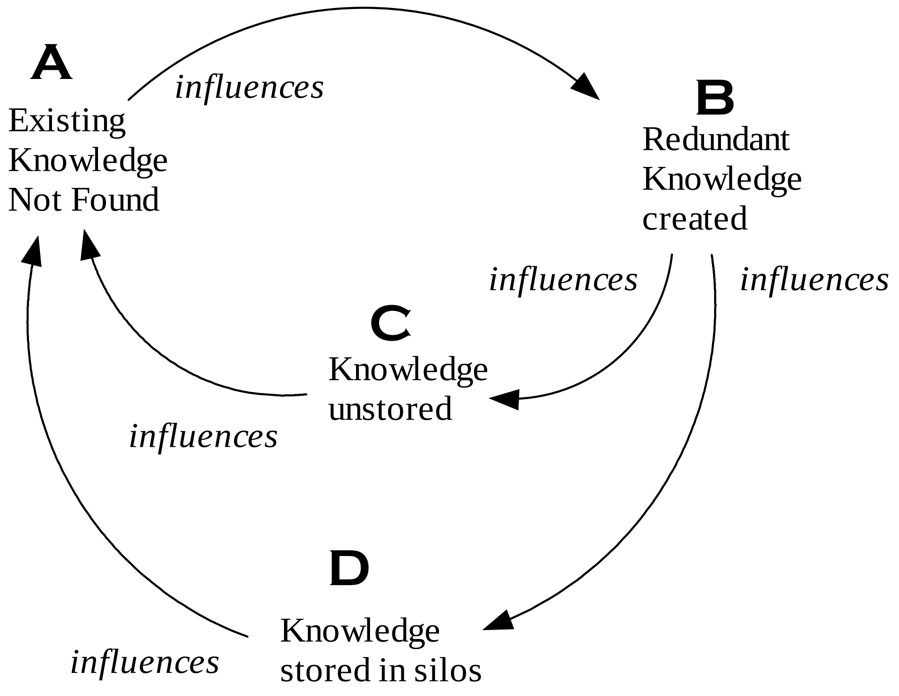
> "*We are hired as engineers; our main goal is to develop and to create new products. We are not paid to take other people's work and to improve upon it … that just isn't the nature of the game.*"

Looking at these behaviors the team began to see patterns of *reinforcing processes* and realized that they should address the behaviors contributing to reinforcing processes that were leading to undesirable states. Figure 2 is a diagram of one of the reinforcing processes found. When a scientist cannot locate knowledge (Point A on the diagram), redundant knowledge is created (Point B). When redundant knowledge is created, it is either not stored at all, due to a lack of compensation (Point C), or if it is stored, it is stored in silos (Point D). When knowledge is not stored (Point C), it is difficult (if not impossible) for others to locate it (Point A), and the process of creating redundant knowledge starts over again. Similarly, when knowledge is stored in silos (Point D), it cannot be easily located, reinforcing the process of knowledge duplication. In other words, the undesirable state–*existing knowledge cannot be found*–resulted in behaviors that led to other undesirable states–*redundant knowledge created*, *knowledge not stored*, and *knowledge silos*.

### Step 4: Identify Overarching Themes.

The KM team took the information they had gathered about desirable and undesirable states, closed and open systems, and associated behaviors, to create a systemic picture of KM at PWR. In particular, the team built on the details gathered in steps 1-3 to develop major overarching, broad themes associated with undesirable states. Two major themes were identified: snapshot solutions and the absence of generative knowledge.

**Figure 2. Reinforcing Process at PWR**



**Snapshot Solutions**. Previous attempts to fix or change undesirable states had influenced only small pieces of the overall KM process, based on 'snapshots' of the problems. For instance, prior initiatives succeeded by encouraging team members within a project to share their knowledge. However these lessons were not shared with the broader organization. The separate and static analyses of past events did not predict systemic behavior. In several situations, although KM technologies seemed to be appropriately implemented, some behaviors tended to reinforce undesirable states rather than desirable states. For example, in 1998 the firm implemented *Expert Yellow Pages*, an application that allowed scientists to identify themselves as domain experts. However, scientists felt that their knowledge contribution went unrecognized since they had no idea of how that knowledge was being used and had little control on how their knowledge was presented to others. As of 2006 only 25% of the scientists were listed as experts in the application.

