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Leveraging Knowledge Creation Through Failure Analysis: An Ontological Orientation

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Abstract

Knowledge has become a substantial intangible asset of firms, and perhaps their most critical resource. As such knowledge management has emerged as a critical research field for Information Systems (IS). This paper addresses the need for additional research relating to the creation of knowledge in an organizational context. We leverage knowledge creation through use of a surrogate, the process of failure analysis and failure identification (FA/FI). Considering FA/FI as a characterization process, we employ an ontological orientation to improve intra- and inter-organizational knowledge creation activities with an empirical investigation at a large, semiconductor-manufacturing organization. This paper examines an emerging challenge for IS (knowledge creation). Additionally, it combines theory and related extant research with empirical investigation to create a set of constructs for knowledge creation, subsequently framed as a set of propositions. Second, by mapping these constructs to a specific process instantiation, we provide a measurable foundation to test the knowledge creation constructs. Finally, we instantiate a process for knowledge creation via ontological modeling. In the development of the knowledge ontology, we identified the need for defining the knowledge unit and have instantiated a process for its development via the knowledge lens. These artifacts can enable researchers and practitioners to approach a complicated, yet critical, organizational obligation.

Keywords: Knowledge creation, knowledge management, knowledge lens, knowledge, unit, ontology, organizational learning

Introduction

Knowledge representation focuses on concepts of content, taxonomy, and informational completeness. Using this orientation, knowledge is addressed in terms of identification, development of its attributes, and an evaluation of its adequacy. From an Information Systems (IS)[1] perspective, representational and systemic formalisms are considered that can aid the knowledge creation process. Ontology characterizes knowledge detail and offers representational and systemic characteristics conducive to knowledge creation.

While other surrogates may show promise, we focus on failure analysis and identification due to its unique perspective to knowledge creation. The utility of failure analysis for knowledge creation has been well documented within Case-Based

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[1]We will use IS (the acronym) as a characterization of a discipline which includes knowledge systems and knowledge management, as well as traditional information systems; however, it should be noted that the characteristics of knowledge, as noted later in this paper, vary significantly from those of information.

Reasoning literature. Generally, the existence of failure, certainly failure with any intensity or importance, elicits a direct correctional response, often resulting in new knowledge. Further, proactive failure avoidance can consider failure as the absence of some essential property or process with failure avoidance becoming a knowledge creation exercise to correct the omitted property or process.

This research considers **how knowledge ontology and the definition of a knowledge unit facilitate organizational knowledge creation.** In particular, we focus on generation of ontology for failure analysis/failure identification (FA/FI) and describe how it supports knowledge creation. Using the systematic development of FA/FI ontology as its basis, in a large, semiconductor-manufacturing corporation, we generate a set of propositions that theoretically associate the knowledge creation process with ontology.

This paper has five sections. In section two, we discuss knowledge etymology from various reference disciplines. Section three discusses our research approach. We describe the role and utility of failure analysis as a surrogate for knowledge creation. In the fourth section, we provide data analysis and findings, which lead to a set of propositions relating to Organizational Knowledge Creation. Finally in section five, future research directions are summarized.

Knowledge Systems Etymology

The production of knowledge is now more than half of the gross domestic product for most highly developed countries (IFC 2001). As such, knowledge replaces traditional capital goods as the commodity of interest. Knowledge economics consider knowledge generation over possession. Researchers (Mata, et.al. 1995) have demonstrated that possessing a unique process or being the first to market provide, at best, only temporary competitive advantage. Attributes, such as capital resources or information technology are vulnerable to imitation or purchase; only intellectual capital demonstrates the characteristics required in a resource-based view of the firm (Barney 1991) of unique capability and immobility.

Knowledge systems result from derivations from many disciplines, the most noteworthy: philosophy, management, economics, computer science, and now information systems. We consider three primary, etymological research dimensions (Table 1): Knowledge Definition and Representation; Innovation and Knowledge Creation; Learning and Knowledge Transfer, and Organizational Knowledge.

Knowledge Definition and Representation

Taxonomic elements differentiate aspects of knowledge. Plato defined knowledge as "justified true belief" requiring three conditions: something is true, someone believes it is true, and the particular someone's belief is, indeed, justified (Nonaka and Tackeuchi 1995). Anderson developed ACT (the Architecture of Cognition Theory), which noted that human cognition arises as an interaction between declarative and procedural knowledge structures (Anderson 1976) with declarative memory modeled as a semantic network. For procedural memory Anderson adapted the Newell's production rule ideas. Through his career, Anderson attempted to 'break' his theory, leading more to expansion than replacement, culminating in ACT-R: Adaptive Character of Thought renamed as Atomic Components of Thought (1998) incorporating intelligent agents and subsymbolic processes for procedural learning. Different taxonomies have also been considered by researchers: Polanyi identified tacit and explicit types (1966); Piaget (1969) noted physical, logical, and social characterizations; and Lundvall and Johnson (1994) emphasized know-how, know-what, and know-who aspects.

