Systems Theory and Knowledge Management Systems: The Case of Pratt-Whitney Rocketdyne

Mark Chun
Assistant Professor
Graziadio School of Business
Pepperdine University
mchun@pepperdine.edu

Kiho Sohn
Chief KM Officer
Pratt-Whitney Rocketdyne
kiho.sohn@pwr.utc.com

Priscilla Arling
Assistant Professor
College of Business
Butler University
parling@butler.edu

Nelson F. Granados
Assistant Professor
Graziadio School of Business
Pepperdine University
ngranado@pepperdine.edu

Abstract. *Despite a growing body of research on knowledge management (KM) systems, many managers are still unsure how they can implement a KM system that will effectively contribute to the firm's competitive advantage. A common framework is one that breaks down KM into four main activities: knowledge creation, storage, transfer, and application. This paper describes one company's use of an alternative perspective–a systems thinking approach–to define and improve KM within the firm. Pratt-Whitney Rocketdyne moved away from viewing KM as separate processes, to view the organization holistically as a system of people, processes, and technology. Based on this perspective, the company identified and changed key behaviors within the KM environment that led to undesirable states, effectively establishing a generative learning environment. Based on this case study we derive a set of concepts and propositions that can be used by both academic and practitioners to improve KM practices.*

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

I. 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 its goals [37]. To actualize knowledge management (**KM**) within a firm, managers frequently turn to technology-based initiatives such as knowledge repositories and expert databases [2]. 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 [9, 13].

This reality is particularly striking in the face of significant research in the last decade directed at better understanding knowledge and improving the implementation of KM solutions. Numerous researchers have investigated organizational efforts to manage knowledge and implement KM systems [11, 23]. Alavi and Leidner [2] propose a framework of four knowledge processes to aid in the study of KM in organizations: the creation, storage, transfer, and application of knowledge. However, related research so far falls short of addressing how the four processes and technology interact with each other and with respect to an organization's structure and goals. Increasingly, researchers recognize that multiple processes, structures and resources within a firm interact to affect KM efforts [34]. 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 [2].

In this paper, we build on this emerging perspective and posit that a KM system (**KMS**) is better managed when viewed holistically as a set of people, processes, and technology, not merely as a set of individual knowledge processes or IT systems. Our claim is motivated by a case study of Pratt-Whitney Rocketdyne (**PWR**). Based on the harsh reality that 50% of the engineers in the aerospace industry are eligible for retirement in the coming years, PWR implemented KMSs to retain and use the knowledge that otherwise would be lost. However, they experienced marginal benefits. Therefore, in 2001, the company embarked on a major initiative to revamp its KMSs using a *systems thinking* perspective. As a result, PWR created a systemic environment that encourages behaviors associated with integrative and generative knowledge management.

II. THEORETICAL BACKGROUND

Knowledge Management in Organizations. A knowledge-based view of the firm characterizes knowledge as a source of advantage [6]. In this view knowledge is embedded in and expressed through multiple organizational resources, including its people, processes, and technologies [21]. Much of the research on knowledge within firms has concentrated on conceptual foundations, such as taxonomies of knowledge [28, 30], KM in organizations [11] and KMSs [29]. Within these foundations, four processes are often identified as important to managing firm knowledge: knowledge creation [32], knowledge storage [5], knowledge transfer [16], and knowledge application [8, 14]. Alavi and Leidner [2] suggest that it is by actualizing, supporting and reinforcing these four processes that IT can contribute to organizational KM.

Recent research has largely focused individually on each of the four main KM processes in order to understand how these processes affect the ability to manage knowledge [10, 15, 17]. While the related literature has brought new insights, this approach isolates the individual process and may therefore limit the ability to understand the connections and relationships of the phenomenon in a larger whole.

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 [25]. It is through this type of integrative understanding that the drivers of a successful KMS implementation can be identified. 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 [1, 19, 35]. A system is defined as *"an entity which maintains its existence through the mutual interaction of its parts"* [36, pg. 298]. Systems theory provides a framework by which groups of elements and their properties may be studied jointly in order to understand outcomes.

Ackoff [1] believes that a systems theory approach is fundamental to the study of organizations, so he translated von Bertalanffy's original definition of a system to the organizational context (see Table 1). 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.

