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■ *Research Article*

The Dimensions of Process Knowledge†

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Many researchers are of the view that a firm's knowledge assets include its structure, culture, processes, employees and physical artifacts. The knowledge management (KM) literature has tended to emphasize *employee knowledge* as a locus for KM efforts. While this viewpoint is perfectly rational and justifiable, there is also a considerable amount of knowledge embedded in the firm's operating procedures. In this paper, we espouse viewing organizational knowledge from this perspective and propose a framework to manage process knowledge. Starting with a definition, classification of processes, and a characterization of the knowledge generation process, we provide seven dimensions by which process knowledge can be viewed: structure, personnel and coordination, performance and tools, discourse, results, quality and implications. They are intended to serve as a starting point for managing process knowledge. The dimensions are illustrated with several examples and implications of the framework are pointed out. Copyright © 2005 John Wiley & Sons, Ltd.

INTRODUCTION

Rapid changes in business and technology are forcing organizations to learn at an unprecedented rate. Many are realizing that unless knowledge collection and transfer occurs at an equally rapid rate, their competitiveness is affected, leading them to focus more intently on their knowledge assets. Though the full specification of the set of these assets is evolving, there seems to be a consensus that they include the organization's employees, structure, culture and processes (Van der Bent *et al.*, 1999; Walsh and Ungson, 1991). Of these, the knowledge management (KM) literature has tended to focus on identifying employee knowledge, particularly their tacit knowledge, on the grounds that this is where the useful knowledge resides (Lesser and Wells, 1999; Lubit, 2001; Martiny, 1998). While this viewpoint is perfectly valid and useful, process knowledge[1] is also an essential part of organizational knowledge and has tremendous significance from a knowledge management perspective. To begin with, organizations have a sizeable intellectual investment in the form of formalizations of processes. Descriptions of manufacturing processes, for instance, include the raw material and equipment used, the appropriate environmental conditions to be realized, the treatment times, etc. These descriptions are essential to training employees, establishing standards and communicating best practices within the organization. But they are by no means static. There is an ongoing investment as organizations monitor processes to effect efficiency improvements. Many have mechanisms in place to collect knowledge from the results of processes such as customer surveys, quality control charts and performance audits, which are ultimately utilized to modify the process. We espouse viewing knowledge from the process perspective. We recognize however,

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[1]We recognize that there is some degree of overlap between process knowledge and employee knowledge. This is pointed out further in the paper.

Table 1 Examples of manufacturing, service and design processes

P1—The manufacturing process for Polyamide 6, a Nylon (Wiltzer, 2000)
1. Hot liquid caprolactam is conveyed from storage tank 1.1 or 1.2 to reactor 2 2. Raw caprolactam from extract water and wastewater containing caprolactam is received by a three-step extract water evaporation 3. The raw caprolactam undergoes polycondensation in reactor 1 4. The caprolactam from reactor 1 is pumped under pressure into reactor 2 5. The polyamide flows from reactor 2 into reactor 3 depending on the level 6. Surplus water is taken off through a reflux column into a sealed pot 7. The product is extracted and dried after granulation
P2—The Consumer Lending Process (Leath, 1998)
1. Origination—application submission, processing, underwriting 2. Review and booking—reviewing application information, approving the loans 3. Documentation—maintaining files on the loans 4. Collection and recovery—pursuing late payments, debt recovery, etc.
P3—Design of a tape-position controller (Ball *et al*., 1994)
1. Define functional requirements of device 2. Define high-level modules 3. Devise representation of modules and interconnections in block diagram form 4. Design tape motion sensor 5. . . .

that some amount of process knowledge is tacitly held by employees and presumably acquired through training and experience. The extent to which it is explicit is a moot point, but the need to structure and organize it is vital to the KM effort. A recent study by the American Productivity and Quality Center (APQC, 1997) concluded: 'If you do not have a knowledge management strategy, a framework, and an information technology model to support it . . . you end up in chaos' ('framework' is underlined for emphasis). It is our objective to suggest a framework which can aid in this endeavor. In the remainder of the paper, we define the domain, link it with organizational learning, propose and elaborate on the framework, and conclude with discussion of the framework and its research implications. The dimensions are intended to serve as an initial step for organizations wishing to exploit knowledge assets from processes.

DEFINITION AND CLASSIFICATION OF ORGANIZATIONAL PROCESSES

A major part of organizational activity (exceeding 90% in some cases) can be described in terms of processes. A crude definition of a process is as a grouping of related activities (Garvin, 1997). According to Davenport *et al*. (1996), a *process* is an ordering of activities across time and place, with a beginning, an end, and clearly identified inputs and outputs: a structure for action. Pentland (1995) goes as far as to suggest that a process is a grammar for action, prescribing the rules by which activities are assembled together and carried out. We will alternatively use the terms 'routine' and 'AA' (aggregated activity), and 'OP' (organizational process) for referring to processes. Processes typically consist of dozens of activities, each with inputs and outputs. A routine which consists of only one activity is generally not referred to as a process. Performance appraisal is not a process by this definition if it consists only of evaluating an employee. The activities are automated in some cases, while in others they are carried out manually. The inputs and outputs could take the form of materials, personnel, information, etc. which vary with the type of process and functional area (Garvin, 1997). For example, consider the manufacturing, service and design processes listed in Table 1.