Knowledge may not be complete, yet be adequately useful. This concept relates to that of bounded rationality, which highlights human decision making using imperfect knowledge (Simon 1997). For information processing, Simon's work with Newell mapped human problem solving and decision making to computer processing. Simon ignored the concept of implicit knowledge, considered as 'noise,' a view consistent with extant economic theorists of the industrial age. Ironically, economics and information systems concentrate almost exclusively on explicit knowledge; however, Polanyi noted the criticality of tacit knowledge where knowledge cannot be completely codified: *While tacit knowledge can be possessed by itself, explicit knowledge must rely on being tacitly understood and applied. Hence all knowledge is either tacit or rooted in tacit knowledge. A wholly explicit knowledge is unthinkable.* (Polanyi 1966).

Table 1. Knowledge Systems Etymology Relating to Organizational Knowledge Creation

Research Dimension	Partial Research Reference	Reference Orientation	Dominant Concepts
Knowledge Definition & Knowledge Representation	Plato (see Nonaka, et.al. 1995) Simon 1997, 2001 Newell 1990 Anderson 1976, 1998 Bunge 1977 Gruber 1993 Guarino 1998 Kim and Fox 2002 Wand & Weber 2002 Churchman 1979 Markus, Majchrzak, Gasser 2002	Philosophy, Mathematics Computer Science/AI, Philosophy, Economics Computer Science/AI Computer Science/AI, Psychology Philosophy & Logic Computer Science, Psychology Information Systems Industrial Engineering Information Systems Operations Research, Management Science Information Systems	justified, true belief definition bounded rationality, information processing, chunking knowledge systems, production rules, problem-solving ACT-R, declarative & procedural knowledge structures formal models for ontology design principles for ontology & knowledge sharing ontology & information systems ontology of measurement of enterprise systems ontology, conceptual modeling & information systems general systems theory emergent knowledge process theory
Innovation & Knowledge Creation	Nonaka 1991, 1995, 1998 Wenger 2001 Schank 1986 Riesbeck & Schank 1989 Kolodner & Riesbeck 1990	Management Organization Development Computer Science/AI Computer Science/AI Computer Science/AI	knowledge creation theory, knowledge spiral, tacit knowledge communities of practice dynamic memory case-based reasoning
Learning, Knowledge Transfer, & Organizational Knowledge	Ausubel (see Driscoll 2000) Arrow 1969 Senge 1990 Boisot 1995 Szulanski 1996 Ravindran 2000 Subramani & Hahn 2000	Psychology Economics Management Management Management Information Systems Information Systems	discovery & meaningful learning internal stickiness organizational learning social learning cycle knowledge & apprehension knowledge & apprehension knowledge management & motivation/incentive

Ontology addresses the formalism of knowledge. Organizations struggle with disparate knowledge sources, including databases, files, documents, images, etc., which seldom represent knowledge items consistently or completely. Ontology, in its broadest definition, is *the nature of being* (Swartout and Tate 1999). Gruber's (1993) definition is often cited where ontology is *a specification of a conceptualization*, which formalizes knowledge within a specific concept allowing for a standard vocabulary to represent it. Wand and Weber (2000) expanded on the work of Bunge (1977) to develop formal models for information systems ontology.

The emphasis on real world phenomena reveals the dual nature of ontologies, which themselves with respect to mechanism and content (Chandrasekaran, et.al. 1999). Early ontology research emphasized mechanism, using an artificial intelligence language to represent its content. Ontology connotes a standard format; however, its application is not uniformly standardized. Guarino (1998) notes that, *ontology*, within an engineering context, involves a specific vocabulary to reflect a certain reality combined with assumptions regarding the intended semantics of the vocabulary. A simple ontology may include a hierarchy of concepts, bounded by subsumption relationships. More complex ontologies include axioms increasing its complexity with relationships, concepts, and constraints to fully bind the intended interpretation. Knowledge ontology consists of a conceptual model, a thesaurus, and a set of expanded attributes and axioms (Edgington, et.al. 2002).

An ontology may be evaluated based on it usefulness or based on its expressiveness (Wand and Weber 2002). Usefulness addresses how well the ontology accounts for the users' experience. Expressiveness concerns the model's ability to address construct overload, redundancy, excess, and deficit. The goal of ontology is to faithfully represent the domain of interest promoting faithful interpretation and understanding of the domain.