There is an important classification of events called *behaviors.* Behaviors are events that initiate other events. For example, claiming many deductions on your tax form is a behavior because it is likely to cause another event, a tax audit. 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. Viewing and interpreting processes from this holistic viewpoint and over time is the essence of the *systemic approach* to analysis [4].

A system's *environment* consists of the 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. Systems that interact with their environment are called *open systems*. Open systems exchange information, energy or material with their environments [18, 35]. Systems that do not interact with their environment or that have no environment are called *closed systems.* A *dynamic system* is one to 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.*

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; 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 element 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 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 knowledge to suit the needs of the individual user's needs. It entails continuing the creation and innovation of knowledge.	Senge, 1990.

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 [3]. An example of a reinforcing process is the relationship between principle and interest in a bank account. When an interest rate is applied to principle, it increases the interest earned. The interest earned is then added to the principle, causing it to increase. Due to their ability to greatly compound growth or decline, reinforcing processes are also known as vicious cycles.

Systems thinking was derived from systems theory and is the basis for the learning organization [35]. Systems thinking focuses on causes, rather than events, and does not isolate the smaller parts of the system being studied. Rather, it considers the numerous interactions of the system in question [18, 35].

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 to suit the needs of a new application or a new user [35]. Generative learning enables innovative approaches to new problems rather than mere reactionary and often ill-suited re-application of old ideas to new problems.

A systems theory 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 the growth or decline of either desirable or undesirable outcomes. Each knowledge process may lead to reactionary solutions or true generative learning. Depending upon how the four processes have been implemented, they can be viewed as closed, open or dynamic systems, each influenced more or less by the external environment.

While the systems thinking perspective has been incorporated into to the IS literature (see for example [4, 7, 12, 31]), only a few researchers have examined the holistic perspective of systems thinking in the context of KM [25, 26]. Therefore, we propose research that further contributes to the enhancement of KM practices based on the systems thinking perspective.

Towards A Systems Thinking Approach in KM Implementations. Systems thinking suggests that studying single events is reactionary. Instead, studying long-term patterns of behavior is an approach better suited to understanding how systems can be improved over time. In this paper, we argue that a KM systems thinking approach is appropriate for understanding the complex and dynamic nature of KM. We define *KM systems thinking* as a perspective that views the overall events, behaviors, processes, and states associated with knowledge in an organization. Next, we describe the research methodology and case study of PWR, which will allow us to develop a framework for KM systems thinking.

III. RESEARCH METHODOLOGY: CASE STUDY

Consistent with our goal of better understanding the development of KMS implementations over time, this research was designed as a single longitudinal case study. Our study focuses on *how* KM systems thinking was used at PWR, for which case study methodology is appropriate [38]. The related longitudinal analysis aided in providing a rich understanding and evaluation of continuity and change [38]. In particular, it enabled us to examine the phenomenon in a natural setting and to engage in theory-building in an area where there has been relatively little prior research and theory formulation [27].

Data collection involved multiple sources of historical and longitudinal data, which were triangulated to establish construct validity and reliability. The data collection was done in two phases during a 21-month time period. In the first phase, the researchers collected both public and confidential corporate archival data related to the KMS implementation process. The primary sources of data were archived corporate internal analyses, organization charts, strategic planning documents from the KM department, minutes of meetings, external consultant reports, internal correspondence, memos, and e-mails. Secondary sources included industry reports, public disclosures, media publications, and Internet articles. While collecting archival data, one of the authors documented the general direction of the KMS implementation process, the primary actors involved, and the major decisions made over time.

In the second phase of data collection, formal interviews were conducted with individuals who sponsored, supported, or participated in the KMS implementation. In particular, we interviewed the top executive management teams from across the firm's eight product groups and six program teams. These interviews provided detailed data on how the KMS implementation decision was perceived and experienced. It also provided details on how KM evolved during implementation. To ensure accuracy and to promote triangulation, case data were reviewed and verified by key actors involved in the KMS implementation. Participant 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 used by the interviewees in explaining the firm's KMS efforts. The analytical codes and sources of evidence were then grouped into logical categories in order to segment the data. The data was 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 KMS implementation, and outcomes over the course of the KMS 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 of analysis also helped to expand and tease out the data in order to formulate new questions and levels of interpretation. Once coding was completed, the researchers examined the data in order to generate meanings.