It is evident that there are major differences in these processes. Manufacturing processes[2] tend to

[2]Here, it refers to any process that involves production of a tangible good.

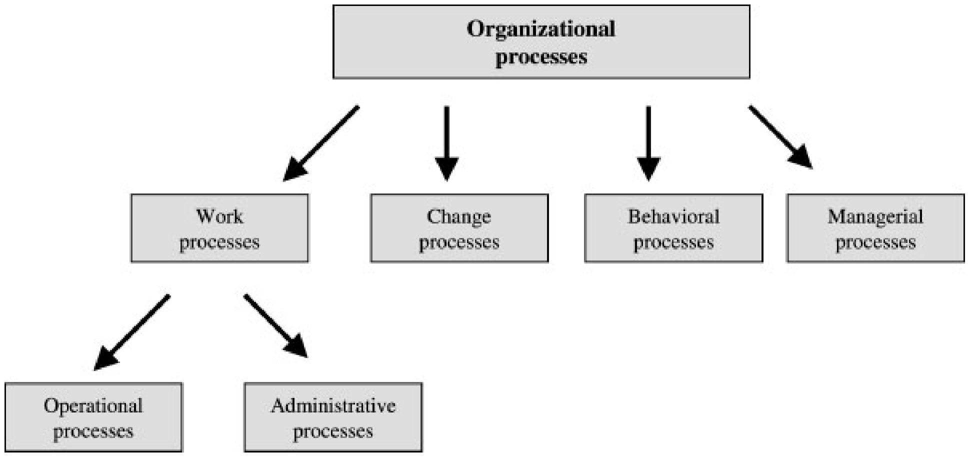

Figure 1 Garvin's classification of organizational processes (Garvin, 1997)

be very structured,[3] dealing with raw material and its transformation to a finished good. They are automated in many cases. Non-manufacturing processes,[4] on the other hand, deal with information as a raw material. Cognitive processes[5] such as design involve human beings to a greater extent and tend to be highly individualistic. Process P3 in Table 1 shows how one individual attempted a design problem (Ball *et al.*, 1994). The steps followed vary with the individual attempting the problem. Processes also vary greatly from organization to organization and across functional areas. It is beyond the scope of this paper to identify the full set of characteristics of organizational processes since the purpose is simply to identify the types of knowledge that we can obtain from them. Towards this objective, we introduce a classification of OP, based on the framework introduced by Garvin (1997).

According to Garvin (1997), OP could be broadly classified into work processes, behavioral processes, change processes and managerial processes (see Figure 1). *Work processes* simply transform inputs to outputs and are synonymous with our definition of a process. These could be broadly classified into *operational* and *administrative* processes depending on whether they are related to production or support it. *Behavioral processes* are patterns of behavior and ways of interacting and include decision making, communication and organizational learning. *Change processes* are concerned with transforming the organization. Behavioral and change processes are more complex since they include variables from the broader organizational context such as culture, strategies, and environmental relationships. We will consider only work and managerial processes in this research.

The American Productivity and Quality Council classifies OP into *operating*, *management* and *support* processes (APQC, 2004). The APQC groups operational processes according to the product development life cycle, which starts with a vision, and then proceeds through design, manufacture etc. as seen in Table 2. Garvin's classification roughly corresponds to the APQC (American) classification, with two major differences. Administrative processes are separated from managerial processes whereas in the APQC classification both are grouped together. Secondly, strategic processes in the APQC would perhaps fall into the 'behavioral' category in Garvin's classification. The typology that we will use is based on both approaches, but we will consider a classification valid *across* different organizations rather than applying to those within a single organization as is done by the APQC. The broad categories in our typology are *operational*, *support* and *managerial* processes. Operational processes have been expanded to include engineering/design, manufacturing/service and financial/accounting processes. Support processes include administrative and legal processes. The latter are subsumed under 'manage external relationships' in the APQC classification. Thus our classification uses the broad categories developed by Garvin and also utilizes some of the subcategories in the APQC scheme. It includes the following types of processes: engineering/

[3]'Structured' refers to the extent to which the steps of the process are discrete and clearly discernible.
[4]'Non-manufacturing' refers to processes involving an intangible good.
[5]A cognitive process is one which involves a substantial amount of creative or mental activity such as creating a design for a book cover.