Ontological representation benefits an organization (Kim and Fox 2002) in several ways: (1) knowledge sharing is easier, (2) ambiguity and error are minimized by enhanced structure, (3) computational representation is facilitated, and (4) conformance measurement is enhanced, thus aiding productivity and quality management. Swartout and Tate (1999) refer to ontology as *the basic structure or armature around which a knowledge base can be built.*

The systems approach addresses the knowledge creation process. General systems research supports the reality of an imperfect knowledge environment where knowledge acquisition is difficult or incomplete. Churchman's work (1979) on general systems theory acknowledged the imperfect knowledge environment in which decision and knowledge workers reside. This lack of a comprehensive reality produces the inevitable opportunity for failure. All systems have at least one design aspect that makes it incomplete. Part of effective design is the search for any system's source of deception in this regard. Markus, et.al (2002) consider the lack of complete, explicit, a priori requirements for emergent (or created) knowledge in their design theory for emergent knowledge processes.

Gruber (1993) noted that ontology is a systematic account of existence. Newell (1990, p. 50) defined a knowledge system, including those subsumed within technology, as embedded within an external environment: *Its body of knowledge is about its environment, its goals, its actions, and the relations between them.* Unlike individuals, though, Newell considered the knowledge system to be able to apply all knowledge it possessed to a specific determination of action and once acquired knowledge is never lost.

Innovation and Knowledge Creation

Organizations rely heavily on knowledge creation. Grant (1996) and Spender (1996) identified knowledge as the critical resource within the firm. Nonaka (1991) framed tacit knowledge as the source of organizational success through sustained competitive advantage. As noted by Hitt, et.al. (1998), *"Companies that rely solely on improving productivity are not likely to survive. Only those firms that develop and market new, unique goods and services gain an advantage over their competitors."* Edgington and Chen (2002) highlight economic benefits for organizations aggressively supporting formal knowledge creation activities. The theory of knowledge creation (Nonaka and Tackeuchi 1995) includes three primary aspects: abstraction, synthesis, and interaction. The knowledge spiral specifies the process of knowledge creation as an interaction between tacit and explicit knowledge, which can occur at individual or organizational levels.

Case-based reasoning (CBR) has its beginnings in script-based knowledge representation. Two limitations with traditional information systems relate to their difficulty to address analogy and to deal with dynamic memory (Shank 1986), conditions useful for knowledge creation. Dynamic memory is a flexible, open system that adjusts based on new observations, which can be generalized, stored, and when necessary, reorganized. CBR stores prior episodes in a holistic manner to provide a reliable storage and retrieval memory system of relevant situations. Riesbeck and Shank (1989) describe CBR as a dynamic memory system that remembers, reminds, and passes along experience. Some are capable of learning, where learning can extend from rote memory to explanation by analogy. CBR learning generally results from subsumption of new cases or components into a component organizational structure or by re-indexing pointers. Xu (1995) notes five CBR advantages: (1) Solving problems with partially understood domains, (2) Providing a closer match to actual human reasoning, (3) Providing efficient reasoning, (4) Allowing faster knowledge acquisition, and (5) Providing unique explanation capability.

CBR is particularly relevant in the context of failure analysis by its focus on memory and reasoning structures to address failure conditions. An indexing scheme (MOPS) is used for organizing the failure and event (or condition) relationship (Schank 1986). New cases developed from failures allow for learning with the system reorganizing and re-indexing itself. The existence of failure-driven memory allows for prediction, avoidance, and correction to occur as desired. Examining and explaining errors can point to conditions of motivation, processing, or resource omission leading to the development of an alternative belief, which, when justified, becomes created knowledge. Indexing and search are critical components for the application of dynamic memory to failure analysis.

Kolodner and Riesbeck (1990) define CBR as problem solving or interpretive. Problem solving considers solutions to new problems derived from old solutions (and problems). With interpretive CBR, new situations are evaluated from old situations.

So, problem-solving CBR can be viewed as a failure correction process and interpretive CBR can be viewed as failure avoidance. Both incorporate the abstractions of assumptions and justifications to expand the existing body of knowledge.

Learning, Knowledge Transfer, and Organizations

Learning and knowledge transfer consider knowledge delivery to individuals within the realm of attenuation and interaction. Learning provides knowledge with different intensities. Ausubel (Driscoll 2000) distinguished discovery learning from receptive learning and meaningful learning from rote learning. Arrow (1969) describes the difficulty of transferring knowledge to a recipient as *internal stickiness*, with four characteristics: aspects of the knowledge transferred, of the source, of the recipient, and of the context in which the transfer takes place. Simon (2001) refined Miller's research on short term memory. Boisot (1995) notes that knowledge acquisition is frequently a social event, namely, one where there is a knowledge provider and a knowledge recipient. Companies involved in business reengineering processes typically seek failure analysis as a way of evaluating "should be" scenarios (Krasner, et.al. 1992) for software process improvement. Their research noted a trial-and-error learning requirement within process design. Of note is the typical employment of *lessons learned* as a typical failure analysis approach for process improvement. Hahn and Subramani (2000) note that vocabulary facilitates knowledge exchange within a community while impeding communication across communities.

