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Abstract

Getting products to market in a timely manner offers companies the opportunities of competitive advantage. To achieve `timely delivery in a knowledge-based industry requires more than simply capturing knowledge and storing it for re-use. The use of knowledge management systems, it is argued can be use strategically to improve make-span processes and thus enable competitive advantage. This research of a commercial refrigeration manufacturing company shows that knowledge, both explicit and tacit, can be captured and then stored in a knowledge management system. This KMS can then be mined effectively, with both the KMS and knowledge mining process resolving the identified strategic business problems.

Keywords: Strategic knowledge management, ontology, action research, design science, heuristic knowledge mining

1 Introduction

"The management of knowledge is promoted as an important and necessary factor for organizational survival and maintenance of competitive strength. To remain at the forefront organizations need a good capacity to retain, develop, organize, and utilize their employees' capabilities. Knowledge and the management of knowledge appear to be regarded as increasingly important features for organizational survival" (Mårtensson 2000). Porter (1991, 1993) argues that the fundamental purposes of strategic management are to maintain competitiveness through cost efficiencies and to maintain position in the market (Porter, M.E. 1991; Porter, M.E. 1993). This paper reports a detailed research project on an Australian refrigeration engineering company which had a number of problems; it was taking too long to get new products to market and was in a position where the expertise of the design engineers and their knowledge was never captured and resultantly vulnerable to recruitment by competitors. As a result the company's competitive position was at risk and their costs were too high as design and development took too long. This paper addresses an exemplar that shows with detailed application of ontology and analysis of the ontological system using heuristic knowledge mining, that knowledge management (KM) can be a useful strategic tool, supporting Milton et al (2010).

2 KM as Strategy

Knowledge management research has shown that KM is a useful strategic tool and has been used to focus on organizational improvement (Davenport & Prusak 1998). Business today operates in a knowledge-based business framework. New technologies and methods have been studied to facilitate knowledge management in organizations, not just for day-to-day uses but also about strategically using knowledge to improve business (Davenport & Prusak 1998; Ichijo & Kohlbacher 2008; Nonaka & Takeuchi 1995). This research has focused on knowledge that employees in companies already have but which has not been used to its full potential (Quintas, Lefrere & Jones 1997). Capturing this knowledge, it is argued, can improve quality of products and services reduce costs and improve organisational use of time.

(Kamara, Anumba & Carrillo 2002) argue that KM is the way that organizations make value out of their intellectual assets via methods, tools and techniques to improve the business. From an engineering perspective, knowledge management includes the way to use knowledge to extract information from an overloaded environment and to re-use that engineering and manufacturing knowledge to achieve design requirements and reduce overtime delivery of products by better time utilization (Quintas, Lefrere & Jones 1997). IT based knowledge management systems are not new. They have been used since the early eighties (Kamara, Anumba & Carrillo 2002). Implementing knowledge management systems (KMS) alone though is not the key to success. Organizations that have implemented KMS have still struggled in achieving business improvement. There are other problems related to people and organizations that need to be addressed.

People hold some elements of knowledge as tacit knowledge. In engineering this can be professional knowledge and experience and can relate to specific design processes built up over long periods of design and manufacture. IT systems can certainly store explicit knowledge as artefacts and documents and worked properly can store captured knowledge. However there are problems with knowledge capture which often means that attempts at the use of KM for strategic purpose fail (Kanjanabootra, Corbitt & Nicholls 2010).

Strategically used, knowledge can be referred to two 'knows'. Firstly, know what the organization already knows and secondly know what the organization needs to know (Silvi & Cuganesan 2009). By following this approach it can be argued that the strategic benefits of the use of KM can be realised. This research has covered both of these two strategic aspects. For example, "Knowing what we know" is reflected in the process of capturing both explicit and tacit knowledge from the design engineers and storing that in a knowledge management system for the engineers to re-use in the design process. The other part of using KM strategically, “knowing what we need to know”, is covered in the second part of the research by applying a heuristic process mining technique to the captured knowledge in the KMS. This analysis reveals the organizational design and development processes, and enables their mapping and interpretation. This means that irrelevant steps in the design and development processes can be identified and eliminated, resulting in a shorter make-span period, improved efficiency in design and development leading to cost reduction, and enabling improved competitiveness through getting product to market more tome effective manner.