Table 2 APQC classification of organizational processes (APQC, 2004)

Operating processes	Management/support processes
Develop vision and strategy	Develop and manage human capital
Design and develop products	Manage information technology and knowledge
Market and sell products	Manage financial resources
Deliver products and services	Acquire, construct and manage property
Manage customer service	Manage environmental health and safety
	Manage external relationships
	Manage improvement and change

design, manufacturing/service, financial and accounting, administrative, legal and managerial. Examples of these can be found in Tables 1 and 4. The classification covers all manner of aggregated organizational activity. Process P1 in Table 1 is an example of a manufacturing process, P2 an example of a financial/accounting process and P3 an example of a design process. The reader will note also the rationale for classifying financial/accounting processes as operational processes rather than administrative or support processes. In a bank, *lending* is an operational process by our classification, whereas this would be classified as an administrative or support process in APQC.

ORGANIZATIONAL LEARNING AND PROCESS KNOWLEDGE

Different frameworks have been advanced to characterize the *knowledge management cycle* in organizations (Demarest, 1997; Pearlson, 2000; Ruggles, 1998). The major activities in the cycle include identification, generation, codification and transfer. The preliminary stages of identification and generation are concerned with the acquisition of knowledge. Sources of knowledge could be internal or external, including experienced employees, consultants, experts and trade reports. The relevant knowledge is identified and generated through familiar techniques such as discussion groups, presentations and shared workspaces. Since we are proposing a framework to aid in knowledge organization, we are concerned with the first three stages of the cycle in this research.

The generation of process knowledge differs from the generation of tacit knowledge held by employees. The latter is generated through discussion groups, online conferencing etc., while explicit process knowledge is generated as a result of conscious management and monitoring of processes. Table 3 summarizes these differences. Organizations depend on process improvements for productivity increases. Accordingly, they are continuously fine tuning the parameters of the process such as changing the order of activities, temperature, pressure and ingredients, to increase throughput, quality and efficiency. The process of monitoring and making changes can be characterized as Observe, Analyze, Design, Implement (Kim, 1993). Thus, when changes are implemented to a process, results are observed, analyzed, and improvements are made. This process of learning is said to be *single-loop learning (performance loop)*, which occurs when an employee observes *process outputs* and makes modifications to improve them. *Double-loop (relevance loop)* learning occurs when an employee questions the beliefs and

Table 3 Differences between personnel and process knowledge

Knowledge domain →	Personnel knowledge	Process knowledge
Type of knowledge	Mostly tacit	Mostly explicit[a]
Degree of formality	Informal: based on employee experience	Formal: based on organizational experience
Method of generation	Interviewing, discussion groups, etc.	Process management: Observe, Analyze, Design, implement
Extent to which it can be codified	Not to a great extent	Explicit part, provided context is preserved[b]

[a]As stated earlier, one aspect of process knowledge, namely 'performance knowledge', shares the same characteristics as 'personnel knowledge' referred to in this table.
[b]See Wensley and Verwijk-O'Sullivan (2000).

assumptions behind the *process set-up* and makes fundamental changes to its structure (Davenport and Beers, 1995; Hackbarth and Grover, 1999). For instance, consider a computer firm that has traditionally leased equipment to small and mid-sized companies. For these types of clients, leasing is an expedient method of reducing capital costs. The leasing process could involve activities such as identifying the client's needs, preparing a contract, and delivering the equipment. An employee observing the process could suggest improvements to the manner in which the process is carried out. If the employee observes that salespersons need to write down the client needs, go to the office and have a contract made out, he/she could suggest that both activities be carried out simultaneously. On the other hand, observing the prices on new and used equipment, and the willingness of clients to spend on information technology, he/she could question the rationale behind the *leasing* process and could suggest fundamental changes to the process itself, namely, providing direct sales of equipment. Single-loop learning in this case involves observing and learning from process performance, and results in changes to process parameters such as changing the order of activities. Double-loop learning involves learning about the process in relation to its environment and making a radical change to the process, namely the inclusion of direct sales. Both types of learning activities require and generate a considerable amount of knowledge, the characterization of which is one of the tasks at hand.

DIMENSIONS OF PROCESS KNOWLEDGE

Knowledge, according to Davenport and Prusak (1998), is 'a fluid mix of framed experience, values, contextual information, and expert insight that provides a framework for evaluating and incorporating new experiences and information'. Knowledge is contextual and includes an actionable summary and interpretation of experience. Similarly, process knowledge is also experiential, contextual and actionable. A process is the result of institutionalization of practice as pointed out earlier and process knowledge is a valuable byproduct of this process. It is contextual since it is difficult to characterize outside of the process. It is embedded in structure, training, management and technologies. Thus *process knowledge* is defined as contextual, experiential, value laden and insightful information about a process, including how it is configured, how it is coordinated, how it is executed, what outputs are desirable and what impacts it has on the organization. It is actionable, since the knowledge can be used for training employees, communicating best practices or for effecting improvements. The best way of characterizing this knowledge is to use the Observe, Analyze, Design, Implement framework (Kim, 1993). We have re-ordered these as Design, Implement, Observe, Analyze, but rather than use these labels, we will use process-specific labels as illustrated in Figure 2. These labels are popular in the workflow literature (for an example, see WFMC, 1999). The