Szulanski (1996) and Ravindran (2000) consider apprehension in knowledge transfer. Subramani and Hahn (2000) highlight the motivation of users with respect to the success of knowledge management systems when the users' structuring contributions provide visibility and greater social status. The willingness for knowledge provider and receiver to engage in knowledge transfer is affected by trust(Mayer, et. al.1995) by introducing vulnerability into the definition of trust; that is, the awareness by the trustor that there is something to be lost. Zaheer, et.al. (1998) explored trust in inter-organizational exchange and demonstrated its significance to performance.

A Failure Analysis Context for Knowledge Ontology

Our team spent over a thousand hours making observations conducting a series of structured interviews resulting in a detailed analysis of the situation that formed the basis of construction of a knowledge ontology for semiconductor wafer defect analysis. Archival database records of task requests spanning several years and over 50 documents pertaining to FA/FI requests were manually reviewed. The entire document store was mined for vocabulary usage using software categorization tools. About 55 hours of formal and open-ended interviews were conducted to understand the existing structure and process of FA/FI. The interviews involved vice-presidents, group managers, lab experts, and lab customers.

This research employs failure analysis/failure identification (FA/FI) as a surrogate for organizational knowledge creation.[2] Failure analysis and ontology techniques were selected to provide a rich combination of structure and perspective that were expected to facilitate knowledge creation, sharing, and transfer. As previously noted, prominent researchers (such as Churchman, Simon, Anderson, Ausubel, and Shank) have embraced the concept of failure or incomplete knowledge as core elements to process development, decision-making, and learning. We defined a knowledge unit (described later), instantiated it through our ontology, and implemented it through a content management application.

We developed this ontology at a large, semiconductor-manufacturing corporation (code-named LSM) where competitive advantage is sustained by reinventing each manufacturing process. Chip manufacturing failure is identified, analyzed, and corrected. As the corporation grew, FA/FI activities became highly specialized, spanning labs and geographies. As each lab evolved, highly specialized vocabularies developed among the analysts. In the interest of market competitiveness, textual and imaging reports were created and filed, but not constrained to a common format or procedure.

Specifically, our efforts focused on structural failures recorded by the TEM (transmission electron microscopy) labs. These are sophisticated laboratories where high-precision instrumentation tools detect chemical and structural composition anomalies of wafers. FA/FI is performed whenever a chip within one of the sample lots fails to meet standard quality guidelines. Failed wafer samples are analyzed with respect to the presence of undesired material or formation, or absence of desired material or formation.

[2]The process of FA/FI, a characterization process, can motivate the creation of improvements. Additionally, characterization of failure AND of FA/FI led to the creation of an organizational knowledge level not realized initially.

If an anomaly occurs within testing, it may be sent to the TEM lab for precision imaging to verify the absence of a required material, the inadequacy of a required material, or the presence of an undesired material. It was anticipated that the knowledge that they gained would be available to subsequent labs involved when the process was validated and production manufacturing was authorized. However, LSM found that in most cases these subsequent labs were having extreme difficulty leveraging the previous achievements of the original FA/FI processes. The captured knowledge did not yield improved efficiency and these subsequent labs often were starting from scratch as a time-saving strategy.

They choose a content orientation for ontology construction versus a mechanistic orientation.[3] It was neither in the interest nor the schedule limitations for the LSM staff to learn a unique language and the preference was to focus on the conceptual aspects of the ontology. Further, the scope of the project was framed by the representation of a **knowledge ontology,** defined as **a distinct unit of knowledge based on content, with limited mechanistic structure constructed, using a specific process to which we metaphorically label as the application of a knowledge lens.**

Knowledge Unit

Most researchers within knowledge management suggest that knowledge extends beyond information aggregation. **A *knowledge unit is a coarse set of information elements bound together by structure, assumptions, justifications, and process*** (Edgington, et.al. 2002). Unlike information and data, knowledge exhibits a multi-dimensional perspective that is enriched and completed from the epistemological attributes of the knowledge unit.

An exemplar of the content of a knowledge unit is shown in Table 2. Content structure considers vocabulary, which will be specific to a conceptual domain. This domain is characterized by keywords and/or narrative description. It includes synonyms, pseudo-synonyms, acronyms, and other semantics. Assumptions and justifications are bounded by axioms and detailed by the epistemological construction and evolution characteristics of the domain elements. The process is framed by the application of the knowledge lens described in the following section.

Table 2. Knowledge Unit Characteristics

Content Structure	Vocabulary & Thesaurus	keywords, narrative, synonyms, pseudo-synonyms, acronyms, semantics
Assumptions	Axioms, epistemological elements	relationships
Justifications	Axioms, epistemological elements	attributes
Process	Application of knowledge lens	domain focus and construction steps

Knowledge Lens

The knowledge lens is deployed as a metaphor depicting the characteristics of *perspective* and *construction* related to knowledge ontology. Information and data are relatively flat in the sense that the associative understanding intended is fairly consistent among disparate contexts. Knowledge, however, is multi-dimensional, as well as context and socially dependent. The knowledge lens provides a perspective guided by the domain target. As with a visual lens, the knowledge lens is adjusted to gain clarity, which addresses the construction aspect of knowledge. One of the benefits of knowledge ontology is that it clarifies and refines the perspective and intended associative meaning of the specific knowledge unit.

