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Abstract

In order to gain sustainable competitive advantage in todayâ s knowledge economy, organizations are looking beyond routine transactional workflow processes to support knowledge-intensive processes. Traditional business process management systems are effective in providing coordination support, but are not geared towards providing relevant knowledge support as well. Also, knowledge management systems are used in an ad hoc manner without explicitly linking them to the underlying organizational processes. Process-based knowledge management (PKM) systems have emerged as a potential solution to support knowledge-intensive processes. However, design guidelines for developing PKM systems are minimal. This paper highlights this research problem, identifies kernel theories governing the design and development of PKM systems, and synthesizes various kernel theories to propose a comprehensive design theory for PKM systems. Feasibility and a comparative evaluation of the proposed design theory are also discussed.

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1. Introduction

Process-aware systems such as business process management (BPM) systems or workflow systems (e.g., IBM MQSeries, Ultimus) have proved to be an effective tool in automating business process and thereby helping improve knowledge worker and organizational productivity (Choenni et al., 2003; Kueng, 2000; Reijers and van der Aalst, 2005). However, in today's knowledge economy, a significant portion of business processes are knowledge intensive and require the efficient management of organizational knowledge to support the execution of the business processes. Organizations are now looking beyond routine work processes to provide support for processes that are highly dependent on human expertise and judgment, and are thus knowledge-intensive.

Knowledge-intensive processes (KIP) can be considered a class of organizational processes that constitute one or more activities that exhibit significant knowledge requirements for their effective enactment (Marjanovic and Seethamraju, 2008). They rely highly on specialized expertise and knowledge, continual learning, and implicit or explicit information transformation by knowledge workers (Bhat et al., 2007). The BPM and Workflow Handbook (2008) highlights—"the next focus for business improvement, and as a result the next wave of workflow and BPM investments, will be found in the optimization of human capital." Furthermore, according to Forrester Inc., economic and business shifts in the global economy such as the shortening of product life cycles, increasing competition, and changing market dynamics are driving a major change in the nature of work (Moore and Rugullies, 2005). In this regard, there is an increasing need for systems that seamlessly support knowledge-intensive business processes to support knowledge work and improve knowledge worker productivity (Moore et al., 2005).

Knowledge management (KM) systems are geared toward providing support for knowledge creation, representation, storage, retrieval, and application (Alavi and Leidner, 2001). While they have been studied in great details by researchers and have existed in organizations in one form or another, often such KM systems have been deployed in an ad hoc manner, without situating them in the context of the relevant organizational work processes. Process-based Knowledge Management (PKM) systems that can provide coordination support for knowledge-intensive processes are a potential solution to address this challenge (Abecker et al., 2000b; Bhat et al., 2007; Dustdar, 2005; Kwan and Balasubramanian, 2002; Remus and Schub, 2003). The goal of PKM systems is to be able to support knowledge-intensive processes that exhibit high reliance on the knowledge and expertise of participants executing the activities. Currently, there are minimal, if any, design guidelines that can aid in the development of such PKM systems. Given the past success of the design theory approach in the prescribing better design guidelines for a wide variety of systems such as executive information systems (Walls et al., 1992), and emergent class of systems (Markus et al., 2002; Walls et al., 2004), it is promising to situate the development of PKM systems in this design science framework.

This article (1) reviews extant literature in business process management, and knowledge management and situates the research problem concerning the support for knowledge-intensive processes using PKM systems, (2) identifies kernel theories governing the design and development of PKM systems, and (3) integrates various kernel theories to propose a comprehensive design theory for PKM systems. The paper is organized as follows. In Section 2, relevant research work from literature is discussed. Next, Section 3 discusses the information systems design theory as the relevant methodology for this work. In Section 4, the proposed design theory for PKM systems is presented in detail with a running example. Section 5 presents the feasibility analysis and validity of the proposed design theory. Section 6 includes a discussion of limitations and future work, and in Section 7 we conclude the paper by summarizing the contributions and highlighting future research directions.

2. Relevant Work

As noted earlier, knowledge-intensive processes require significant knowledge support in efficient and effective execution of its activities (Tautz, 2001). Their knowledge requirements are primarily satisfied through experiential and expert knowledge of organizational role members and thus the knowledge workers have a large impact on the outcome of KIP (Eppler et al., 1999). Additionally, such knowledge-intensive processes may exhibit other characteristics such as the need for currency of knowledge along with creativity and innovation in accomplishing the activities, steep learning curve for knowledge workers in acquiring requisite skills, numerous process-related decision possibilities, and contingency of activities on environmental factors (Eppler et al., 1999; Marjanovic et al., 2008). Examples of knowledge-intensive processes include processes related to customer service or help desk, change management, responding to request for proposals, and incident management.