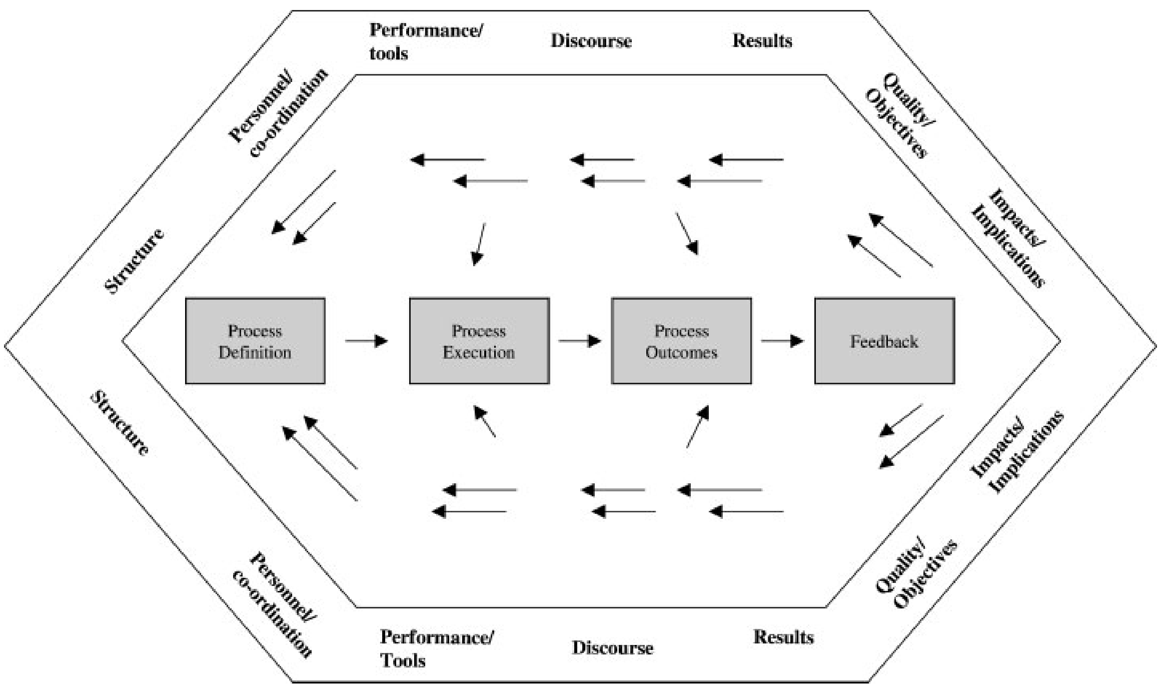

Figure 2 Dimensions of process knowledge

process learning cycle starts with defining the process, then proceeds through execution, observation of outcomes and feedback.

The dimensions of knowledge are associated with the modified learning cycle. The definition or specification of processes creates *structural* knowledge. It is then executed for a particular instance (example, John Doe's loan application). Process execution in our view requires a variety of types of knowledge. Specifically, employees need to be trained and coordinated to execute the process. The knowledge required to *train* and *coordinate* them becomes part of process knowledge. Some processes require employees to use *tools*. Software testing using a testing environment is a case in point. The tool allows employees to run different modules on different test cases and it allows them to record and analyze the results. When employees carry out processes, they accumulate knowledge and this becomes one of the tacit dimensions of process knowledge, namely *performance* knowledge. Managerial processes typically involve multiple participants, framing of context, complex sets of trade-offs, and other careful discriminations which are also present in other complex processes (Garvin, 1997). The record of these actions is what we are characterizing as the *discourse* dimension.

When a process has executed, it produces an outcome, and hence the *results* dimension is also included (please refer to Figure 2 again). In certain types of processes such as manufacturing processes, it is important for the results to meet *quality* requirements. Examples are tolerances, yields, and defects. Non-manufacturing processes would alternatively have certain *objectives* such as being within budget or hiring within a time period, which have the same significance as quality in manufacturing processes. Finally, the execution of a process could have *impact* on the same process or on other processes. A hiring plan developed in an organization could result in employees being hired. Feedback could affect the structure or performance or other processes. Thus the dimensions of process knowledge are: structural, personnel/coordination, performance/tools, discourse, results, quality/objectives, and impacts/implications. These are formally discussed next.