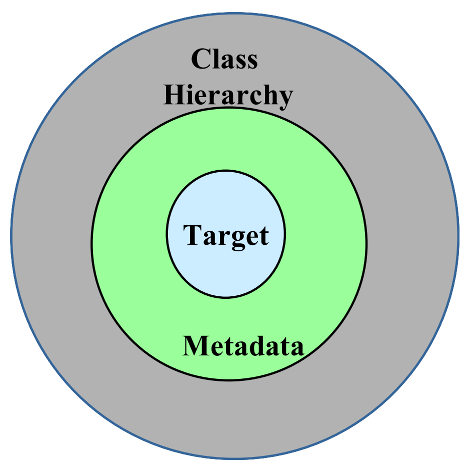

Figure 1: Initial Knowledge Lens View

[3]As noted by Chandrasekaran, et.al. (1999) and Newell (1990), a content orientation emphasizes the underlying domain knowledge independently of a specific mechanism. A mechanistic orientation emphasizes the symbolic characteristics, such as a formal language like DAML-OIL.

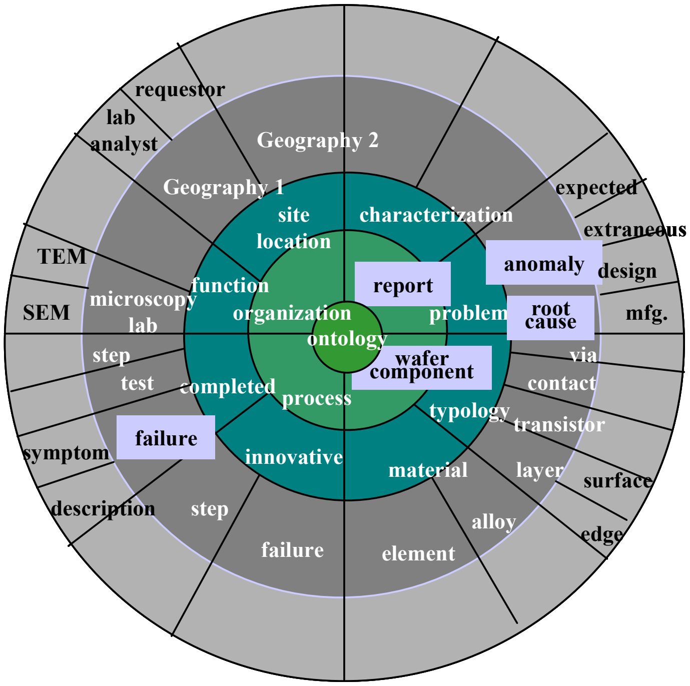

Figure 2: Partial, Refined Knowledge Lens Example

Initially, an individual seeking knowledge sees various types and levels of information (refer to Figure 1), often ambiguously. As the individual focuses with the knowledge lens, the elements start to organize and irrelevant elements are discarded. By further focusing the lens, inherent structure and multi-dimensionality allow for the knowledge unit to be rotated with a minimum of confusion to understand the new perspective. Thus, the lens allows individuals and organizations to gather, retain, and utilize more complex types of knowledge. The initial "target" lens contains mainly imprecise and abstract concepts (such as those highlighted by boxes in Figure 2). Notice that the boxed concepts are scattered and unrelated. Initially, these concepts may not be more than disjoint terms with no consistent classification structure at all, but after applying the ontological process and the lens, the focus develops a richer, multidimensional quality. Details become more prevalent, the organizational structure more defined. The knowledge lens supports the addition of detail, order, and complexity. The knowledge lens is particularly useful with inter-organizational knowledge creation, sharing, and transfer, allowing organizations to refine their own models within the complex, inter-organizational context.

From our examination, we generalized an ontological model for FA/FI, applicable in a cross-domain context. As can be seen in Figure 3, the concept of anomaly[4] is one aspect with a manifestation within three cross-domain contexts: wafer (as in a semiconductor manufacturing domain), patient (as in a health care domain), and software application (as in the software development domain). Anomalies have various levels of criticality and ultimately can be diagnosed to a root cause. The source of the anomaly may be from expectation (i.e., representation misspecification) or from process (i.e., omission).