Eppler et al. (1999) classified organizational processes along two dimensions, namely knowledge intensity and process complexity. Knowledge intensity is characterized as discussed above, whereas process complexity is characterized based on the number of activities involved, number of organizational role members involved and corresponding process coordination requirements, interdependencies between role members and activities, and whether the process changes (dynamic) or evolves (emergent) much over time. An organizational process may fall in one of four possible classes based on whether it is considered to have high or low process complexity and high or low knowledge intensity. Moore (2000) provides a similar framework in which the extent of knowledge sharing, collection, and reuse governs the extent of knowledge intensity in a process.

The focus of this work is primarily on the class of processes that have low process complexity and high knowledge intensity. For example, incident management for IT services typically involves a standardized process involving pre-defined activities such as recording, classification, initial support, investigation, recovery, testing and closure. However, each of these activities are knowledge intensive (Kuhlig et al., 2009) .

In addition to the arguments made earlier, it is noted that knowledge management can potentially serve as a key strategy for the redesign of business processes (El Sawy and Josefek, 2003). Using this strategy for enhancing the organization’s knowledge creation and utilization capacity, seemingly simple organizational processes may be redesigned to provide significant competitive advantage for organizations in today’s knowledge economy.

Within the past decade, several researchers have emphasized the need to extend BPM systems to support knowledge flow in organizations (Dustdar, 2005; Nissen, 2002). Even from a knowledge management perspective, process orientation is critical to providing task relevant knowledge in the context of an organization’s operative business processes (Maier and Remus, 2002a). The KnowMore system, developed by Abecker et al. (2000a) adopts a workflow-based architecture for organizational memory information systems (Abecker et al., 1998), and uses a knowledge intensive task (KIT) specification to model the knowledge requirements of a workflow task. The Knowledge-in-Context (KIC) model (Kwan et al., 2002), extends the four perspectives (functional, organizational, informational, and behavioral) of a process model proposed by Curtis, Kellner, and Over (1992) to derive the knowledge requirements of the process. The KIC model has been implemented in a workflow-based information system called the KnowledgeScope, the core components of which include Workflow Support Services, a Knowledge Application System and a Knowledge Repository.

Another stream of work has looked at defining and implementing process-oriented knowledge management strategies (Maier and Remus, 2002b; Maier and Remus, 2003), and architectures for the integration of business process management (BPM) systems and knowledge management systems (Hoffmann et al., 1999; Jung et al., 2007). While these developments supporting integration of knowledge management functionalities in BPM systems are noteworthy, they represent specific design instances and do not address the issue of generalized set of design guidelines for this class of systems.

From a methodology standpoint, past research in this area can be classified in the area of organizational memory information systems (Stein and Zwass, 1995), generic knowledge intensive systems (Schreiber et al., 1999), and emergent knowledge processes (Markus et al., 2002). Stein and Zwass (1995) propose a framework for organizational memory information systems whose goal is to manage past organizational knowledge in support of current organizational activities. Several design instances of organizational memory information systems have since been proposed (Nevo and Wand, 2005; Van Stijn and Wensley, 2001; Weiser and Morrison, 1998; Wijnhoven, 1999). The CommonKADS methodology (Schreiber et al., 1999) is methodology for knowledge analysis and knowledge intensive systems development. It proposes a “knowledge model” for specifying information and knowledge requirements of a knowledge intensive system. While it has proved successful in development of knowledge management systems, it has limited, if any, provisions for an integrated link with business process coordination and management. Markus, Majchrzak, and Gasser’s (2002) proposed design theory for emergent knowledge processes focuses explicitly on meeting requirements that pertain to dynamically changing processes. While there may be an overlap between emergent and structured knowledge-intensive processes in some cases, the knowledge requirements are quite different (Marjanovic, 2005).

Some researchers have studied knowledge-intensive process design. For example, Bhat et al. (2007) discuss the use of ontologies in design KIP. A similar approach has been proposed to develop knowledge-intensive case-based reasoning systems (Díaz-Agudo and González-Calero, 2007). However, a unified approach for the design of process-based knowledge management systems that emphasizes support for KIP is lacking.

3. Information Systems Design Theory

In order to provide prescriptive design guidance for the development of PKM systems building on extant research, the information systems design theory (ISDT) approach, initially proposed by Walls, Widemeyer, and El Sawy (1992) has been adopted as an overall framework. Walls et al. (1992) suggest that a design theory is prescriptive and goal-oriented, as opposed to a predictive or explanatory natural science theory. A design theory is considered to relate to the design product as well as the design process.