**Generative Learning**. The KM team found that there was an absence of generative learning. This is illustrated in the comment above when a scientist stated that he was "*not paid to take other people's work and to improve upon it*." Even when knowledge was successfully created, stored, or transferred, it was traditionally difficult to customize and leverage that knowledge and apply it to a new problem. Scientists created new solutions, but often did not leverage past lessons. True new knowledge was not being generated because scientists were not constructing relations between the previous lessons learned and stored (or recounted by others, in-person) and the conception of new problems.

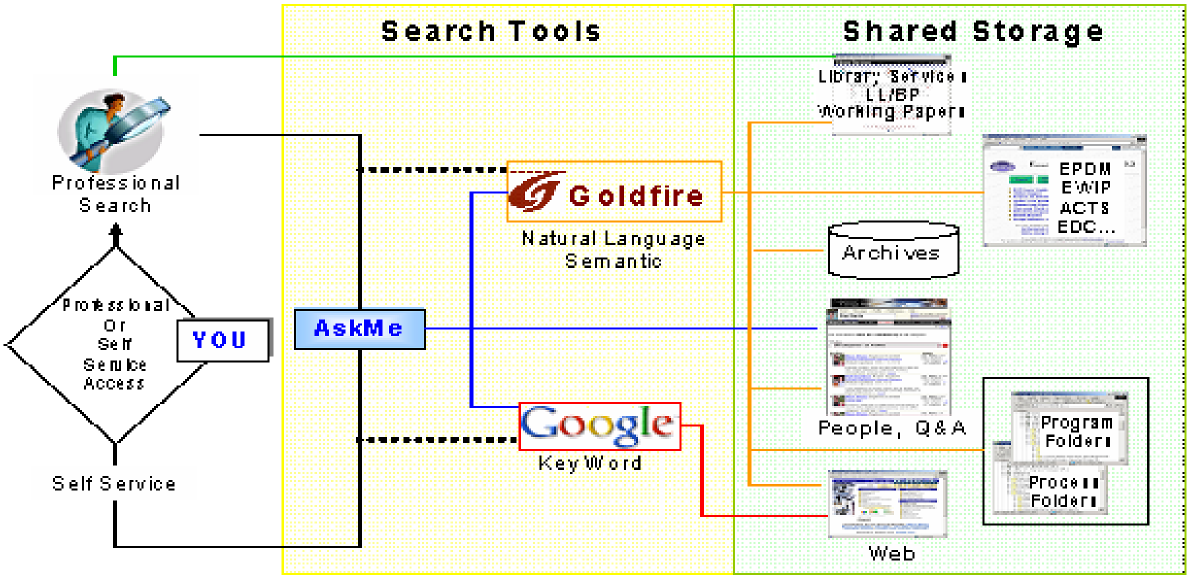
Looking at the current systems, the team felt that one way to facilitate generative learning was to make both the KM environment and the information systems more *dynamic*. For the team a dynamic information system was one where employees could not only input, change, or discard knowledge content, as with open systems, but they could also influence the processes and knowledge flows. By participating in the construction of knowledge flows, the scientists would be able to actively and selectively attend to the relevant existing knowledge of others. A dynamic system would also enable scientists to construct relations between the knowledge of others and their own experiences, in order to generate true new knowledge.

### Step 5: Implement an IT-enabled, Systemic KM Environment.

In order to overcome snapshot solutions and facilitate generative learning, the KM team envisioned an environment where scientists would be able to define the flow and direction of knowledge and get involved in the design of the KM information systems. It would be primarily the responsibility of the IT department to implement the technology infrastructure, but the users would have a responsibility to enforce how the technology-based systems were used. The objective was to mitigate the natural reaction of scientists to protect their individual knowledge.

In April 2003, the KM Team implemented *AskMe*, a KM software application that allowed the identification of knowledge experts and access to specific knowledge topics via a central repository. The application also allowed users to modify the application according to their individual needs (see Figure 3). One of the purposes of implementing *AskMe* was to encourage generative learning by allowing scientists to share knowledge, to identify themselves as experts on specific topics within the application, and to conduct chat and blog sessions. The KM team enabled a function within *AskMe*, called *Lessons Learned*, where best-known practices for a specific project category or product type were documented and made available. There was built-in functionality to associate key knowledge experts with the lessons learned. All of these capabilities enabled the use of existing knowledge and an understanding of how that knowledge could be integrated to produce generative learning.