IV. KM AT PRATT-WHITNEY ROCKETDYNE

The case of PWR represents a rich setting for research in the context of KM systems thinking for two main reasons. First, a KM initiative founded on systems thinking is an ongoing effort at PWR. Second, the KM initiative has been viewed as a success, delivering over $25 million in cost and opportunity savings over two years.

Antecedent Condition. 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 around the world. Since its origins, Pratt & Whitney 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 between 6 months to 5 years, depending on the scope of the project. Throughout their career at PWR, engineers—called *scientists*—are encouraged to switch process groups and product groups in order to diversify their skills. Scientists were evaluated mainly based on the success of projects they participated in, so they had little incentive to share their knowledge with other groups.

Prior to 2001, each employee from the firm's diverse set of product groups and program teams had her own idea of how knowledge was to be managed. This resulted in knowledge silos that were frequently not shared among product groups and program teams. In addition to the knowledge silo problems, there was a distinct generational gap between the more seasoned and newly hired employees, which contributed to an unwillingness to share knowledge throughout the firm. Hence, the ability to learn from existing knowledge was limited. Overall, these factors led to a reactive approach to managing knowledge and resulted in the inability to establish a unified vision of KM.

Applying Systems Thinking to KM at PWR. In January 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:

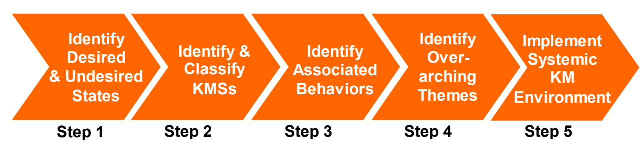
> "*We dealt with very proud 'rocket scientists' who did not want to ask questions. Many of them had their means of managing their own knowledge, which resulted in thousands of knowledge silos.… Documents were located all over the firm and it was a challenge to identify, locate, or use them…We are good 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, which 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 PWR mitigated reinforcing processes that led to undesirable states, and promoted behaviors that led to desirable states. Below, we describe these steps in detail.

Figure 1. PWR's KM Systems Thinking Initiative



Step 1: Determine State of Knowledge Processes. During the first month of the project, the KM team's first task was to learn about current KM practices. The team performed this analysis by interviewing scientists. The main objective of this effort was to identify existing desirable and undesirable states related to the four basic knowledge processes (see 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 a property of a KMS where *true* new knowledge was created. True new knowledge was characterized as not previously existing. One undesirable state was knowledge duplication, or

Table 2. Sample of Desired States and Behaviors

Desirable State	Associated Behavior
True new knowledge is created through innovation and customization of existing knowledge.	Scientists easily find existing knowledge and associated contact sources.
New knowledge is stored in a place and manner that is accessible to others.	Scientists periodically stored knowledge if it aided personal job performance.
Encoded knowledge is transferred through an information system.	Scientists share knowledge if they were 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 transferable to others.	Scientists share their knowledge and expertise if asked or approached.
Existing knowledge is applied to solve new problems.	Scientists can easily identify and locate knowledge across multiple knowledge sources.

Undesirable State	Associated Behavior
Knowledge created is redundant.	Scientists cannot locate existing knowledge within the firm.
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.	No value or employee compensation tied to or associated with knowledge storing and sharing.
What knowledge is stored or where it is stored is not known by others.	Scientists cannot identify domain experts.
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 is hard to understand and customize	Scientists unwilling to take the time to educate other competitive project groups.

Source: KM team interviews and preliminary findings document, 2001.
Note: See Step 3 on how the associated behaviors for each desired and undesired state were determined.

perceived true new knowledge that in fact already existed.

Once the desirable and undesirable states were determined, the KM team investigated more closely 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 KMSs and identified the ways in which they were closed or open. The objective was to gauge whether their properties contributed to either desirable or undesirable states (see Table 3).