Table 1 shows the important components of an Information Systems Design Theory (ISDT). A set of meta-requirements for the design product are derived from relevant kernel theories. The design method for the artifact construction is governed by the design product meta-requirements as well as kernel theories, which may be possibly different than the design product kernel theories. The meta-requirements also guide the meta-design principles and artifacts for the design product, which are further tested using design product hypotheses to understand the extent to which the meta-requirements are actually met. Similarly, the design method hypotheses test whether or not the design method results in an artifact that is consistent with the meta-design.

Table 1. Components of an Information Systems Design Theory (Walls et al. (1992; 2004))	
Design Product	
Kernel theories	Theories from natural or social sciences governing design requirements
Meta-requirements	Describes a set of goals to which the theory applies
Meta-design	Describes a set of artifacts hypothesized to meet the meta-requirements
Testable design product hypotheses	Used to test whether the meta-design hypotheses satisfies the meta-requirements
Design Process	
Kernel theories	Theories from natural or social sciences governing design process itself
Design method	A description of procedure(s) for artifact construction
Testable design process hypotheses	Used to verify whether the design hypotheses method results in an artifact which is consistent with the meta-design

The current work focuses on the design process as well as the design product aspect of the design theory. The design product aspect includes a meta-design for a class of PKM systems based on meta-requirements and relevant kernel theories. The design process aspect in the context of KIP addresses an important design problem in itself by prescribing a novel design method for PKM systems development. The proposed design method builds on relevant kernel theories as well as the meta-requirements of PKM systems.

4. PKM Design Process

In this section we present the PKM design theory for designing Process-based Knowledge Management Systems. We begin by presenting the meta-requirements for a PKM system and then discuss the design process, kernel theories that form the basis of the design process, and the meta-design features of a process-based knowledge management system.

4.1 Meta Requirements for a PKM System

In order to derive the meta-requirements for a PKM System, we analyze the extant literature and identify kernel theories that characterize an effective knowledge management system. The meta-requirements derived through this literature analysis are presented below along with the relevant literature.

A key requirement for any knowledge management system is to support one or more organizational knowledge management processes including knowledge creation, knowledge storage and retrieval, knowledge transfer, and knowledge application (Alavi et al., 2001). Knowledge application in the context of knowledge intensive processes is enabled through the provisioning of relevant knowledge to a knowledge worker. Therefore a PKM system needs to be able to support knowledge workers in task execution by providing the requisite knowledge.

MR1: A PKMS should support knowledge worker in task execution by providing requisite knowledge.

The flow of knowledge in organizations is tightly integrated with and complementary to the flow of work (Nissen, 2002). Process-based knowledge management systems, which are designed to support knowledge intensive structured processes, also need to be integrated with process coordination systems to effectively manage the knowledge needs within such processes.

MR2: A PKMS should be integrated with work process co-ordination systems

Given the distributed nature of organizational cognition, Alavi and Leidner (2001) state that the transfer of knowledge to where it is required is an important component of knowledge management. Knowledge transfer in organizations occurs at various levels including between individuals, groups and the enterprise, and such transfers are key strategies for managing knowledge and human capital in the context of business processes (El Sawy et al., 2003). Knowledge transfers are often mediated through repositories, and storage and retrieval mechanisms that add to an organizational memory. Correspondingly, the meta-requirements for a PKMS include the following:

MR3: A PKMS should enable transfer of knowledge from individual to enterprise

MR4: A PKMS should enable transfer of knowledge from enterprise to individual

MR5: A PKMS should enable exchange of knowledge among multiple individuals and the enterprise

In addition to supporting knowledge application, knowledge transfer, and knowledge storage and retrieval processes, a process-based knowledge management system should create new knowledge that can help improve the business process or create improved and more valuable outcomes from the business processes (El Sawy et al., 2003).

MR6: A PKMS should enable the generation of additional values that help improves process and process outcomes

A process-based knowledge management system also has to respond to the changing environment and knowledge needs within a knowledge intensive process. Specifically, since knowledge needs are highly dependent on user background and expertise, a PKMS should enable personalized delivery of knowledge to process participant. Personalization can prevent overload, provide additional value for process participants and increase process execution speed (El Sawy et al., 2003).