Structural

The structural dimension is concerned with configurations of a process, particularly the orderings of activities which characterize organizational processes (Malone *et al*., 1999). It encompasses the sequence in which activities have to be performed, the inputs and outputs that they have, the constraints under which they are carried out, and the manner in which these can be changed to optimize the process. There are various methodologies for modeling the process structure and the literature on this is very extensive. Such methodologies include Petri nets, variations on state transition networks, program specification techniques, transaction models, UML, logic, and frames (Amaravadi, 2004). SAP, for example, has a methodology for modeling business processes which it refers to as the event process chart. The methodology includes constructs as well as icons to represent interactions between events, functions, processes, and organizational units (Curran *et al*., 1997).

The description of a process enables formation of mental models and is often the main vehicle for knowledge sharing (Leppanen, 2001). Process descriptions are vital in manufacturing processes since the parameters and constraints are stringent. In the manufacture of chemical compounds, for instance, the reaction times, the temperature and pressure, composition of input materials, and the type and composition of catalyst used need to be closely adhered to or the firm risks losing the entire batch. On the other hand, in design and managerial processes, there is a greater cognitive component and the opportunity for variations in structure within different groups. Organizations attempt to experiment with process configurations in order to increase throughput, reduce cycle time, or increase efficiencies. The record and rationale for these changes are a valuable derivative of the learning process and essential to knowledge sharing.

Personnel and coordination

In processes where manual intervention is necessary, the company's employees have a very important bearing on the output. 'The operators must be very flexible in their problem solving behavior . . . very ingenious in using all sorts of available knowledge when applicable and their diagnostic performance increases with experience' (Leppanen, 2001, p. 579). Since processes are typically handled by multiple employees, the *personnel and coordination* dimensions refer to the training and management that are necessary for the process to achieve its desired result. Thus it includes issues such as: What are the process expertise requirements? How many individuals are required? How often should they meet? What criteria should be used to evaluate them? How should they be trained? For how long should employees be trained? How should they be coordinated? What development programs have been carried out and what are the results of these programs?

Performance and tools

Knowledge is both required and generated as a result of process execution. The performance dimension is concerned with knowledge associated with the execution of the process and tools used. Included under this rubric is knowledge about the factors which affect the efficiency and throughput, the type of problems that arise and their resolution, the support tools and their peculiarities. One example of this type of knowledge (in a fast food restaurant) is a method of distributing pepperoni on deep-dish pizzas so that it overcomes the problem of 'clumping', where all the pepperoni gathers in the middle. The solution to even distribution is to arrange the pepperoni in the form of spokes, on the pizza, before placing them in the oven (Argote, 1999, p. 91). Overcoming problems associated with process execution is a significant component of performance knowledge. Since tools are utilized to execute processes, these are also associated with performance knowledge. *Tools* are artifacts required or utilized in process execution. Tools can be physical tools such as jigs, fixtures, and testing apparatus, or conceptual tools such as engineering methodologies. Tool knowledge is concerned with how to operate the tools, its settings and idiosyncracies. At the outset of this section, we discussed the example of a software environment to carry out testing. To carry out the testing, an operator has to know the settings, the different test options and the order in which the inputs are supplied. Thus performance/tool knowledge includes knowledge of tools, along with knowledge of how to execute the process and troubleshoot problems.

Discourse

Certain types of processes such as strategy formulation and design are iterative and involve a considerable amount of negotiation and discourse, to obtain ideas, surface problems, obtain additional information, resolve issues, and arrive at a consensus. The discourse dimension, sometimes called due process, refers to the meandering process of arriving at decisions (Hewitt, 1986, Gerson and Star, 1986). It is time consuming, and involves multiple parties and trade-offs/compromises. Hiring the CEO of a company is such an example since it is a lengthy process involving the board, the personnel department and top management of the company, with each group having different views. The discourse process generates knowledge about the history leading up to a decision: the rationale behind decisions, the time frames, the key actors, the alternatives considered, and the compromises that were made (Hewitt, 1986; Gerson and Star, 1986). This type of knowledge is necessary to evaluate or trouble-shoot processes or to make deeper adjustments (incorporate double-loop learning) to them.

Results

The *results* dimension concerns two types of knowledge: the outcomes of a process being executed and results concerning its effectiveness. For instance, in a loan situation, the amount of the loan issued as associated with the type of customer is an example of the former type of knowledge. Actually, it would become knowledge only when analyzed over a period of time over a large number of customers (Hackbarth and Grover, 1999). Patterns such as the type of customers and average loan amounts can then be discerned. The second type of knowledge concerns results of *process measures*, i.e. 'performance loop' type information. In the loan situation, these can include the number of 'touch points' (the number of times the bank handles a particular application), the amount of time it took to process the loan, the number of write-offs (due to non-payment), etc.