The team found that many KMSs had characteristics of *closed* systems. For instance, they found that at times scientists were not using knowledge from other projects or departments. Scientists often kept information in personal filing cabinets or on their personal hard drives rather than on network servers. The KM team saw these as closed system characteristics because only the employee had the ability to retain or discard the knowledge. One underlying reason was the security and confidentiality policies, which led some KMSs to be engineered as closed systems. They were individualized, departmental or project team oriented. These closed system characteristics prohibited the scientists from learning from the experiences of other scientists and project groups. Therefore, while security policies were satisfied, these design features hindered the value of the KMSs to the organization, leading to undesirable states.

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. Nonetheless, these open systems were the first stepping stones to a systemic KM environment.

Table 3. Sample Inventory of Existing KM systems

KM System	Closed System Characteristics	Open System Characteristics
Scientist's Knowledge	- Knowledge resides in scientist's head. - Knowledge is stored in personal filing cabinets or on a hard drive not accessible to others	- Input to the system is influenced by interpersonal interaction with colleagues. - 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, build knowledge networks.
Intra-company KM conference	- Only invited scientists who focused on KM were invited.	- Knowledge could be attained by scientists from other firms.

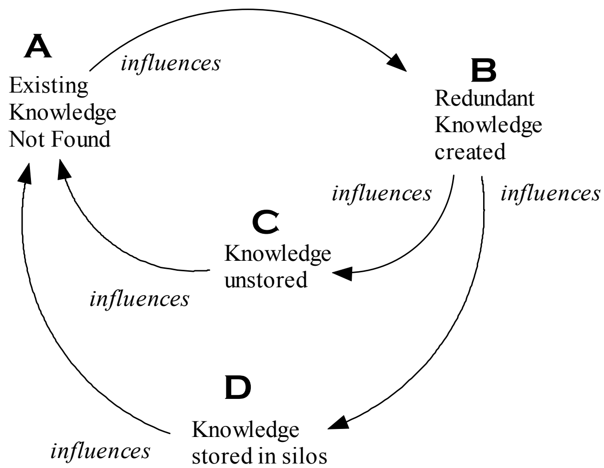
Source: KM team interviews and preliminary findings document, 2001.

Step 3: Identify Behaviors Associated with States. In Step 3 the KM team had two objectives: 1) to identify the behaviors associated with desirable states, to ensure that those behaviors were retained, and 2) to identify behaviors associated with undesirable states, so that those behaviors could be discarded or discouraged (see Table 2). The team spent two months conducting interviews with scientists, gathering data and documenting behaviors. Two key behaviors were related to desirable states. First, most of the scientists at PWR were willing to share their knowledge if they were personally asked. Second, scientists showcased and shared their knowledge if they were presented with an opportunity.

On the other hand, the team found two key behaviors associated with undesirable states. First, scientists shared knowledge when working together in projects, but the lessons learned were not easily accessible to others. Therefore, redundant knowledge was often created when scientists failed to search or find existing knowledge. Second, the work environment at PWR 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.*"

Figure 2. Reinforcing Process at PWR



Looking at these behaviors the team began to see patterns of *reinforcing processes.* Behaviors associated with one knowledge process initiated another behavior and a change in state in another knowledge process. The team 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 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 this process of knowledge duplication.

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 and created a systemic picture of KM at PWR. Their objective was to find major overarching themes associated with undesirable states that would guide the redesign of KMSs. The team was able to identify two themes: snapshot solutions and the absence of generative knowledge.

Snaphsot Solutions. First, the team realized that previous attempts to fix or change undesirable states had influenced only small pieces of the overall KM at PWR. Past system implementations had studied just 'snapshots' or instances of behaviors and desired states. These static analyses of past events did not predict systemic behavior. There was little awareness of the implications of closed or open systems characteristics or of the reinforcing behaviors associated with knowledge processes. In several situations, the KM team found that 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 were not rewarded for contribution to or use of this application. As of 2006 only 25% of the scientists were listed as experts in the application.