MR7: A PKMS should enable the personalized provisioning of KM services to a participant

4.2 Design Process

In this section, we outline the design process that can be used to develop artifacts that satisfy the meta-requirements described earlier. In order to illustrate the design process and demonstrate the feasibility and applicability of each of the design steps within the process, we use an example knowledge intensive process called RFP-response process. The RFP response process is typical of the sales processes of large consulting firms and knowledge-based organizations. It is a structured and consistently repeated process consisting of several knowledge intensive tasks. A simplified version of the RFP Response sales process is shown in Figure 1. A knowledge intensive process such as the RFP response process can greatly benefit from a process-based knowledge management system that can support process participant in executing their tasks, help knowledge transfer across participants and knowledge reuse across process instances, and create new knowledge based products. In the rest of this section, we describe our design process use elements of the RFP response process to illustrate the feasibility and working of the individual design steps.

The design process consists of 7 different design steps. Corresponding to each design step, we describe the objective of the design step, the kernel theories underlying the design step, the output design document and its purpose, and a discussion on the meta-requirements addressed by the particular design step.

Step 1: Develop business process model

The first step of the design process is to develop a process model of the underlying knowledge intensive business process. The objective of this design step is to identify the tasks in the underlying business process, the dependencies among the tasks and roles and users performing the tasks. The kernel theories that govern this design step include process and workflow modeling methods such as Petri nets and UML activity diagrams. The output design document for this step is an activity diagram such as in Figure 2 describing the tasks, task sequence and a description of tasks along with roles assigned to perform the tasks. The purpose of the design document is to help analyze the relationships between knowledge intensive tasks when identified, in context of other tasks and the overall business goal. The output of this design step helps satisfy meta-requirements *MR2* by situating the PKMS Artifact in a business process model and thus enabling the invocation of the relevant PKMS components within the context of a workflow system. It also helps satisfy meta-requirement *MR6* by documenting process knowledge in the form of a process model.

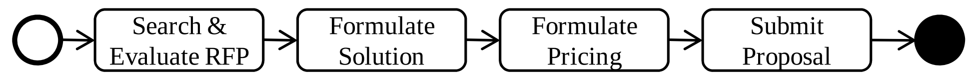

Figure 1. A Simplified RFP Response Process

Step 2: Identify knowledge intensity of each task in the process model

The objective of this design step is to identify knowledge intensiveness of each task within a business process. We use the Eppler et al. (Eppler et al., 1999) framework as the underlying kernel theory governing this design step. Eppler et al. (Eppler et al.) identify six attributes for describing knowledge intensity. The attributes include contingency, decision scope, agent innovation, half-life, agent impact and learning time. A knowledge intensive task is defined as requiring high agent innovation, involving multiple decision paths, contingent upon numerous eventualities and being highly dependent on agent actions. They are also characterized by long learning time to perform the task and lower knowledge half-life, where knowledge quickly becomes obsolete. In this design step, each task in the business process needs to be rated on the six attributes to estimate their knowledge intensity. Estimating the ratings is a part of the requirements gathering process and can be based on expert opinion and customer input. The tasks are then ranked and prioritized based on their knowledge intensity. For example, in the RFP response process *formulate pricing* and *submit proposal* can be relatively straight forward tasks involving fewer decision paths, lower agent innovation and learning time. However, tasks *Search & Evaluate RFP* and *Formulate Solution* may require higher learning times, decision paths and are highly dependent on agent actions.

Table 2. Knowledge Intensity Scores for RFP Response Process Tasks

Task	CT	DP	AI	HL	AM	LT	KI
Evaluate RFP	1	1	0	0	1	1	4
Formulate Solution	0.5	1	1	0.5	1	1	5
Formulate Pricing	0.5	0	0	0	1	0.5	2
Submit Proposal	0	0	0	0	0	0	0

CT: Contingency, DP: Decision Path;AI: Agent Innovation; HL: Half-life; AM: Agent Impact; LT: Learning Time; KI: Knowledge Intensity Score

A sample assignment of values to the various attributes of the knowledge intensity for the tasks within the RFP response process as discussed above is given in Table 2. The numbers indicate the ratings for different attributes as identified by Eppler et al. on a 0- 1 scale. The knowledge intensity score (KI) of a task is a summation of the ratings for each knowledge intensity attribute. A higher knowledge intensity score (KI) indicates a more knowledge intensive task. The design document output through this design step includes a prioritized list of tasks based on their knowledge intensity. The output design document helps identify knowledge intensive tasks that require knowledge management support and help prioritize PKM features and system development. This design step helps satisfy meta-requirement *MR1* by identifying tasks that have heavy knowledge requirements and thus enabling the development of systems that can provide knowledge support in the context of those tasks.