**Figure 3. Architecture of *Askme* and *Goldfire***



For example, if a scientist has a question on a specific topic (e.g., nozzle deterioration rates, combustible devices, turbo machinery, liquid rocket propulsions), it can be posted in the *AskMe* application. Other scientists can contribute to the *AskMe* knowledge base, resulting in a team collaborative development effort to reuse knowledge and generate new knowledge. Within *AskMe*, experts can also be targeted and asked to answer the question. As other scientists contribute new knowledge to the topic, it is captured in a running blog and made available to anyone who has interest. Email updates are sent to anyone who requests periodic updates. At the end of the process, users rate the contributions and a document is indexed by key subject words, stored in the *AskMe* application, and made permanently available to others in the organization.

However, still missing was the capability to search the *entire* organization for knowledge. Many closed systems remained in the organization by design, such as departmental knowledge repositories. In December 2003, the KM team implemented a software application called *Goldfire.* The application was an advanced KM search engine that utilized natural semantic language to perform advanced searches across the company's numerous sources. *Goldfire* enabled the engineers to conduct semantic language searches that linked their search query sentence structures and key words to other knowledge sources. The application complemented the *AskMe* application by providing the ability to conduct knowledge searches on external sources using the Internet, further enhancing the construction of relations that would lead to the creation of new knowledge. These technical system improvements created a ripple of changes in the KM environment. The changes in the search capabilities and user interface prompted some scientists to take a new look at the system. Those scientists in turn found that by using already documented knowledge, they could significantly cut their project time. Kiho mentioned,

> "*… by leveraging and learning through prior [documented, referenced] knowledge, our scientists were able to cut at least 30% of the learning curve out of the picture and spend most of the time focusing on creating new knowledge for our projects*."

Such successes were quickly documented by the KM team and disseminated throughout the organization, in hopes of changing a culture predisposed to hoarding knowledge. The culture does appear to be changing. One of the KM team leads commented:

> "*Our engineers love the cookie cutter idea [the ability to access general knowledge from the knowledge repositories], and they are able to put their own selection of icing on it [to manipulate and use knowledge according to how they want] … our users are able to take the existing knowledge, and to manipulate and customize it according to their specific needs.*"

The implementation of *AskMe* and *Goldfire* discouraged some behaviors that led to undesirable states in the old KM environment. For example, the two applications enabled scientists with specific subject-area expertise to be identified and recognized as experts within PWR, and to become more valuable in their communities. As subject matter experts became better known for their expertise, they were more willing to contribute new knowledge to the KM systems, became more actively involved in postings via *AskMe*, and used the application as a repository for team development efforts. This also resulted in the further utilization and acceptance of the KM systems, as well as a trajectory for changing the behaviors and culture at PWR. A KM team member recalled:

> *"The KM team initially thought that we needed to use compensation as a motivation for our scientists to use and adopt the KM systems … over time, we learned that our scientists wanted to be seen as valuable to the organization. AskMe and Goldfire helped us to accomplish this. …it resulted in these experts being more recognized and contacted more by others who were dealing with the same problems."*

The use of *AskMe* and *Goldfire* changed the *Expert Yellow Pages* from an open system to a dynamic system because it provided the scientists with the capability to add to or manipulate the content of the knowledge within the application. For example, scientists were able to add information to the on-line chats and blogs, and change the content and flow of knowledge in the applications over time. The scientists were also able to suggest functional changes to the applications.

Together, the changes in search capabilities and the ability to influence the flow of knowledge greatly reduced the frustration with KM that the scientists had previously experienced. As Kiho noted above, scientists were able to focus more on creating new knowledge and learning curves were reduced. KM related work became less of required task and more of an opportunity for scientists to show their value to the organization. Rather than being frustrated by being forced to use KM systems, the scientists learned how both providing and leveraging existing knowledge could result in truly new knowledge for which they would be recognized.