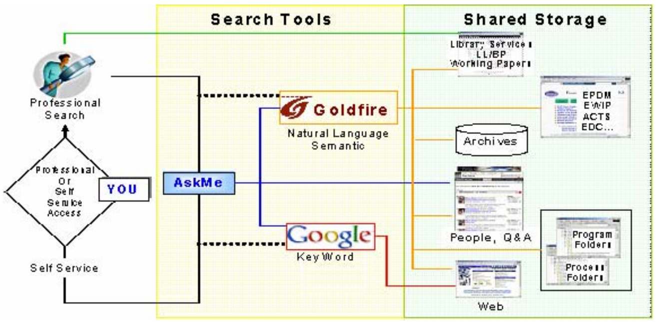
Absence of Generative Learning. Second, the KM team found that there was an absence of generative learning. Even when knowledge was successfully created, stored or transferred it was often difficult to customize and leverage that knowledge and apply it to a new problem. Scientists created new solutions, but often did not to leverage past lessons. Looking at the current systems, the team felt that one answer to facilitating generative learning would be to make both the KM environment and KMSs more *dynamic.* For the team a dynamic KMS was a system where employees could not only input, change, or discard knowledge content, as with open systems, but they could also manipulate the knowledge processes within the system; that is, one where employees could influence knowledge flows.

Step 5: Implement a Systemic KM Environment. In order to overcome snapshot solutions and facilitate generative learning, the KM team decided to create an atmosphere where the scientists were brought into systems implementations and contributed to the KMS design. Specifically, they envisioned an environment where scientists would be able to define the flow and direction of knowledge as well as how the KM applications were designed and used. 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. *Goldfire* helped scientists to realize the benefits of sharing knowledge as they benefited from the system themselves. One of the KM team leads commented:

> "*Our engineers love the cookie cutter idea [the ability to access general knowledge from the KMS], 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.*"

In April 2003, the KM Team implemented *AskMe,* a KM software application that allowed users to modify the application according to their individual needs (see Figure 3). The main purpose 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 application allowed

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



identification of knowledge experts and access to specific knowledge topics. *AskMe* also provided centralized access to knowledge that was created in prior knowledge sharing activities. 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.

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* also enabled *AskMe* to conduct knowledge searches on external sources using the Internet.

The implementation of *AskMe* and *Goldfire* allowed the KM team to discourage many of the behaviors that had caused undesirable states in the old KM environment. For example, the use of *AskMe* and *Goldfire* changed the Expert Yellow Pages from an open system to a dynamic system. This was accomplished by linking the scientists' contact information to the on-line chats and blogs, and enabling scientists to contribute, extract or change content over time.

The *AskMe and Goldfire* applications and the KM team's reengineering efforts 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 customized or personalized changes to the KMS environment must be first analyzed to ensure that it does not detrimentally affect other parts of the entire 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 KMS users to monitor changing needs. They seek user feedback and benchmark metrics to understand how well the system is working. Additional benchmarking efforts are conducted according to industry standards. Finally, in order to continuously improve, the KM team shares their implementation successes with other industry players and compares notes to evaluate their relative performance.

V. DISCUSSION

In this section we discuss the implications of the case study of PWR and derive key KM systems thinking concepts and propositions.

A. Implications

Behaviors and States. Based on PWR's experience, we suggest that identifying behaviors and states is a key benefit of the systemic perspective. It is the recognition that technology alone, or a KM process alone, may not create a value-adding and long-lasting KM environment. This perspective involves understanding the behaviors and their *consequences* so that implementing a technology-based application may add value by creating desirable states.

In addition, system implementations need to consider not only desired states and their associated behaviors, but undesired states as well. Recall that the KM team's first step was to determine the state of key knowledge processes, including desirable and undesirable states. The 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.

Behavior in Organizations. Understanding the interrelationship of KM processes and the consequence of behaviors can help organizations towards implementing a value-adding, systemic KM environment. However, we also suggest that in order to fully leverage organizational knowledge, understanding the consequences of behaviors is not enough. In organizations the consequences of behavior are unpredictable because organizations are *contrived systems* [18]. Humans in organizations respond in different and unpredictable ways to events and the behaviors of others. In contrast, biological or mechanical systems typically have preset responses or *reactions* to a given stimulus. A reaction is a system event that is deterministically caused by another event [1]. In contrast, a behavior may or may not be sufficient to cause another event or lead to a desired state.

Ackoff [1] 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. Therefore, a given behavior may not deterministically cause the desired change. Yet it is the purpose of KM initiatives to design systems, particularly technology-based systems, which are antecedents to responses associated with desired states. For instance, a system can be designed so that before knowledge is stored other sources are checked for redundant knowledge and if such knowledge is found, storage is aborted and the knowledge creator is notified. When new knowledge is stored, annotations about the existence of that knowledge can be set across different KMSs. 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 in that direction.