Quality and objectives

For manufacturing and service processes, product quality is one of the important, albeit intangible, outputs of a process. The *quality* dimension is concerned with quality of the process and its outcome. It encompasses knowledge about quality indicators, their current and target values, and techniques to improve quality. Quality indicators include such things as timeliness, cost, and quantity. This dimension has some overlap with the tools and performance dimension. For non-manufacturing processes, quality may not be relevant and therefore we have also included the label of *objectives* to encompass the requirements to be met by administrative and managerial processes. It can include such things as minimizing claim amounts (in claims processing) or hiring a CEO by a certain date (in a hiring process).

Impacts and implications

Processes are typically interlinked with other processes such that changes to one have important implications for other activities within the organization. In fact, these are often the critical processes in the organization (Lientz and Rea, 1998). Design and managerial processes are cases in point since they are concerned with key decisions that drive other OP. The redesign of an engine could require retooling of assembly plants, modification to components that are purchased, and perhaps changes in supplier relationships as well. Similarly, when a company decides to issue stock, it is obligated to inform the Securities and Exchange Commission and its shareholders. The implications dimension is thus concerned with implications for organizational action. As with the results dimension, there are two types of implications corresponding to the two types of learning. The results of a process could have implications for making adjustments to the process or for making changes to other activities. It should be evident that this dimension comes into play when modifying existing OP or designing new OP based on existing processes.

AN ILLUSTRATION OF THE DIMENSIONS OF PROCESS KNOWLEDGE

The following mini-case describes the process of designing components (such as suspensions, transmission, and engines) for a heavy equipment manufacturer (HEM) located in the Midwest. HEM[6] manufactures a variety of construction and farm equipment such as bulldozers, combines, dump trucks, backhoes, and scrapers. The company is organized into a number of departments including marketing, product management, purchasing, human resources, manufacturing, and testing. Product and component designs are initiated by the product management group in response to competition, feedback from customers, or from engineers.

The design process can be characterized as consisting of a number of phases starting with the product concept, terminating with production, and a number of reviews in between. The product/component concept is developed by the product management group and is handed over to the team which handles the design. The team, headed by a project manager, is cross-functional in nature, consisting of representatives from each department. The concept document lists detailed specifications of the component such as required horsepower, weight, maximum speed, blade capacity, angle, depth, and maximum capacity.

Depending on the level of experience, the task is assigned to an engineer within the team. The project now enters the *alpha phase*, where the emphasis is on the feasibility of the design. The design task is assigned to an engineer who develops two to three alternative designs for the component. The concept is developed progressively, with weekly intra-team reviews. The engineer develops two or three crude designs, specifying the general parameters of the component, such as shape, size, material etc. In the process, the engineer consults previous designs, results of past simulations, etc. He/she receives feedback from team members regarding manufacturability, materials, etc. For instance, an engineer may be tasked to develop a door for a combine that opens 90°. A materials specialist within the group may suggest a special type of hinge for the door and a manufacturing technician may provide feedback regarding the area required for welding the hinge in place.

When the initial designs are thus developed, a formal presentation is made to a core group consisting of the senior representatives from each department. The group reviews the designs based on criteria such as cost, robustness, manufacturability, and vendor availability, and selects one for further development. If all the designs are equally satisfactory, a PUGH analysis is carried out. In this type of analysis, the functional specifications of each of the competing designs is rated against various criteria such as criticality of component, failure mode, noise, and machinability. Once a design is thus selected, the project enters the *beta phase*. The emphasis in this phase is proof of concept. A prototype of the component is developed and tested using computer simulations as well as a variety of test beds. Noise, engine specifications, stresses, fatigue, reliability, etc. are tested on this equipment. The results of the test are maintained in a database. Depending on the results, modifications to the shape, hardness, and reinforcements of the component are carried out. For instance, if in the transmission the gears are noisy, the material may be changed, or if there is leakage, additional seals are added.

The project now enters the gamma and delta phases. In the *gamma phase*, the design is almost production ready. The component is installed in the equipment and customers are brought in for feedback. Depending on the component, customers could give comments regarding the operating characteristics of the machinery, such as ease of starting, speed, noise, ground clearance, and manouverability. Further modifications are made if necessary. During the *delta phase*, manufacturing systems are tested. The idea is to ensure that parts

[6]The name is disguised. The case has been constructed by interviewing employees who wished to remain anonymous.

are fed in, in the right order, that operators have the correct instructions, they are trained correctly and the product is assembled in the right quantity and quality. At this stage, the design is entered into production.