The KM process reengineering efforts also had tangible benefits. All together the efforts, including the development of *AskMe and Goldfire*, cost a total of $2.5 million. Within one year of its implementation, the company was able to leverage the new KM environment and deploy KM practices to recognize a cost savings effort and opportunity in excess of over $25 million. Yet the one-year mark was not the end of PWR's KM team efforts. Maintaining a systemic KM environment is an on-going effort. Any changes to KM systems must first be analyzed to ensure that they do not detrimentally affect other parts of the system. Continuous training and the further education of the scientists, especially new scientists and other new hires, is required on a regular basis. New employees are encouraged to complete KM training as they start their jobs. The team also maintains constant communications with the users of the KM information systems to monitor changing needs. They seek user feedback and benchmark metrics to understand how well the KM applications are working. Additional benchmarking efforts are conducted according to industry standards. Finally, to continuously improve, the KM team shares its implementation successes with other industry players and compares notes to evaluate its relative performance.

## LESSONS LEARNED

In this section we perform an inductive process of theory-building based on the results of our case study. We start by discussing the new insights gained from the study of PWR's application of systems thinking to KM. Then, we propose a set of constructs that supports future applications of KM systems thinking. Finally, we offer several propositions on how the experience of KM systems thinking at PWR may apply in other contexts.

### Insights Gained: Behaviors and States in Organizations

Based on PWR's experience, we suggest that the process of classifying behaviors and states in a KM project is a valuable aspect of the systems thinking methodology. This process aids in the recognition that technology alone, or a KM process alone, may not create a value-adding and long-lasting KM environment. The process involves understanding behaviors and their *consequences* so that implementing a technology-based application may add value by creating desirable states and avoiding undesirable states. Recall that the first step was to determine the state of key knowledge processes, including both desirable and undesirable states. The KM team recognized the need to avoid short-term fixes to the existing KM environment. Such fixes, typically motivated by 'snapshots' of desired states, would only temporarily or partially change the KM environment.

We suggest however that in order to fully leverage organizational knowledge, understanding the consequences of behaviors is not enough. The consequences of behavior in organizations are unpredictable, because humans in organizations respond in different and unpredictable ways (Garud and Kumaraswamy, 2005; Kast and Rosenzweig, 1972). Therefore, a specific behavior may or may not be sufficient to cause another event or lead to a desired state. In contrast, biological or mechanical systems typically have preset responses to a given stimulus, also known as *reactions* (Ackoff, 1971). The value of the systems thinking approach is that it acknowledges the lack of deterministic certainty in organizational behavior, and provides tools such as systems diagrams (Figure 2 is one example) that help KM professionals consider the different possible outcomes. Moreover, the PWR case suggests that not anticipating the behaviors that may lead to undesirable states (e.g., not storing new knowledge) can increase the chances of failure.

Ackoff (1971) notes that systems whose behaviors are responsive to events, but not reactive, are called *goal-seeking* systems. These systems can respond differently to events until they produce a particular state. We suggest that KM systems, particularly technology-based systems, need to be considered and designed as goal-seeking systems. For instance, a tool like *AskMe* could be designed so that before knowledge is stored, other sources are checked and if redundant knowledge is found, storage is aborted and the knowledge creator is notified. When new knowledge is stored, annotations about the existence of that knowledge could be set across different KM systems. While such events would not be wholly deterministic in creating overall desired states such as an absence of redundant knowledge creation, they would move KM environments one step closer to that goal.

For those seeking to learn from the PWR initiative, the unpredictable nature of organizational systems also points to an important limitation. The systems thinking methodology that PWR adopted will not deterministically lead to similar successes in other organizational environments. Knowledge processes are composed of requirements that are complex, distributed across different actors whose knowledge base is uncertain, and which evolve dynamically (Markus and Majchrzak, 2002). Therefore, while the particular application of systems thinking to KM at PWR led to favorable outcomes, the specific steps and processes that PWR used may not be easily translated to other firms or industry contexts. Rather, we propose a set of core systems thinking concepts and propositions to be applied to KM in other settings.

### KM Systems Thinking Concepts

Based on our review of the PWR case and systems thinking literature, we propose the following adaptation of systems thinking concepts to the KM context. First, we propose the same definitions of state, event, behavior, and process presented by Ackoff (1971), which are shown in Table 1. Then, we define:

- *KM system*: A system whose goal is to seek desirable states for knowledge creation, storage, transfer, or application.
- *Closed KM system:* A KM system where knowledge flows only within the system.
- *Open KM system*: A KM system where knowledge flows to and from its environment.
- *Dynamic KM system:* A KM system where participants have influence over both the content and the flow of knowledge within the system.