For those seeking to learn from the PWR initiative, the contrived 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 [24]. Therefore, while the particular way of applying 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 next propose a set of core systems thinking concepts to be applied to KM. We also make propositions about the potential benefits of KM systems thinking which can be examined and tested in other settings.

B. KM Systems Thinking Concepts and Propositions

Concepts. Based on our analysis of the PWR case and on the review of the existing 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 from Ackoff [1], presented in Table 1 of section II. 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 that does not exchange knowledge with its environment.
- *Open KM system*: A KM system that exchanges (receives or sends) knowledge with 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 the application of systems thinking to KM, we offer the following propositions based on the core concepts of KM systems thinking defined above:

Proposition 1. *KM systems evolve and mature in stages typical of other information systems.*

Ross [33] 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 KMSs at PWR evolved. Initially, knowledge systems were mainly closed at the individual or departmental levels, analogous to the *application silo* stage. Eventually, 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, further initiatives by the KM team led to development of standardized knowledge 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 KMS 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.

Further research is necessary to understand the commonalities and differences between IT systems in general and KMSs in particular. Nevertheless, we suggest that a systemic view of KM environments facilitate moving KMSs toward advanced stages of maturity.

Proposition 2. *Design of KM systems as dynamic systems will lead to advanced stages of maturity.*

As in the case of PWR, KMSs exhibit characteristics of closed systems, open systems, and dynamic systems. Most KMSs are partially open or partially closed. At the individual, departmental, and organizational level they are continuously interacting, at least partially, with the environment. On the other hand, most KMSs today are not dynamic, as defined here. We define dynamic KMSs as systems where participants influence system knowledge contents and flow over time.

We argue that many of the desirable states for effective KM are facilitated by dynamic KMS design. For example, scientists at PWR used the Expert Yellow Pages to input their contact information and domain expertise. However, the output of the system exhibited closed system characteristics. There was low usage of the system to retrieve knowledge. This situation is analogous to a document stored in a desk; knowledge is created and stored but seldom identified, sought after, or transferred. The Expert Yellow Pages had characteristics of a closed system due to the combined effect of its design and the behavior of the scientists. In addition, scientists were not able to directly influence the content or their interaction with the system. 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. This 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.

Proposition 3. *Generative learning emerges from the existence of desired states and behaviors that reinforce each other in the processes of knowledge creation, storage, retrieval, and application.*

Based on our analysis of KM at PWR, we suggest that generative learning is a process that requires special design. The analysis of reinforcing processes that led to desirable and undesirable states helped PWR make adjustments to mitigate the behaviors that led to undesirable states, and increase the behaviors that led to desired states. Recall from the study that the *AskMe* application allowed scientists to use the content within the Expert Yellow Pages to seek out company experts on knowledge topics. The application also facilitated knowledge exchange among scientists as they actively engaged in blog and chat discussions related to another scientist's request. This design led to a change in the scientists' behaviors to *want* to share knowledge. It also enabled scientists to discuss knowledge topics, to contribute their own sources of knowledge to the discussion, and to create a running blog entry so that others could access the knowledge in the future. In other words, this systemic approach to KM represented a change in behaviors to encourage generative learning.

VI. CONCLUSIONS

Contributions. Our contribution in the use of systems thinking for knowledge management is two-fold. First, we add to prior work to show *how* systems thinking can aid the implementation of successful KMSs. At the core of our findings is that systems thinking offers a new perspective to address the often overlooked consequences of KM behaviors that tend to degrade KMS implementations. These are often behaviors that inhibit effective KM processes, leading to 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 posit that KMS implementations should be carefully designed and orchestrated to ensure that the associated behaviors contribute to desirable states in the KM environment as a whole.

Second, based on the results of the case study and on the theoretical underpinnings of systems thinking, we offer a set of KM systems thinking concepts and propositions about the generalizability of our findings to other contexts. These propositions represent the lessons learned from the case study which can potentially benefit other KM initiatives.