- *Structure*: The design process can be roughly characterized as initiation, alpha phase, beta phase, gamma phase, delta phase, and production. Inputs to the process include specifications, prior designs, and feedback; outputs are the results of reviews and tests, various proposed designs, modifications, manufacturing, and assembly instructions.
- *Personnel and coordination*: Qualifications and prior experiences of designers. What is the best way to conduct product reviews? How to provide specifications? How best to transfer the design into production?
- *Performance/tools*: Knowledge of the engineer. It is very specific to the task at hand and can be characterized as the tacit or functional knowledge of the employee. Critical to this dimension are the results of previous designs, access to test databases and prior experience of the engineer.
- *Discourse*: Record of design changes, alternative designs considered, results of tests and reviews, problems identified, and changes made to address these problems.
- *Results*: The final output of the process, the actual design, whether it was on schedule, the amount of time it took, etc.
- *Quality and objectives*: Rather than quality, it is the objectives that will be relevant here, since the components are not yet in production. The basic objectives will be those specified in the concept document, viz. blade angle, bucket capacity, horsepower, etc.
- *Implications*: How can the design process be speeded up? What types of components are feasible in general? Which components will require vendor sourcing? Is vanadium steel available in 3-foot sections?

KNOWLEDGE DIMENSIONS AND PROCESS TYPES

Rather than simply view processes as operational, administrative, and managerial, we have classifed them into engineering/design, manufacturing/service, financial/accounting, administrative, legal, and managerial processes. These processes deal with fundamentally different sets of inputs, outputs, and constraints. Not all dimensions are relevant for all processes. Those that are relevant for a particular process type will depend on whether or not the process is well defined, critical, involves coordination, and has well-defined (i.e., measurable) outputs. In manufacturing processes, for example, the structure and outputs are well defined. Therefore dimensions such as structure, personnel, performance, results, and quality are very relevant, while the discourse dimension and impacts dimensions are not very relevant. For administrative, financial, and legal processes, the structure, personnel, performance, discourse, and results dimensions are very pertinent. On the other hand, for managerial and design processes, the relevant dimensions are the discourse, results, and impacts, while other dimensions are not so relevant. In the following, we give additional examples of OP and identify some of the relevant items of knowledge. (Please note that examples of the structural dimension have already been given in Table 1.)

Industrial process—performance dimension

In an industrial process to strip hydrogen sulfide (H_2S) from waste gases, consider the following description which fits in with the performance dimension (Anonymous, 2001, p. 35): ‘In cases where flaring will not reduce H_2S concentration sufficiently to meet the emission limit, . . . other treatment methods must be used. These include iron sponges (and other iron-based absorbents), chemical scrubbers and water scrubbers. A recently completed research and development project . . . determined that an iron oxide-based adsorption medium—Media G2—could efficiently and cost-effectively remove H_2S from biogas.’ The extract describes how H_2S can be removed from waste gases and is therefore an example of the performance dimension.

Consumer lending process—personnel dimension

A study of 10 financial institutions identified a number of best practices in the lending process. Among them, the study found that ‘in addition to the delinquency rate, focusing on the cure rate and loan portfolio were the optimal ways to determine an individual collector’s productivity’ (Leath, 1998, p. 38). As described in the case, the ‘cure rate’ is an effective method of evaluating loan collectors and illustrates one aspect of the personnel dimension.

Purchasing process—coordination dimension

The following is an illustration of the coordination dimension in the UK food service industry: ‘The

Table 4 Process types and dimensions

Process type	Examples	Relevant dimensions
Engineering/design	Furnace set-up, boiler inspection, new product development	Discourse, results, impacts, and implications
Manufacturing/service	Manufacturing Nylon, assembling motherboards	Structural, personnel/coordination, performance and tools, results, quality
Financial/accounting	Preparing financial statements, auditing	Structural, performance and tools, results, impacts and implications
Administrative	Hiring employees, buying equipment	Structural, personnel/coordination, performance and tools, discourse, results
Legal	Issuing stock, preparing labor contract	Structural, personnel/co-ordination, performance and tools, discourse, results, impacts, and implications
Managerial	Strategic planning, negotiating a supplier contract	Discourse, results, impacts, and implications

catering review group meets every six weeks and is used as a vehicle to coordinate the operational fulfillment of consumer requirements at site level. This review group consists of the marketing manager, . . . The review group acts as a forum for discussion but also has the power to veto or ratify a proposal. This decision is made by consensus . . .' (Mawson and Fearne, 1996, p. 39). The constitution and operation of the group are illustrative of one aspect of the coordination dimension, although effective interaction techniques would be a more valued component.

Customer service process—quality dimension

A major computer manufacturer uses the following measures for monitoring its customer service process (adapted from Davenport and Beers, 1995): percentage of product returns (2%), percentage of orders delivered on time (99%), number of calls answered per day (2400), number of calls abandoned (80), amount of waiting time for callers (5 minutes). The numbers in parentheses indicate acceptable values of these indicators and are illustrative of the quality dimension.

Engineering design—results dimension

The following is a hypothetical example of the results dimension: 'A car manufacturer found that engineering and development of a new model cost $1,000,000, with $250,000 spent on development and the rest on tooling. The process required 25 engineers, 100 indirect employees and 3 years to complete.' If this information were linked with sales of the car, there is an opportunity for evaluating the effectiveness of the process.