Step 3: Identify knowledge requirements for each knowledge intensive task

The objective of *design step 3* is to identify knowledge requirements for the knowledge intensive tasks identified in the previous step. The knowledge required to complete a task may be of different types. We rely upon three different taxonomies of knowledge types to capture the different aspects of task knowledge. We use the tacit-explicit classification of knowledge (Nonaka, 1994; Polanyi, 1962) to identify task related knowledge that is documented as well as knowledge that is rooted in experience and is in the form of an individual's mental models. Next, we classify task knowledge into procedural (know how) and declarative (know about) categories. This categorization helps identify appropriate knowledge representation mechanisms to store and transfer task knowledge. We then identify general knowledge as well as contextually and technically specific knowledge.

Such a categorization helps identify knowledge reuse scenarios and appropriate knowledge sources (Markus, 2001). For example, general and technically specific knowledge can be obtained from external sources whereas contextually specific knowledge is limited to internal sources. The design document output through this design step includes a task knowledge requirements specification that helps determine knowledge requirements of a task and the potential knowledge reuse scenarios. This design step helps satisfy meta-requirement *MR1* by identifying the type of knowledge to be provisioned to a knowledge worker and *MR3* and *MR5* by helping identify potential knowledge transfer and reuse scenarios which are further described in *design step 5*. An example knowledge requirement specification for *Search and Evaluate RFP* is given in Table 3.

Table 3. Knowledge Requirement Specification for Evaluate RFP Task

		General	Contextual	Technical
Declarative	**Explicit**	Funding agencies eligibility restrictions	Organizational capabilities and resources	Knowledge of hardware (catalog) Knowledge of software (catalog)
	Tacit	Probability of success with different funding agencies	Comparative evaluation of opportunities in context of organization	Knowledge of configuring technical infrastructure, reliability, usability of technical infrastructure etc.
Procedural	**Explicit**	How to evaluate RFP	How to lookup organizational capabilities	
	Tacit	How to evaluate RFP Probability of success given a certain capability	How to estimate probability of success in context of organizational capabilities	

Step 4: Identify knowledge sources in organization and outside

The objective of *design step 4* is to identify different sources of knowledge in an organization as well as external sources of knowledge. Several researchers have proposed alternative taxonomies of organizational knowledge that can be used to identify organizational knowledge sources. Holsapple and Joshi (Holsapple and Joshi, 2004) classify organizational knowledge into schematic knowledge and content knowledge, and Becerra-Fernandez and Sabherwal (Becerra-Fernandez, 2001) develop a classification of knowledge reservoirs consisting of people, artifacts and organizational entities. The design document output through this step includes a knowledge map describing sources of knowledge identified in knowledge requirements specification. An example showing relevant knowledge reservoirs for the RFP response process is shown in Table 4. This design document helps identify organizational knowledge sources and helps satisfy meta-requirements *MR1*, *MR3* and *MR4* by identifying knowledge sources that can satisfy task knowledge requirements, and source and recipient end points for knowledge transfer between individuals, and an enterprise knowledge reservoir.

In some cases, not all knowledge sources can be identified during the design phase. While this can be a limiting factor, the impact of such uncertainty can be reduced by using an iterative method for eliciting knowledge sources and ensuring extensibility of the eventual KM system.

Table 4: Knowledge Sources

Knowledge Reservoir	Example
People Category	
Individuals	List of Experts
Groups	HIT sales team, E-Commerce sales team, Utilities industry sales team
Artifacts Category	
Practices	RFP Eval Procedure
Technologies	RFP Search Tool
Repositories	Proposal Database
Organization Category	
Organizational Unit	Grant writers listserv
Inter-organizational network	RFP Specialists Community of Practice

Step 5: Assess Knowledge Reuse

This design step builds on design step 4 to identify knowledge producers and users in an organization. The kernel theory that forms the basis of this design step is the knowledge reuse framework proposed by Markus (Markus, 2001). This design step involves identifying task specific knowledge creation and reuse scenarios and classification into four different knowledge reuse classifications that include shared work producers, shared work practitioners, expertise seeking novices, and secondary knowledge miners. Based on organizational procedures and context, the *Evaluate RFP* task of the RFP response process can be classified as a “Shared work producers” knowledge reuse situation when the task is jointly performed by a diverse or a homogeneous group of participants, whereas it can be classified into a “shared work practitioners” scenario when several instances of the Evaluate RFP task are independently performed across the organization by different knowledge workers. The output design document for this design step includes a listing of task-specific knowledge creation and reuse scenarios. This design step helps identify and develop knowledge flows within an organization in support of the knowledge intensive process, thus satisfying meta-requirements *MR3*, *MR4* and *MR5*.