Future Research. Systems theory is very general and has been used in so many diverse disciplines that some may argue that it lacks the specificity needed to bring real value to the KM field. We believe however that the following three analytical techniques associated with system theory are valuable in the KM context:

1) **Analysis of Behavior Over Time.** One of the strengths of a systems thinking approach is its facility to incorporate change over time into a problem analysis. One way to better understand temporal changes is through behavior over time (BOT) graphs. BOT 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 [20]. The reinforcing processes discussed in the case, as well as balancing processes, are two of the building blocks of the systems thinking approach that capture trends in behavior over time.

2) **Systems archetypes.** Systems thinking has been applied to a wide variety of systems in many scientific disciplines. One of the benefits of using this approach is the availability of well-established *system archetypes* that can be used by academics and practitioners alike. System archetypes describe patterns of events that are common to many systems. Senge [35] 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. One example is the *limits to growth* archetype, which describes a reinforcing process in a goal-seeking system. The process creates a spiral of success but also unintentionally creates secondary events that eventually slow down success, which is common in many KM implementations. Examples of the limits to growth archetype are when firms grow, but then stop growing, or when individuals increasingly share knowledge, but then plateau.

3) **Systems diagrams.** A systems thinking approach includes multiple types of diagrams that assist in analyzing 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. Behavior over time graphs as well as stock and flow diagrams are two more examples of the pictorial techniques that can facilitate problem analysis.

Limitations and Research Opportunities. One of the limitations of this research is related to our ability to generalize our findings. Due to the nature of the in-depth case study methodology in this research, there is a limit to what we can claim is applicable in other contexts. More studies need to be performed to develop a comprehensive and robust KM systems thinking methodology. Through the application and analysis of the systems thinking perspective in other settings, we will gain a richer understanding of its potential benefits.

Another avenue for research is related to inter-firm collaboration for knowledge exchange, which is naturally inhibited by culture and trust barriers across firms [22] and by regulations that prohibit collusive practices. A systems thinking approach may uncover the behaviors and reinforcing processes that tend to inhibit inter-organizational knowledge sharing.

REFERENCES

[1] Ackoff, R.L. "Towards a System of Systems Concepts," *Management Science*, 1971, 17(11), 661-671.

[2] Alavi, M. & Leidner, D. "Review: Knowledge Management and Knowledge Management Systems: Conceptual Foundations and Research Issues," *MIS Quarterly*, 2001, 25(1), 107-136.

[3] Anderson, V. & Johnson, L. "Systems Thinking Basics: From Concepts to Causal Loops," Pegasus Communications, Waltham, MA, 1997.

[4] Angell, I. O. "Systems Thinking About Info. Systems and Strategies," *Journal of Info. Systems,* 1990, 5, 168-174.

[5] Argote, L. "Organizational Learning: Creating, Retaining, and Transferring Knowledge," Kluwer Academic Publishers, Boston, MA, 1999.

[6] Barney, J.B. "Firm Resources and Sustained Competitve Advantage," *J. of Management.,* 1991, 17(1), 99-121.

[7] Buede, D. M. "The Engineering Design of Systems: Models and Methods," John Wiley & Sons, New York, NY, 2000.

[8] Chun, M. & Montealegre, R., "The Problems of Embedded ISs and Embedded Knowledge: Implications for Systems Integration and Knowledge Management," *Journal of IT Management*, 2007, 18(1), 38-64.

[9] Cohen, D. "What's Your Return on Knowledge?" *Harvard Business Review*, 2006, 84(12), 28-31.

[10] Cross, R., Parker, A., Prusak, L., & Borgatti, S. "Supporting Knowledge Creation and Sharing in Social Networks," *Organizational Dynamics,* 2001, 30(2), 100-120.

[11] Davenport, T. & Prusak, L. "Working Knowledge: How Organizations Manage What They Know," Harvard Business School Press, Boston, MA, 1998.

[12] Garrity, E. J. "Synthesizing User Centered and Designer Centered IS Development Approaches Using Systems Theory," *IS Frontiers*, 2001, 3(1) 107-121.

[13] Gilmour, D. "How to Fix Knowledge Management," *Harvard Business Review*, 2003, 81(10), 16-17.

[14] Grant, R.M. "Prospering in Dynamically-competitive Environments: Organizational Capability as Knowledge Integration," *Organization Science*, 1996, 7(4), 375-387.