3 The case study company

The Company involved in this research is a customizing refrigerated display cabinet manufacturer. The company manufactures customized refrigerators in various forms such as food product display units in supermarkets, wine cellars, fresh produce displays, dairy cabinets etc. These customized refrigerators differ between units as each customer has particular requirements. For example one section of any supermarket has to store dairy products which requires one temperature set point while in another section of the same supermarket there is a need to store meat or seafood frozen products which require another temperature set point. This is an important issue, as some of the products require an accurate temperature set point because the products may lose their quality if the temperature set point cannot be maintained. Furthermore, their clients’ (which are mainly the big supermarket operators in Australia) requirements are very specific. For instance, some supermarket locations have greater numbers of consumers than other locations, therefore, the turn around rate of their commodities in display cabinets are also high. This means new products at ambient temperature or products just arrived from a delivery have to be added to the cabinet more frequently. Such differences in the company’s products then are a direct effect of the needs for different cabinets’ cooling capacities.

In addition, supermarkets know that customer behaviour is constantly changing and their demand for products to be sold in different ways is increasing. This is a key factor in the deployment of refrigerators as most of the products in supermarkets can be, and often are, displayed in open cabinets. This is necessary because products now must have a good appearance to the customer without visual obstruction and which make it easy for customers to choose products.

The company also has to meet the national standard for refrigerated display cabinets AS 1731: Australian Standard. These standards are changing frequently and in the past two years are being modified again to meet new carbon emission requirements. Therefore the company has to bring these needs and changes into the design and development of new refrigeration products by using their expertise in engineering knowledge to design and manufacture refrigerated display cabinets that meet the needs of supermarket clients, their customers and both new and old manufacturing and environmental standards. The company then has indicated that it needed assistance in developing better and more effective processes for product improvement and improve the time it takes from concept to manufacture to meet the changing demands and individual requirements of their clients.

The design of refrigeration systems is not deterministic; it can at best be ‘simulated’ using gas diffusion and cooling space simulation modelling approaches. The engineers at the company already have access to simulation programs (CFD Software) but in their opinion there are too many assumptions associated with the input parameters and as a consequence, the output results are not sufficiently accurate for their purpose. Previous research of the aluminium smelting industry (Nicholls & Cargill 2006) suggests that operations research modelling can be used but that there is also a knowledge problem. In this research, the proposition is that the real expertise is in the tacit and embedded knowledge of these engineers.

Observations by the researcher of the engineers’ production planning meetings shows that resolving problems is done by trial and error using tacit knowledge and expert knowledge in discussions.

Currently the make-span of a new product at the company can be as long as 1 year. It is critical strategically for this make-span to be reduced to survive in the marketplace.

4 Research Processes – action research, ontologies, and design science

The first step in this research involved the iterative building of a knowledge management system using action research (Baskerville & Wood-Harper 1996) supported by multiple-layered techniques including structured interviews, serendipitous interviews, shadowing, observation of meetings, observation of laboratory testing and embedded the researcher into the work of the engineers over a 5 month period (Kanjanabootra, Corbitt & Nicholls 2010). The engineers involved were integral to the design and development process used in building, changing, adopting, using and re-changing the knowledge management system. In this initial part of the research, the researcher and the host-organization were working together intentionally to solve particular problem(s) (Baskerville & Wood-Harper 1996; Hart & Bond 1995). In action research a number of cycles process of research action and evaluation are interlinked until the problem is solved. In this study the end product was knowledge management system built on an ontology derived from expert knowledge of the researcher – a mechanical engineer. The researcher used cycles of versions of the ontology and the developing KMS through feedback between the engineers and the researcher to gain a complete as possible understanding of the actual changing process. Following (Baskerville & Wood-Harper 1996), the research went through typical action research stages: problem identification, collaboration, action taking and evaluation of the outcomes of the action

Integral to this action research process were the development of the ontology and the construction of an artefact - the product development system knowledge-based system. "A Knowledge based system is a computerized system that uses knowledge about some domain in order to deliver a solution concerning a problem (Ammar-Khodja, Perry & Bernard 2008, p. 90)." Knowledge based systems also facilitate knowledge sharing and re-use in organizations. The system is used to capture domain knowledge. In this research knowledge relates to refrigerated display cabinet testing processes. The tool used in this research to for the knowledge based system construction is ontology in the sense about the structure of the reality (Guarino, Oberle & Stabb 2009). Following Kim et al (2009) this research utilizes ontology as a basis for structured MK and as the foundation for a data mining exercise. However Kim yet al (20009 focus on analysis of static business process whereas this research applies a similar analysis to a dynamic process of product testing, design and development .In the Kim analysis there is a set procedure. In this research the process is unordered and variable.