Step 6: Develop Task-User Knowledge Profile

The objective of this design step is to develop an instrument to identify the knowledge gap between task knowledge requirements and user knowledge. Abecker et al. (Abecker et al., 1998) propose a knowledge intensive task specification that can be used to specify the task-specific user knowledge needs. An example KIT specification for the *Formulate Pricing* task is shown in Figure 2.

```
KIT:
(name:              Generate-pricing-model
relevant-input: {list-of-items, rfp}
expected-output: {pricing-sheet}
information needs: {
    (name:            get-pricing-templates,
     description:    "pricing templates to develop a pricing
                      form for a given task instance"
     preconditions: {}
     agent-spec:     {retrieval-agent select $p}
     parameters:     {list-of-items, rfp}
     from:            {pricing-templates-db}
     contributes-to: {pricing-sheet}
    )
})
```

Figure 2. A sample KIT specification

The output design document is a task specific user profiling template to capture task-specific user knowledge. Such a profile can be used in a user profiling mechanism to infer user knowledge requirements and user interests specific to task over time. This design step helps satisfy meta-requirements *MR1* and *MR7* by personalizing knowledge delivery based on task context as well as user knowledge needs.

Step 7: Design task-specific knowledge management components

The final design step utilizes the design documents to develop task specific KM support services that integrate with a business process management system to form a process-based knowledge management system. The task-specific KM support services that can be designed include knowledge application services, knowledge creation services, knowledge repositories, and knowledge transfer services. The task specific knowledge support services can be developed by mapping the task knowledge characteristics and source knowledge characteristics identified in steps 3 and 4 to a catalog of knowledge management techniques. For example, procedural knowledge can be stored as and provided through expert systems and knowledge based systems whereas declarative knowledge can be stored as and provided through database systems. Similarly, socialization based knowledge management techniques can be used to transfer tacit knowledge, whereas document repositories can be used to transfer explicit knowledge. A summary of the KM support services, their design methods and relevant details are provided in Table 5.

4.3 Formal Specification and Meta-Design

We introduce a formal notation to represent the key constructs of the PKM problem space and propose a meta-design for process-based knowledge management systems. The meta-design then describes the relationships between the constructs and their relationships in terms of the organizational knowledge management processes including knowledge application, knowledge storage and retrieval, knowledge transfer and knowledge creation.

Basic Concepts

Task Set (T): Given a knowledge intensive process, all the tasks that compose the process constitute the task set denoted as T.

Knowledge Intensity Attribute Set (KI)*:* The knowledge intensity attribute set, denoted as KI, is a set of attributes use to denote the knowledge intensity of a task. The elements of the Knowledge Intensity Attribute Set include Contingency, Decision Scope, Agent Innovation, Agent Impact, Learning Time, and Half Life (Eppler et al., 1999).

Entity Set (E)*:* The entity set, denoted as E, includes knowledge workers, groups and systems that are either sources or recipients of knowledge.

Source Entity Set (S)*:* The source entity set, denoted as S, is a subset of the entity set and represents sources of knowledge.

Recipient Entity Set (P)*:* The recipient entity set, denoted as P, is a subset of the entity set and represents recipients of knowledge.

Actor Set (A)*:* The actor set, represented as A, is a subset of the entity set and represents knowledge workers who apply knowledge in the performance of process tasks.

Knowledge Set (K)*:* The knowledge set K is set of uniquely identifiable knowledge objects.

Knowledge Type Set (KT)*:* The knowledge type set captures different typologies of knowledge. Examples of the elements of the knowledge type set include tacit, explicit, declarative, procedural, general, technically specific, contextually specific, and so forth. The set is denoted as KT.

Task Knowledge Set (K^{ti})*:* Task knowledge set, $K^{ti} \subseteq K$, consists of the knowledge objects required to successfully complete a task $t_i \in T$.

Knowledge Worker Task Knowledge Set (K^{tiwj})*:* Knowledge worker task knowledge set, denoted as $K^{tiwj} \subseteq K^{ti}$ consists of knowledge objects possessed by a knowledge worker w_j that can be used to successfully complete a task $t_i \in T$.

Source Knowledge Set (K^{si})*:* Source knowledge set K^{si} , is a subset of K, and represents the set of knowledge objects that are possessed by source s_i.

Available Knowledge Set (KA^{ti})*:* Available knowledge set KA^{ti} is a subset of task knowledge set K^{ti} , and represents the set of knowledge objects available for application to complete task t_i.

IT Agent Set (IT)*:* IT Agent set, denoted as IT is a set of information technology agents and systems available to help manage knowledge.

PKM Meta-Design

We represent the PKM meta-design as a series of relations that model the relationship among different constructs as follows.

Task Knowledge Intensity Relation (R^{TKI}) *:* Task knowledge intensity is defined as a ternary relation $R^{TKI} = \{(t, ki, rt) | t \in T, ki \in KI, rt \in RT\}$ over the sets T, KI, and RT, where T is a set of tasks, KI is the knowledge intensity attribute set and RT is a rating scheme such that RT = $\{ xi \,|0 \leq xi \leq n, xi\,, n \in \mathbb{R}\}$.