These rudimentary examples bear out the hypothesis that process knowledge can have several dimensions, of which some are salient in certain types of processes, and that tapping it can be of utility in communications, process design, training, etc. The framework has several implications, which are discussed next.

DISCUSSION AND IMPLICATIONS

We have considered process dimensions from a *knowledge management perspective*, although other perspectives have been presented in the literature. There has been an extensive body of literature considering processes from an *engineering*, i.e. workflow automation (Stohr and Zhao, 2001) and *re-engineering* standpoint, i.e. BPR (business process re-engineering) (Davenport *et al*., 1996). In workflow automation, the emphasis is on modeling the structure of the process and automating it with software. Issues such as activities, their constraints, dependencies, and authorizations are considered (Stohr and Zhao, 2001). In BPR, the objective is specifically to achieve process improvements. There is a special emphasis on identifying critical processes, developing measures, assessing their performance, making improvements, and assessing the costs and benefits (Gardner, 2001; Lientz and Rea, 1998). Despite sharing the same objectives (process improvement) and overlap in the information analyzed (in the structural and quality dimensions), these perspectives are not intended to tap process knowledge as we have attempted to do and besides lack holistic approaches to it.

In attempting to provide a KM perspective, we have avoided labels such as outputs (subsumed by structure and results), costs (also subsumed by results), productivity (same), work-in-progress (not considered), and status (not considered) which could potentially communicate a data orientation. We have also not considered process evaluation (subsumed by implications) and functional knowledge (subsumed by performance knowledge). Instead, we simply focused on the process learning cycle and used labels appropriate to this. Whether the labels are justified and whether or not they are adequate is difficult to validate in an empirical sense because of the qualitative nature of the framework. They can, however, be refined experientially by being applied in various organizations, for various types of processes.

The framework provides a preliminary foundation for organizations in tapping knowledge resources that are in the process form. In order to go about acquiring the knowledge, a more detailed characterization as it pertains to each dimension is required. (This has been carried out to some extent in the paper, although not formally). Whether or not such a characterization can be carried out with the KM perspective intact is debatable. The structural dimension has been characterized as inputs, steps, outputs, and constraints, but this has little value except in the fully interconnected form, because this is the nature of knowledge. Consider the following description of an assembly process (Garg, 1999, p. 419): 'Board 1 and Board 2 are assembled along with other parts into modules of type A. Type B modules are manufactured at a different site. The Marry Station . . . loads special software that enables type A and type B modules to work together. However, by redesigning these modules, this operation can be eliminated altogether.' Clearly, structural knowledge is intertwined with the inputs, outputs, and operations. Communicating this knowledge is not possible without the use of process charts. Even if it were useful, it may not constitute knowledge to a production manager, who might be more interested in aggregate characteristics such as throughputs and capacities. As another example, the discourse dimension can be characterized as issues (can these be clearly distinguished?), actors, viewpoints, and time periods. This perspective can yield information on what a particular actor may have said at a particular time, but not necessarily his/her motivation or objectives, which have to be evaluated based on the entire discourse. Utility aside, each of the dimensions is also complex and interrelated. For instance, there is overlap between the structural, quality, and performance dimensions because increasing quality will require changes to the tooling and the way activities are carried out. Similarly, the quality dimension can encompass measures for each activity of the process, which could vary with the type of product. A detailed characterization of process knowledge could potentially be problematic, unless the context of the entire process were somehow preserved and individual items of knowledge were presented within that context (see also APQC, 1997). This responsibility rests with designers of KM systems.

The design of effective KM systems is contingent to a large degree on the existence of effective methodologies and tools. *Methodologies* are techniques for modeling process knowledge, and can encompass Petri nets, discourse maps, cause maps, etc. In the KM literature, tools are defined as those which support one or more phases of the KM cycle (Tyndale, 2002; Wensley and Verwijk-O'Sullivan, 2000). There are several dozen generic tools suitable for this purpose, a simple example being a tool to organize documents. However, we use tools in a restricted sense to mean those which support the *acquisition* and *codification* of knowledge. Generally these tools support advanced techniques such as ontologies and knowledge maps rather than simply using rules.

It is necessary to assess and, if needed, develop such tools and methodologies to support the KM process. It is expected that there will be well-developed tools for the structural and discourse dimensions (see Stohr and Zhao, 2001; Amaravadi, 2004), but for other dimensions techniques from artificial intelligence (see Amaravadi, 2001) may have to be utilized. It is also expected that the methodologies will have to be tailored for each type of process. Indeed, the development of effective knowledge management systems is one of the principal goals of the KM community which can greatly benefit from improved codification techniques. This is even more critical in the case of process knowledge.

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