The primary purpose of developing the research ontology was to retain organizational knowledge - what kind of knowledge did the organization want to retain? The company needed to retain both the explicit and tacit engineering knowledge. The explicit knowledge exists in artefacts such as documents, lab report, designs and plans, quotation to clients, manufactured products, displays and working notes. However, the company executives noted that this explicit knowledge cannot be used by itself. The engineers have to combine these knowledge elements together to make the use out of the knowledge and utilize their tacit knowledge built on experience and training. Much of this knowledge is kept in multiple formats, and locations. This is because different members in the team have managed each source of knowledge. If any engineers leave the company it will take time for the other team member to learn where things are and take over the job. Therefore, these elements of explicit knowledge needed to be captured and stored in an ontology to retain the organization knowledge. The ontology had to be constructed in ways that can answer questions regarding retaining organizational knowledge.

The second purpose of developing the ontology and building the resultant KMS was to use the stored and reorganised explicit knowledge together with the captured tacit knowledge to reduce excessive product make-span times in the company. The artefacts used in this process included: calculation reports; manufactured refrigerated display cabinet testing reports in hard copy, located in the engineers' offices and electronic copies, located in the company local network; manufactured refrigerated display cabinet testing log sheets, located with the testing reports; product catalogues; production procedures; measured parameters in the computer in the laboratory office; all product drawings; actual refrigerated display cabinets; documented customer requirements; and tacit knowledge from each engineer through interviews, observations and shadowing. Evaluation of the systems throughout the action research process showed that creating an ontology to organize and then build a KMS to store knowledge from multiple sources in an accessible format facilitated the engineers' ability to re-use knowledge from their previous product development actions.

There were a numbers of activities involved in the ontology development process. Researchers conduct these activities in a different order in their own research (Li, Raskin & Ramani 2008). Gennari et al. (2003) defined ontology construction as 4 steps: knowledge capture, creating classes, sub-classes, and instances of the ontology, then defining the relationships of classes – a process followed in this research (Gennari et al. 2003). The ontology construction stage involves knowledge modelling. Using one of three knowledge modelling approaches (Sure, Staab & Studer 2009; Uschold & Gruninger 1996). The top-down approach models knowledge by defining concept or class and relationship in generic levels then extending it into more specific details. The bottom-up approach first uses concepts which have most specific detail defined then acquire further knowledge and build the ontology in parallel. The middle-out approach first uses concepts or classes which are the most important then obtains the remainder of the interested domain knowledge. Each approach is used to generalize and specialize to form the ontology structure hierarchy. In this research the middle-out approach has been applied to construct the company product development ontology as the domain expertise and interactivity of the engineers enable the most important concepts and classes to be determined. The tool used to construct the company product development ontology is Protégé, version Protégé 3.3.1. (Stanford University 2009 viewed 3/11/2010). Protégé is a domain-neutral tool which can be applied in a broad range of applications. During the KMS construction process only terms and procedures familiar to the engineers were used.

The KMS is a complex piece of software which cannot be detailed here other than to show exemplar parts. On evaluation with management and the user engineers, the strategic goal of maintaining business continuity through capturing the domain knowledge (tacit knowledge) of the engineers was achieved.