Knowledge Object Properties: The properties of a knowledge object is given by the binary relation $R^{KT} = \{(k, kt) | k \in K \; and \; kt \in KT\}$ over the sets K and KT, where K is a set of knowledge objects and KT is a set of knowledge types.

Knowledge Transfer: Knowledge transfer, where knowledge *k* is transferred from source *s* to recipient *r* is defined as a ternary relation $R^{TR} = \{(k, s, p) | k \in K^{si}, s \in S, p \in P\}$ over the sets K^{si}, S, and P as defined earlier. This relation helps in representing the knowledge flows necessary to support a knowledge intensive process.

Knowledge Creation: Knowledge creation is achieved through the processes of combination and socialization. We define knowledge creation process as a quarternary relation R^{CR} $=\{(k,s,it,o)|k \in K^{si}, s \in S, it \in IT, o \in K\}$, where knowledge source *s*, possessing knowledge *k*, use information technology *it* to support combination or socialization to create new knowledge *o*.

Knowledge Application: Knowledge application processes involve the application of available knowledge by an actor to perform a particular task. Consequently, we define knowledge application as the relation R^{AP} $=\{(k,a,t)|k \in KA^{Ti}, a \in A, t \in T\}$, where $\mathrm{KA}^{\mathrm{Ti}}$ is the set of knowledge objects available to perform task *t* by actor *a*.

Knowledge Storage and Retrieval: Knowledge storage and retrieval involves the use of information systems to capture knowledge and make it available when required. The type of information system best suited for storing and retrieving knowledge is dependent on the type of knowledge. Consequently, we define knowledge storage and retrieval as the relation $\mathrm{R}^{\mathrm{SR}}$$=\{(k,it)|it \in IT, k \in K^{KT}\}$,, where K^{KT} = $\{k \in K|\, R^{KT}[k_i] = R^{KT}\left[k_j\right] for\ every\ k_i, k_{j,}\}$ is a set of knowledge objects that share the same set of properties.

Personalization: Personalization is achieved by filtering the knowledge flows to present knowledge customized to the knowledge worker's needs within the context of the task. The set of personalized knowledge delivered to a knowledge worker *wj*, from source si is given by $K^P = \{k \in (K^{si} \cap K^{ti}) \setminus K^{tiwj}\big|k, si, wj \in R^{TR}\big(K^{si}, S, P\big)\big\}$, where each knowledge object *k* in the set, along with the source *si* and knowledge worker *wj* belong to the knowledge transfer relation $\mathrm{K}^{\mathrm{TR}}(\mathrm{K}^{\mathrm{si}}, \mathrm{S}, \mathrm{P})$. The filtering of knowledge flows is given by subtracting the knowledge workers task knowledge $\mathrm{K}^{\mathrm{tiwj}}$ from the source task knowledge$(K^{si} \cap K^{ti})$.

In using a set theoretic notation and relations to represent the PKM meta-design, we allow for the technology independent design of PKM systems and formal analysis of the problem space to develop new algorithms and systems for knowledge management. For example, the relations can be mapped to a relational database design or graph based system designs. Moreover, the set theoretic formal specification allows for logical inference to create rules and new algorithms or in the construction of ontologies using formal concept analysis.

5. Feasibility and Evaluation

In this section, we present a preliminary validation of the proposed design theory by demonstrating the feasibility of the proposed design process and comparing the PKM approach with other modeling approaches with respect to the 7 meta-requirements for process-based knowledge management systems.

Table 5: Knowledge Support Services

KM Support Service	Objective	Design Approach	Meta-requirement addressed
Knowledge Application Service	Provide requisite knowledge to users for specific task	Map knowledge requirements with source knowledge by selecting technique based on knowledge type	MR1, MR3, MR4, MR5
Knowledge transfer service	Transfer knowledge between experts and novices and shared work practitioners for each task	Map knowledge sources and recipients by selecting technique based on knowledge type	MR5
Knowledge repository service	Support knowledge externalization/Internalization in the context of each task	Develop templates for storing knowledge created in context of tasks using models such as KIC (Kwan et al., 2002) and KIT models(Abecker et al., 1998).	MR3, MR4
Knowledge creation services	Support socialization/combination in the context of knowledge generated	Develop data-mining, text-mining and socialization systems to support knowledge creation in the context of each task	MR6

We demonstrate the feasibility of the PKM design approach by illustrating the complementary nature of the PKM design artifacts with existing systems analysis and design methods and diagrams. Each of the PKM design and analysis artifacts can be integrated with existing systems development methods and tools to eventually aid in the implementation of process-based knowledge management systems through established systems development methodologies. A mapping of the PKM design artifacts to existing system analysis and design activities illustrating their complementary relationship with typical analysis and design tools is shown in Table 6.