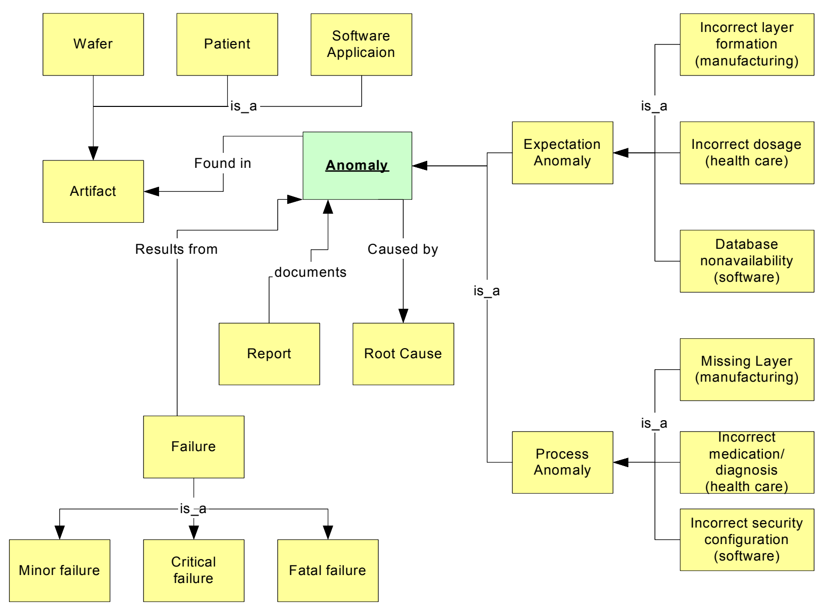

Figure 3: Failure Analysis Model Focusing on Anomaly

Mapping Knowledge Creation Constructs to FA/FI Process

One can view FA/FI as an instantiation and case-based surrogate for knowledge creation. Failure is a state relating to omission, or excessive, instantiations or patterns. Combining our project in a cumulative approach with that from earlier researchers we developed a conceptual model (Figure 4) for Organizational Knowledge Creation within the context of FA/FI where knowledge ontology frames the knowledge unit and its construction. The model consists of a set of five primary propositions (P1 through P5 in Figure 4). Following each proposition are supporting elements from the LSM project.

[4]We choose the term, anomaly, as a representation of an abnormality which deviates from what is expected. Terms like failure, problem, or error either are reserved within the context of FA/FI or are viewed as too narrow a classification.

Proposition 1

Attenuation provides focus for bounding the knowledge unit. It facilitates the transfer of knowledge from source to recipient. It allows for requisite instantiations of organizational knowledge. Attenuation in this instance can be compared to the practice of setting a factor's variance to one (the standard practice). The model's metric becomes established allowing for a tractable solution. In terms of knowledge creation, attenuation performs a similar purpose.

Proposition 1: Knowledge creation occurs with specific attenuation.

Attenuation was achieved by selecting a domain target, the TEM lab within LSM in the context of failure analysis. This context essentially secures a location on a (mental) map facilitating navigation for individuals and groups.

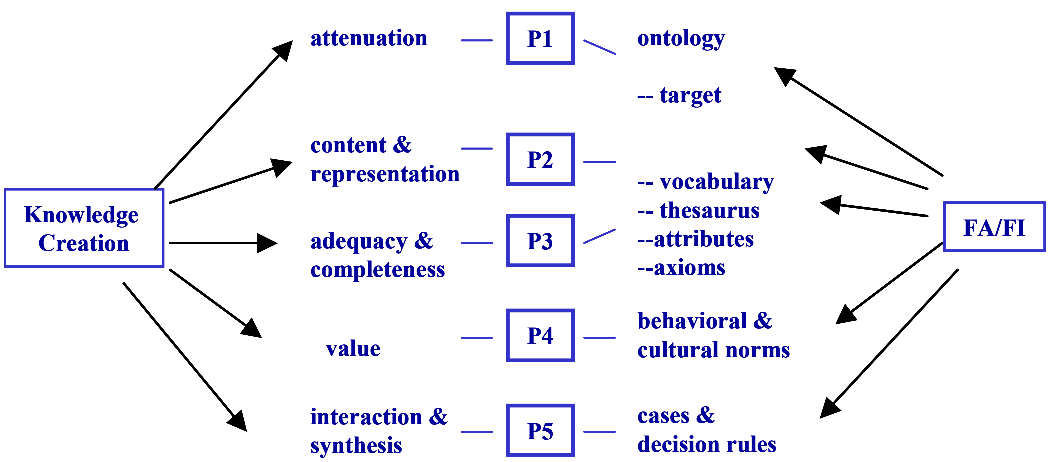

Figure 4: Failure Analysis/Failure Identification as a Surrogate for Knowledge Creation

In this investigation, various levels of attenuation were required. Failure analysis became the lens for the overall task (rather than revenue generation, customer satisfaction, or other strategic activities). Next, interviewees were requested to focus on their own tasks and detail their roles, activities, and goals with respect to failure analysis. In most instances, some conflict in process or terminology was identified and attenuation was requested to clarify their scope and role. Attenuation was not a static event, but was modulated to define and integrate the desired vocabulary and conceptual model.