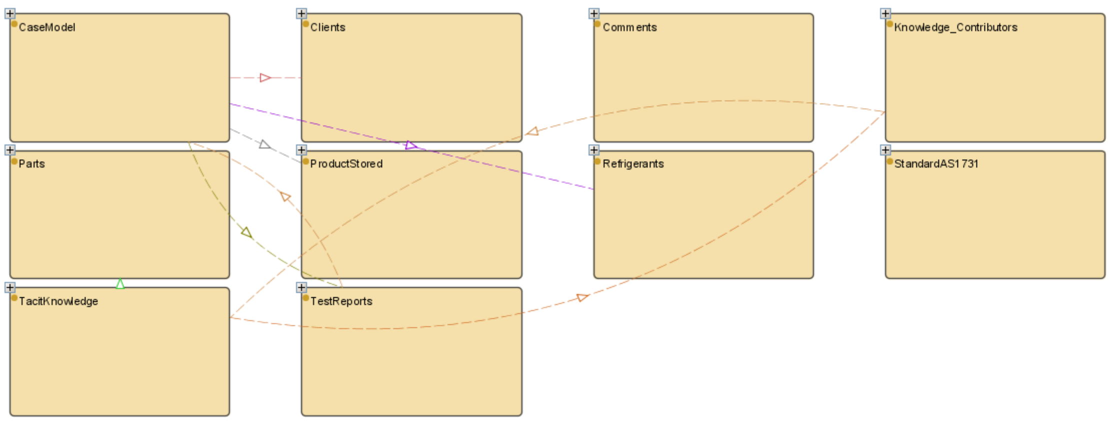

Figure 1 Overall product development ontology structure.

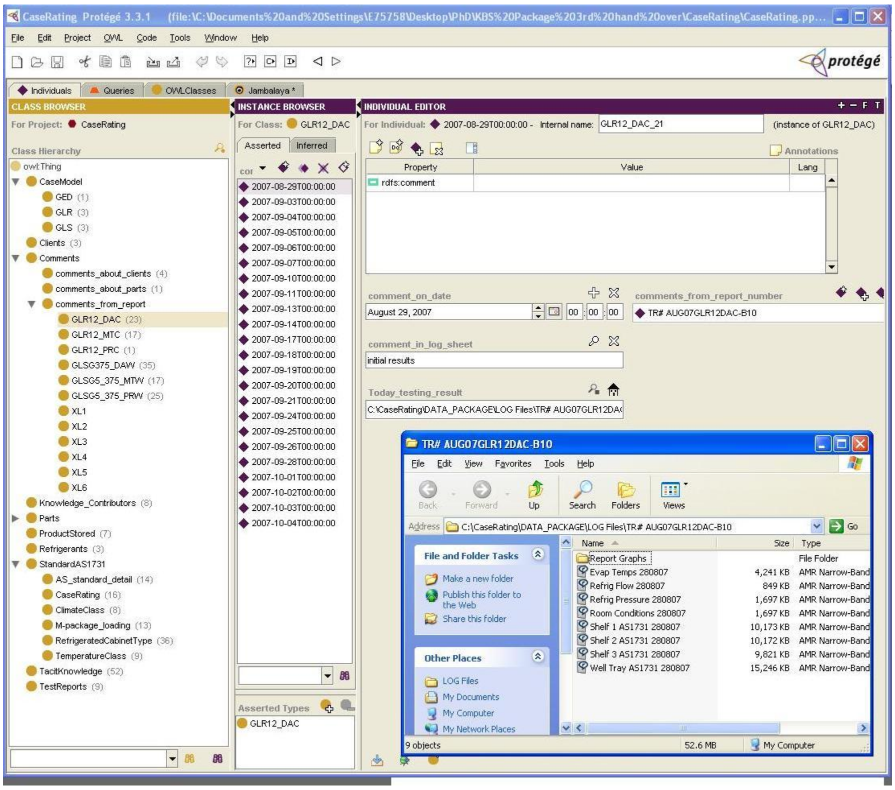

Figure 2 "Comment in reports" class screen shot.

5 Resolving business continuity

The knowledge-based system was developed to version 3. The knowledge-based system helped the engineers input their knowledge, process and knowledge embedded in their product development process. All artefacts of company product development are included together with the lab testing documentation and tacit knowledge collected formally and informally from the engineers. All of the comments in testing log sheets can now be retrieved. Modifications tasks have now been classified in a simpler form which facilitates logging processes. The comments from the engineers such as "we hardly refer back to the old log sheets" and "we want to know we did this", "this happened and we did that, that happened" can now be addressed within the structure of the ontology and stored in the knowledge based system. The engineers can now make queries such as "what happened when the fan speed has been modified in the meat cabinet?", "What about same modification on the dairy cabinet?", "How many cases use rear duct number XXXX and what are the details?" Tacit knowledge that each engineer have discovered during their individual working time is now recorded in the "Tacit Knowledge" class and linked to the cabinet parts. This can help engineers make particular queries by searching through the particular cabinet parts. The query is in included in answers to question such as "is there any note about roof ducts and who is the engineer who did that?" Explicit knowledge about the standards is also now captured and stored in the "Standards" class. This particular class helps new engineers learn about the testing procedure, setting and parameters that cabinet testing process has to meet. The engineers can also make a query such as "what is the detail of M-package loading figure 3." The system also facilitates the engineers to record their process and the way that the knowledge can be used in other aspect. For example in “Comments form log sheet” together with the instances form “Modification Tasks” class can now be used for heuristic process mining. These are just examples of the detail in the system which has captured an almost complete set of both explicit and tacit knowledge in the company.