### Propositions

To provide preliminary guidance on further application of systems thinking to KM, we offer the following propositions based on the core concepts of KM systems thinking defined above and on the findings of the PWR case study. Ross (2003) suggests that information systems infrastructures typically develop in four stages of maturity: application silos, standardized technology, rationalized data, and modular. We observe a similarity between this infrastructure framework and the manner in which KM systems at PWR evolved. Initially, KM systems were mainly closed at the individual or departmental levels, analogous to the *application silo* stage. Eventually, technological infrastructure was put in place to facilitate knowledge storage and retrieval in a centralized form, analogous to the *standardized technology* stage. During the period of our study, the systems thinking approach led the KM team to develop and standardize KM processes that considered undesired states and related behaviors, analogous to the *rationalized data* stage of Ross's model. Finally, we observe PWR moving into a *modular* stage, where the KM infrastructure and knowledge repositories are being implemented companywide. In this way scientists effectively retrieve knowledge that is centralized, yet it can be adapted for local needs based on specific requirements, leading to generative learning.

Based on these findings, we suggest that a systemic view of a KM system will facilitate its advancement to rationalized and modular stages of maturity, where KM processes are tightly integrated, and existing knowledge can be adapted to specific needs wherever they may arise. This systemic view considers the interaction of the four core KM processes, the behaviors that lead to both desirable and undesirable states, and the identification of emerging patterns at the organizational level.

> **Proposition 1**. *A systemic view of a KM system facilitates its move toward advanced stages of maturity*.

As in the case of PWR, KM systems exhibit characteristics of closed systems, open systems, and dynamic systems. Most KM systems are partially open or partially closed. At the individual, departmental, and organizational level they interact—at least partially—with the environment. On the other hand, most KM systems today are not dynamic, as defined here. We define dynamic KM systems as those where participants influence knowledge content and flows over time.

We argue that many of the desirable states for effective KM are facilitated by dynamic KM systems design. For example, scientists at PWR used the *Expert Yellow Pages* to input their contact information and domain expertise. However, scientists were not able to directly influence either the content or their interaction with the application. A holistic perspective that viewed the *Expert Yellow Pages* not only as a storage system, but also as a retrieval system, contributed to the design changes that made the system dynamic, which led to desired states and associated behaviors by its users. In particular, the system was re-designed so that scientists would be able to alter the flow and have direct impact on how the content was retrieved. This leads to our second proposition.

> **Proposition 2**. *Design of KM systems as dynamic systems will lead to desirable KM outcomes.*

Finally, we suggest that generative learning requires a systemic KM design. The analysis of reinforcing processes helped PWR make adjustments to mitigate behaviors associated with undesirable states and increase behaviors associated with desired states.  To achieve the desired state of creating true new knowledge, PWR developed processes to encourage the integration and customization of existing knowledge for new uses, and IT applications were developed to support these processes. Like the *Expert Yellow Pages,* the *AskMe* application allowed scientists to find company experts on specific knowledge topics. However *AskMe* went further, to incorporate reinforcing processes that would encourage desirable states and added dynamic capabilities to the formerly closed system.  *Lessons Learned* highlighted contributions that were considered best practices.  This established a positive reinforcing process that encouraged scientists to contribute so that they could be recognized as well and visibly see that recogntion.  This encouraged scientists to review pre-existing knowledge so that true new knowledge would be created and thereby be considered as the new best practice in an area.  The application also facilitated the construction of relations as scientists actively engaged in blog and chat discussions that aided in understanding how to apply existing knowledge in new ways, customized for the current problem. These connections between peers allowed PWR's KM environment to be more dynamic and able to adapt to a quickly changing knowledge base and knowledge needs.  Goldfire's semantic language search also helped scientists make connections between existing knowledge that previously had not been possible. Scientists gained exposure to related knowledge that they never even knew existed and in doing so, were better able to generate new knowledge. Together the *AskMe* and *Goldfire* systems, along with the systemic approach to KM created a change in behaviors in all four knowledge processes to encourage generative learning. This leads to our final proposition:

> **Proposition 3**. *Generative learning emerges from a systemic KM design that addresses behaviors related to all four knowledge processes of creation, storage, retrieval, and application.*

## CONTRIBUTIONS, LIMITATIONS, AND FUTURE RESEARCH

A key activity in theory building in organizational research is taking ideas from situational concepts to generalizable universals and vice versa (Osigweh, 1989). In this case study we use both approaches to contribute to the development of theory in knowledge management. We take PWR's situational application of systems thinking concepts to derive KM systems thinking concepts and propositions that are applicable at a more general level. We relate PWR's KM work to Ross' information system maturity model and suggest that systems thinking can aid other organizations in achieving higher levels of maturity with their KM systems. In this study, we also take systems thinking concepts and suggest how they may be applied at a more specific level for KM. We apply concepts such as reinforcing processes to the context of knowledge creation, storage, retrieval and application to illustrate how systems thinking can aid KM initiatives.