Proposition 2

The knowledge unit defines the content and representational structure to integrate the elements and meaning of the requisite knowledge. By specifying a knowledge unit, knowledge elements are easier to identify as to their need for expansion, completeness, or replacement.

Proposition 2: Specification of a knowledge unit accelerates knowledge creation.

Initially, vocabulary, concepts, and processes obtained from participants were coarsely defined. As the investigation and model progressed, detail and taxonomy not specified earlier surfaced. The interactions between all participants gained a precision not observed in the initial interviews.

As noted by the LSM project manager, initially "reports were unorganized, unmanaged, and highly dynamic. Several prior projects to build tools and taxonomy failed. The knowledge lens process revealed that "most of the files are not very dynamic" with few instances of conflicting vocabulary, and only a few cases of homonyms and synonyms.

One of the most significant learning benefits was the acquisition of perspective. As noted by one participant, "I am surprised by how much I know! And of how much (detail) there is. I've learned more words throughout this process."

The TEM lab actually performs significantly more requests for characterization of wafer samples (i.e., no failure analysis). This is essentially a validation exercise. By taking the contrary view, as is failure analysis, it is believed that the team was able to capture all the essential elements of characterization, as well as the types and potential causes of failure.

Proposition 3

While the notion of complete knowledge has legitimacy, it is difficult, if not impossible to test. Within a context of attenuation, knowledge has a boundary, but it is possible to use imperfect knowledge and gain acceptable levels of value. In this respect, it is unlike data which demands the characteristic of atomicity.

Proposition 3: Completeness is not a prerequisite for adequacy of knowledge representation and usage.

At LSM, this manifestation of adequacy existed at the beginning, and in a transformed version, at the end of our analysis. In the beginning, we observed that no one person could define the total process in detail, only at broad levels of generalization. From an individual perspective, enough knowledge existed to perform a desired task successfully. However, at an organizational level, the knowledge required for the collective set of tasks was inefficient due to lack of a holistic unit of knowledge. As long as the elements of the knowledge unit required for an individual exist, the organization can perform successfully. The problem experienced at LSM prior to the knowledge ontology related primarily to efficiency. A lab analyst either labored excessively searching to find similar error reports or gave up and recreated the analysis.

At the end of our research period, LSM had created a detailed conceptual model with a number of attributes associated, but had not fully defined the knowledge ontology. Nevertheless, this partial knowledge ontology was sufficient to improve on the ability of search tools to locate reports and to improve the inter-organizational communication provided. As such, the partial ontology was adequate, as viewed by LSM participants, to advance the level of organizational knowledge at LSM.

Proposition 4

Behavioral and cultural norms assign value to knowledge. Usefulness and expressiveness serve as the abstract metrics of valuation. Within an organizational context, usefulness can be transformed to a monetary (e.g., ROI) or non-monetary (e.g., status) metric. Expressiveness in an organization can relate to enhancing communication in either an intra-organizational or inter-organizational capacity. Cultural norms address trust and apprehension aspects embodied within an organization in terms of security and other policies, or within scheduling constraints and goals.

Proposition 4: The value of Knowledge Creation emanates from a cultural or social context.

LSM employs a technology research group whose responsibility is to identify or build innovative technology. No technology could be identified that could completely subsume the ontology development task. In fact, even with regard to searching for meaningful or unique terms, the technology assisted but did not completely replace human interaction.

The knowledge ontology investigation provided immediate value in inter-organization communication. As noted by the project manager, the ontology clarified the workflow process, improving the ability for workflow management and storage integration. The knowledge lens process refocused tools development from considering the identification of images, spectra, and raw data types to "deriving meaning from multiple jobs back to the problem statement." The problem statement changed from "people cannot query the database" to "condensing the results of multiple reports and systems into a cohesive whole."

The levels of trust and apprehension were very complex including not only factors of trust in the moral and legal sense, but particularly for trust of competency among the participants. Security policies aided (and sometimes confounded) the issue of trust in the context of organizational interaction. Status and working meetings were also formalized to ensure reliability. Early in the project, the need for a quick prototype was considered a trust builder and apprehension reliever. The early prototype helped establish a competency level of the providers and coordination metric for the participants.

Proposition 5

The knowledge unit is formed through a process of expansion, completion, or replacement. Knowledge does not originate in isolation, but as a synthesis of varying combinations of existing knowledge. An interaction effect, resulting in discovery, occurs to produce the new knowledge. Interaction may occur by one or more sources (within multiple instantiations of, or compatible, knowledge units): between declarative and procedural knowledge structures, between tacit and explicit knowledge structures, and/or between individuals. Attenuation occurs from the interaction of the abstract with the specific.