This material is classified in a logical ontology built iteratively through practice and then used to create a KMS. In essence the company’s knowledge is not captured and able to be added to on a daily basis. The knowledge is useable and can be used to query processes and past actions. Business continuity is essentially assured through this process.

6 Resolving competitiveness through improved product design and delivery

The second part of the research adopted a design science method (Gregor 2002, 2006; Gregor & Jones 2007; Venable 2006) or engineering type research (Cecez-Kecmanovic 1994) was then adapted and applied to the knowledge stored in the KMS using a heuristic process mining method to extract key facets of knowledge from the KMS that related to the design and development process. This research applies the key principles of building theory and artefacts before, during and as a result of research using iterations of problem diagnosis, technology invention/design and technology evaluation using field studies, and action research. The initial stages of the design were in creating the ontology and then building the KMS. The knowledge classified and then stored in the KMS was then mined.

Heuristic process mining using an α-algorithm has been used in process mining in various applications to help the researcher answer “How?” questions about the studied process, in this case a commercial refrigeration design and development process. The algorithm discovers causality of sequences and ordering of tasks in the process. This α-algorithm has been shown that it can reveal what is hidden in workflows (Weijters & Van der Aalst 2003). However, in this research, a small team of 5 engineers have recorded their product development process complete and noise free.

This research examines a heuristic order of tasks in workflow nets, a subset of Petri Nets. Workflow net is “Petri net which models a workflow process definition” (van der Aalst 1998, p. 17). It is a low level form of a Petri net. Workflow nets consist of T responses to tasks that have been executed and P conditions which correspond to any given stage in the workflow net. Workflow nets also can specify routing of the process. Conditions that determine routing of the case include AND-split, AND-joint, OR-split and OR-joint. This company’s workflow net does not contain OR-split and OR-joint. This is because all of the modification that has been made to the testing cabinet derives from decisions made in the meeting described above. Modifications that have been noted in the testing log are finalized. The workflow net structure is simple, however process expressiveness is high. If any given task A happened then task B always happened right away this likely mean task A has dependency relationship with task B (van der Aalst, Ton & Laura 2004). The α-algorithm focuses on four kinds of ordering relationships between task A and task B in workflow log. These relationships can be seen in the workflow log (Weijters & Van der Aalst 2003). The relationship between tasks in workflow can be found as one or the other among these four types.

- $A > B$ If and only if there is a trace line in W (workflow) in which event A and directly followed by event B.
- $A \rightarrow B$ If and only if $A > B$ and not $B > A$ and this relationship is the so-called *dependency relationship* (*B* depends (directly) on *A*).
- $A \# B$ If and only if not $A > B$ and not $B > A$ this relationship is the so-called *non-parallel* relation.
- $A \| B$ If and only if both $A > B$ and $B > A$ is the so-called *parallel relation* (it indicates potential parallelism).

Following (Weijters & Van der Aalst 2003), there are 3 steps in heuristic process mining. Firstly, dependency and frequency tables are constructed. Secondly, dependency and frequency graphs are induced and lastly workflow nets from D/F graph are generated. This process has been applied to the company product design and development process.

Generally workflow logs contain an event occur at the beginning of the process follow by next events and it keep continuing until the process is finished. The frequency of the order of task A and tasks B has to be counted and recorded. Then the algorithm is used to calculate a D/F value. The result is the dependency metric between task A and task B. The value of dependency and frequency value (D/F) is between -1 to 1. When the value of $\$A \rightarrow^{L} B$ approaches 1 the relationship between 2 tasks is very strong and plausible that task A is the cause of task B. The D/F values were then placed in the workflow, showing an existing workflow complete with D/F values between tasks. The D/F values are used to generate workflow nets (Fig 1) which can be used for analysis and interpretation.