[15] Gray, P.H. & Meister, D.B. "Knowledge Sourcing Effectiveness," *Management Science*, 2004, 50(6), 821-834.

[16] Gupta, A. K. and Govindarajan, V. "Knowledge Flows within Multinational Corporations," *Strategic Management Journal*, 2000, 21, 473-496.

[17] Haas, M. R. & Hansen, M. T. "When Using Knowledge Can Hurt Performance: The Value of Organizational Capabilities in a Management Consulting Company," *Strategic Management Journal*, 2005, 26, 1-24.

[18] Kast, F. E. & Rosenzweig, J. E. "General Systems Theory: Applications for Organization and Management.," *Academy of Management Journal.*, 1972, 15(4), 447-465.

[19] Katz, D. & Kahn, R. "*The Social Psychology of Organizations*," Wiley, New York, NY, 1966.

[20] Kim, D. "Introduction to Systems Thinking," Pegasus Communications, Waltham, MA, 1999.

[21] Kogut, B. & Zander, U. "What Firms Do? Coordination, Identity, and Learning," *Organization Science* 1996, 7(5), 502-518.

[22] Lertpittayapoom, N., Souren, P., Mykytyn, P. "A Theoretical Perspective on Effective Interorganizational Knowledge Sharing," *Proceedings of the 40th Hawaii International Conference on System Sciences*, Kona, HI, Los Alamitos, CA: IEEE Computer Society Press, 2007, 187b.

[23] Majchrzak, A., Malhotra, A., & John, R. "Perceived Individual Collaboration Know-How Development through Information Technology-Enable Contextualization: Evidence from Distributed Teams," *Information Systems Research*, 2005, 16(1), 9-27.

[24] Markus, M.L. & Majchrzak, A. "A Design Theory for Systems that Support Emergent Knowledge," *MIS Quarterly*, 2002, 6(3), 179-212.

[25] Massey, A.P., Montoya-Weiss, M. & O'Driscoll, T. "Performance-centered design of knowledge-intensive processes," *J. of Mgmt. Info. Systems,* 2002, 18(4), 37-58.

[26] Massey, A.P., Ramesh, V. and Montoya-Weiss, M. "Enhancing performance through knowledge management: A holistic framework," *International Journal of Knowledge Management,* 2005, 1(4), 22-41.

[27] Miles, M. B., & Huberman, A. M. "Qualitative Data Analysis: A Sourcebook of New Methods," Newbury Park, CA: Sage Publications, 1984.

[28] Nonaka, I. "A Dynamic Theory of Organizational Knowledge Creation," *Organization Science,* 1994, 5(1), 14-37.

[29] O'Dell, C & Grayson, C. J. "If Only We Knew What We Know: The Transfer of Internal Knowledge and Best Practice," The Free Press, New York, 1998.

[30] Polyani, M. "Tacit Knowing - Its Bearing on Some Problems of Philosophy," *Reviews of Modern Physics*, 1962, 34(4), 601-616.

[31] Panagiotidis, P. & Edwards, J.S. "Organisational Learning – A Critical Systems Thinking Discipline," *European Journal of Information Systems*, 2001, 10(3), 135-146.

[32] Pentland, B. T. "Information Systems and Organizational Learning: The Social Epistemology of Organizational Knowledge Systems", *Accounting, Management & Information Technology*, 1995, 5(1), 1-21.

[33] Ross, J. W. "Creating a Strategic IT Architecture Competency: Learning in Stages," *MIS Quarterly Executive*, 2003, 2(1), 31-43.

[34] Sambamurthy, V. & Subramani, M. "Special Issue on Information Technologies and Knowledge Management," *MIS Quarterly Executive*, 2006, 29(1), 1-7.

[35] Senge, P. "*The Fifth Discipline: The Art and Practice of the Learning Organization*," Doubleday, New York, 1990.

[36] von Bertalanffy, L. "*General Systems Theory: Foundations, Development, Applications*," (2nd ed.) George Brazillier, New York, NY, 1976.

[37] Yu, L. "Does Knowledge Sharing Pay Off?," *MIT Sloan Management Review*, 2005, 46(3), 5.

[38] Yin, R.K. "Case Study Research: Design and Methods," Sage Publications, Thousand Oaks, CA, 1994.