Another contribution and core finding is that systems thinking offers a new perspective that addresses the often overlooked consequences of KM behaviors that tend to degrade implementations. These are often behaviors that inhibit effective KM processes and lead to the implementation of closed systems, undesirable states, and reinforcing processes that feed those undesirable states. Although our research highlights a sequential set of steps taken at PWR, from a broader perspective we propose that KM systems implementations should be carefully designed and orchestrated together to ensure that behaviors contribute to desirable states in the KM environment as a whole. We suggest that designing *goal-seeking* KM systems is one way to accommodate ongoing changes in the environment and people's behaviors.

One of the limitations of this research is the generalizability of the findings, which is limited by the case study methodology used. We have used a theoretically-based inductive approach to propose why the systems thinking methodology is appropriate for other KM systems projects.

However, more studies are necessary to develop a comprehensive and robust KM systems thinking methodology that could be used by multiple organizations. Through the application and analysis of the systems thinking perspective in other settings, we will gain a richer understanding of its potential benefits and the *do's and don'ts* of the application of systems thinking to KM.

For future research, building on the concepts presented here, three additional systems thinking techniques are likely to add value to KM initiatives: behavior over time graphs, systems archetypes and systems diagrams. Behavior over time graphs provide a concise, pictorial representation of how variables of interest change over time and provide clues to the kind of systemic processes that may be at work (Kim, 1999). System archetypes describe patterns of events that are common to many systems. Senge (1990) notes that system archetypes are similar to simple stories that are told again and again. For Senge, archetypes can reveal a simplicity that underlies many more complex management issues. Finally, the systems thinking approach includes multiple types of diagrams to analyze complex issues in a clear and concise manner. Figure 2 in this article, which shows a reinforcing process, is one example of a systems thinking causal loop diagram in the KM context. Other diagrams, such as stock and flow diagrams, are likely to be useful as well.

The PWR KM case is an application of systems thinking within the firm, but KM with organizational boundaries can lead to competency traps and strategic rigidity. An even more holistic perspective expands the boundaries of organizational systems to include external KM sources and inter-firm KM collaboration. For example, an interesting avenue for research is related to inter-firm collaboration for knowledge exchange, which is naturally inhibited by culture and trust barriers across firms and by regulations that prohibit collusive practices. A systems thinking approach and the application of its analytical techniques, may uncover the behaviors and reinforcing processes that tend to inhibit inter-organizational knowledge sharing and the solutions to counter them effectively.

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Figure 1. PWR’s KM Systems Thinking Methodology

**Identify & Desired & Undesired States**

**Step 1**

- Identify states that exist across each of the KM processes (knowledge creation, storage, transfer, application).
- Determine the outcome of the states.
- Determine if the outcomes were beneficial or detrimental to the firm’s KM efforts.

**Identify & Classify KM systems**

**Step 2**

- Identify KM systems that existed within the firm (eg., departmental databases).
- Identify informal KM systems that existed within the firm (e.g. scientists’ knowledge residing on inaccessible sources).
- Determine if the KM systems exhibited closed, open or dynamic system characteristics.

**Identify Associated Behaviors**

**Step 3**

- Identify behaviors that existed as a result of KM activities.
- Identify behaviors that existed as a result of using KM systems.
- Identify behaviors that did not exist (i.e., behaviors that the firm needed to establish).

**Identify Over-arching Themes**

**Step 4**

- Use data on desirable states, behaviors and processes, indicating areas in the KM environment that need to be maintained.
- Use data on undesirable states, behaviors, and processes, indicating themes and areas in the KM environment that need to be redesigned.

**Implement Systemic KM Environment**

**Step 5**

- Understand the interplay between states, behaviors and KM systems.
- Identify what states, behaviors and KM systems needed in an ideal systemic environment.
- Identify which and how KM system solutions can aid in establishing systemic KM.
- Redesign undesirable states, behaviors and KM systems.