Their product development process in the company begins with a prototype cabinet being created and put into a testing laboratory where multiple parameters are measured and reviewed. These parameters included temperature of products installed on every shelf, testing room temperature, refrigerant temperature and pressure and total electrical energy consumption. After each test the engineers brain storm for possible modification tasks that can be made to the prototype cabinet. These possible modifications come from the personal experience of each engineer and from the domain knowledge associated with their different responsibilities. There are 2 engineers responsible for refrigeration calculations; 1 engineer responsible for production; and another 2 engineers responsible for cabinet testing procedures. Engineers have to look at every aspect before making modifications. On some days engineers come up with 1 modification, on some day multiple modifications. The engineers physically adjust and change settings of the prototype cabinet in the laboratory. Then the modified cabinet has to be re-tested for another 48 hours before review. This iterative process is repeated over and over with no set procedures. Decisions are made based on observations and expertise derived from group meetings in an arbitrary fashion, rather than on any planned process or systematic framework. Among these modifications sometimes there are uncommon modifications which happen only once and do not occur again.

Figure 3 shows one sample of the company product development testing log sheets which have been mapped into workflow net. During the data collection period 13 samples of finished products were collected. These 13 testing process were stored as part of the explicit and tacit knowledge stored in the KMS and formed part of the ontology development process. These 13 testing processes were mapped into workflow nets and HPM analysis was applied. The calculation detail, D/F table and new W/F net are excluded from this paper as they occupy many pages of analysis. The outcome from this process is the dependency and frequency value between each pair of tasks.

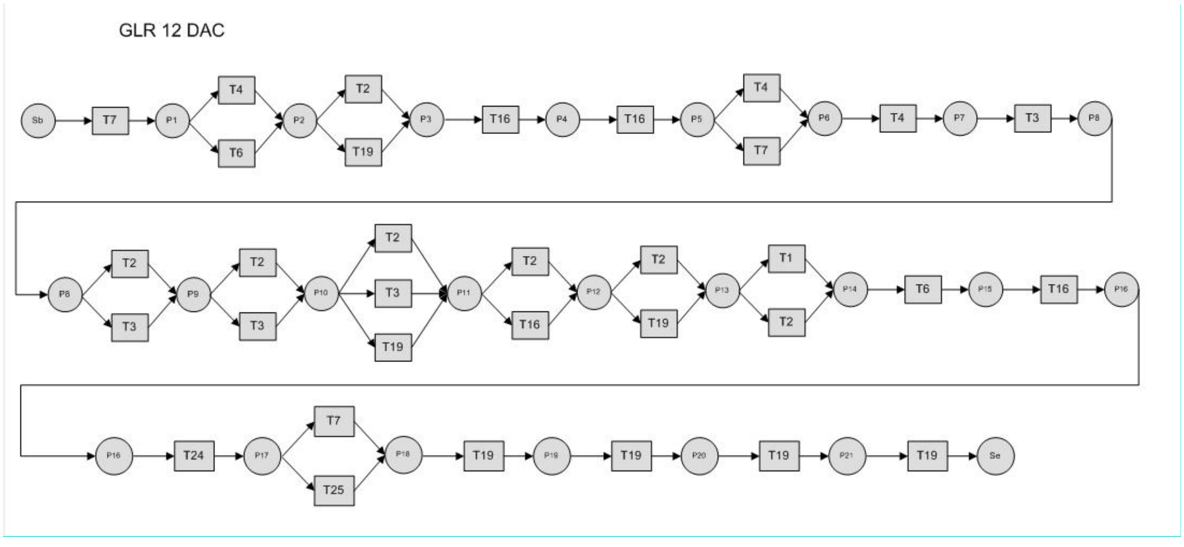

Figure 3 Exemplar product development process logs

In the next step in the analysis the researcher created induced workflow net which included only the pair of tasks which had a dependency and frequency value more than 0.6 only, the efficacy of which was verified by the practice of the engineers themselves. The result of mapping these processes is the highly related task matrix (Figure 4)