Proposition 5: Knowledge creation occurs as an interaction among instantiations of a knowledge unit or among compatible knowledge units.

FA/FI concerns the analysis of archival cases (i.e., dynamic memory) to compare and contrast symptoms to an existing problem. Using a series of decision rules, the archival case is evaluated as to it representation of the existing problem. Compatible elements are then synthesized into a root cause analysis for the new problem.

It was only after a series of interviews that it became clear that the two processes performed by the TEM lab were essentially the same -- that of characterizing the wafer sample sent to the lab. In a pure characterization exercise, the task was to ensure completeness of the sample. In failure analysis mode, the characterization effort was to identify missing materials or structure, or extraneous materials or structure.

Multiple instances of interaction increased the level of knowledge at LSM. Knowledge creation in the form of more efficient access to error analysis reports resulted from the interaction of the newly defined knowledge unit, which resulted from the process of refining the knowledge lens. Maintaining the focus of the lens on failure analysis allowed for the relevant vocabulary to be extracted, taxonomic structure to be refined, and for an initial thesaurus and additional definitional attributes to be created. The knowledge lens process provided the focus to transform tacit knowledge from the analysts' into an explicit form now able to be shared. This process also aided inter-organizational descriptions by highlighting conflicting terminology.

It can be noted that the discovery process occurred with respect to observations on the model representation in a socialized setting. In the development of the knowledge ontology, major improvements occurred by reviewing draft models. Corrections were quickly noted and conflicting terminology was resolved. This process occurred even more effectively when two or more participants were reviewing the models.

Discovery was enhanced by the analysis of facts, participation in the knowledge lens process, and from group participation. As the knowledge ontology was developed, additional detail enriched the models. As stated earlier, the process of applying the knowledge lens was critical (as opposed to merely providing a survey to the same participants). From the knowledge ontology process itself, the activity was sponsored by two LSM organizations with senior management reporting required. Additionally, starting in one lab and then expanding the interviews to customers and other supporting labs enhanced the richness of the knowledge ontology.

Initially, the vocabulary, concepts, and processes obtained from the participants were coarsely defined. As the investigation and model progressed, detail and taxonomy not specified earlier surfaced. The interactions between all participants gained a precision not observed in the initial interviews.

Interaction and synthesis increased the ability to develop the correct representational structure. Even though the activities of the TEM lab were the established focus, initially a coarse workflow of the manufacturing process and of the affected organization structure was reviewed. This allowed for the project team to understand the overall process, understand the various points where a failure may occur, and calibrate the understanding of all the team members.

Conclusions and Future Research

In this study, we examined the process of failure analysis/failure identification as a surrogate for knowledge creation incorporating ontology as a structuring tool and objective of the process. Davenport, et.al. (1996) studied the attempts of thirty organizations to improve their knowledge processes. No universal, rigid, process or technology applied to all, but the common theme among design elements producing success included: a collective knowledge base, modularity, cross-functional (and sometimes, organizational) collaboration, parallelism, and collaboration. Within the evolution and popularity of knowledge and intelligent systems, further research is warranted and timely.

Contributions of this Research

There is an opportunity for the field of IS to make substantial research contributions relating to the creation of knowledge in an organizational context. This paper contributes to IS by developing of a set of propositions motivated by extant research relating to organizational knowledge creation and supported by the observations and results of the LSM project. To lend impetus for researchers to focus on knowledge creation, we have defined a series of propositions to help connect the abstraction of knowledge to a specific instance (i.e., FA/FI) of organizational knowledge. The second major contribution of this paper is the consideration of knowledge ontology as a substantial facilitator of knowledge creation. Knowledge ontology provides a powerful organizational formalism, which strengthens not only the ability to subsume knowledge within technology, but greatly enhances inter- and intra-organizational communication. In the process of developing the knowledge ontology, we have identified the need for defining a knowledge unit and have instantiated the process for knowledge creation via the knowledge lens. The knowledge unit provides the depth and understanding required of knowledge ontology. The knowledge lens is the metaphor describing the process of building the knowledge unit.

Future Research Directions

From our exploratory results, the knowledge ontology has shown support for propositions relating to organizational knowledge creation. We are working with a number of other organizations to analyze their efforts to develop knowledge ontology. These additional efforts include cross-industry domains, such as health, government, and finance. Additionally, extended research within the semiconductor industry will allow for a refinement and analysis of the specific content representation of a knowledge unit, such that we can separate the meta-language from proprietary detail.

It would be interesting to consider how rigid formalization ontology would affect knowledge creation; this investigation involved a fluid approach whereby the models developed could be deployed as desired. The researchers are now in the process of defining the parameters for cross-domain ontology in the area of FA/FI. Finally, additional cases will enable potential research such as causal modeling and confirmatory analysis; such investigations would enhance the generalizability of both our propositions for organizational knowledge creation and for the facilitation value of knowledge ontology.

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