Table 6. Integrating PKM Design Theory with Systems Development Methodologies

Phase	Typical Design Documents	PKM Augmentation
Analysis Phase		
Requirements Capture	Software Requirements Specification Use Cases	Process Model (Design Step 1) Knowledge Requirement Specification (Design Step 3) Task Knowledge Intensity Scores (Design Step 2) Knowledge Sources Map (Design Step 4)
Functional Modeling	Activity Diagram Use Cases	Knowledge flow models (Design Step 5) Knowledge reuse scenarios (Design Step 5)
Design Phase		
Database Design	ER Models Relational Schema	Task-User-Knowledge Profile (Design Step 6)
Architecture Design	Component diagrams	KM Support services and components (Design Step 7)

In Section 4.2, we described the PKM design process including the outputs of each design step and the mechanism through which they satisfy the seven meta-requirements of process-based knowledge management systems. In Table 7, we present a comparison of various alternative design methods with respect to their ability to satisfy the 7 meta-requirements of process-based knowledge management systems. We observe that while most existing design methods include mechanisms to support knowledge workers in task execution, they lack design mechanisms that can help in the generation of new knowledge and creation of additional value added products for the organization.

Table 7. Comparison of different design methods for satisfying meta-requirements of process-based knowledge management systems. The - / + signs indicate whether the design method meets/ does not meet a particular PKM meta-requirement.

Design Methods	References/ Examples	PKM Meta-requirements (Marjanovic et al.)						
		MR1	MR2	MR3	MR4	MR5	MR6	MR7
Business Process Modeling – focuses on the data and control flow in workflow processes	Petri Nets (van der Aalst, 1998), Event-driven Process Chains (EPC) (Dumas et al., 2005; van der Aalst, 1999) Business Process Modeling Notation (BPMN) (OMG, 2009)	-	+	-	-	-	-	-
Knowledge-in-Context modeling approach – focuses on modeling functional, informational, organizational, and behavioral perspectives	KnowledgeScope knowledge management system (Kwan et al., 2002)	+	+	+	+	+	-	-
CommonKADS Methodology – focuses on modeling knowledge requirements in the design of knowledge management systems	CommonKADS methodology for Knowledge Engineering and Management (Schreiber et al., 1999)	+	-	+	+	+	-	-
KnowMore framework – focuses on supporting knowledge workers with requisite knowledge during their workflows.	DÉCOR (Delivery of context-sensitive organizational knowledge) project (Abecker et al., 1998; Abecker et al., 2001)	+	+	-	-	-	-	-

In addition, the design methods are focused on matching task knowledge requirements with available knowledge but do not take into account user’s background knowledge. This deficiency can lead to information overload and decreases chances of user acceptance of the knowledge management systems. The PKM design process presented in this paper builds on past approaches to satisfy all the meta-requirements of a process-based knowledge management system.

6. Limitations and Future Work

The design process presented in this paper has specific shortcomings which we intend to address in future research. A knowledge management requirement and related design activity not addressed in the current paper is the need for metrics to assess the effectiveness of the knowledge management functions knowledge intensive processes. A second limitation is the identification of specific knowledge management tools such as capturing and sharing tools that can facilitate various knowledge management functions. In addition to the above limitations, the meta-requirement 7 related to personalization requires further enhancement to capture organizational and environmental aspects of a task.

7. Conclusions

Knowledge intensive processes account for a significant portion of the business processes in today's knowledge-based economy. Process-based knowledge management systems that can support such knowledge intensive processes are therefore necessary to ensure productivity and efficiency in organizations. The design theory proposed in this paper can serve as a design guide for system analysts and developers to build PKM systems that can effectively support knowledge-intensive processes. In developing the design theory, we have also identified meta-requirements for a process-based knowledge management system and have synthesized various kernel theories to propose a comprehensive design theory for PKM systems.

The design theory articulated in this paper points toward numerous future opportunities. While a qualitative evaluation has been provided in this paper indicating the value provided through the proposed design theory, current efforts are geared towards performing empirical evaluation of the design theory. In that regard, experiments involving the development of design artifacts are planned. The resultant artifacts would be compared based on the extent to which the meta-requirements are met. Action research is another compatible research methodology that is being considered for validating proposed design theory in the field. The results from such research could further inform the impact and utility of the proposed design process.

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