	T1	T2	T3	T4	T5	T6	T7	T13	T14	T16	T18	T19	T25	T26	T28	T29	T31	T35	T41
T1			R1 0.66			R5 0.87	R2 0.75				R1 0.66					R1 0.66			
T2	R14 0.65		R3 0.54		R6 0.88	R4 0.85	R3 0.8	R5 0.66	R2 0.75	R11 0.54	R3 0.57	R17 0.67	R1 0.66	R9 0.75		R3 0.85		R2 0.75	R1 0.66
T3		R5 0.58								R1 0.75		R2 0.75	0.5	R1 0.66					
T4		R3 0.7																	
T5	R4 0.8																		
T6			R1 0.75							R2 0.75	R2 0.75				R1 0.75				
T7		R6 0.87		R2 0.75		R1 0.66				R4 0.83	R1 0.66								R1 0.66
T13									R1 0.66	0.75									
T14		0.66						R1 0.75		R1 0.66									
T16	R3 0.8				R2 0.66	R1 0.66	0.75						R1 0.66			R1 0.75			
T18												R1 0.66			R1 0.75				
T19	R8 0.75									R4 0.85			R1 0.66	R3 0.83		R1 0.75			
T25	R2 0.8				R1 0.66														
T26										R1 0.75		R4 0.57							
T28		R3 0.8										R2 0.8	0.66						
T29																			
T31							R1 0.66												
T35																			
T41		R4 0.5																	

Figure 4 Highly related tasks matrix

This matrix contains only tasks which have dependency and frequency values more than 0.6 from the 13 processes. An algorithm was developed to evaluate the design process. The algorithm is finding the starting task of cabinet testing process as tasks A. Then select the highest D/F value in the task row from the metric. Then the highest D/F value will point to the modification tasks that should be next which is task B. the next step is using that task B as task A to repeat selecting process again until all tasks had been selected.

The result from applied heuristic process mining process and the application of the algorithm to the mapped processes shows that the number of the tasks in the process can be reduced. Collected 13 testing reports show that there are 41 modification tasks performed by engineers. Workflow instances are not similar in all instances in all of the exemplar workflows studied. These tasks are static. A task can only be selected to execute. Most of them have sequences that they have to follow. While the company workflow instances are knowledge-based, all instances are dynamic. These tasks can be executed at anytime of the process without sequential restriction. Practically, engineers perform modification task A and then they have 41 modification choices to select from including repeating task A again. If we considered only single modification task per day the possibility to choose task B and further would be 41! This is equal to 3.34^{49} steps of process instances. This means there are far too many tasks to choose from to modify the refrigeration cabinet. This does not included multiple modification tasks that often occur in one day and happen many times during the whole process. The maximum number of the multiple modifications per day is 5 tasks. The number of the process instances will be even bigger. However, the engineers argued that they know by experience that if they did task A what task B will be. This results in the testing logs that they have been doing being unsystematic. The possible solution to the question can be found from the mined testing process. Heuristic mining process defines that if the D/F value between A and B is high it is plausible that A causes B's occurrence. On the other hand, if the D/F value between tasks A and B is low it is plausible that A has little to do with B. This means if the new testing process contains only relatively high D/F values only, the engineers will not have to waste their time performing tasks that are not related or do not contribute any affect to the testing cabinet. The higher D/F value means more significance of the modification relationship. The new cabinet testing process will contains the highest D/F value throughout the process. This can be assumed as the best candidate process which can reflect the shortest possible testing time.

Examples of the new possible testing process are shown in Figure 4. Data from testing log sheets show that engineers often start the testing process with task 2. Data from the mined process shows if the engineers start cabinet testing process with T2, the next best task B from the D/F metric is T5 because it has the highest D/F value. Then T5 is now task A the next best task B is highest D/F value T1. T1 is now task A the next task B is T6 at D/F value 0.87 and repeated 5 times. T6 is now task A and the next task B is either T16 or T18 because they have the same value. T16 is now task A therefore T1 is the following modification task. T1 has been done already at the third step of the new testing process. Therefore, the new testing process is now complete. Let select T18 as task B on the 6th step of the process. T18 is now task A and task B is T28. T28 is now task A the next tasks B is T2. Up to this stage the T2 has now repeated as it has been done on the first step of the process. Therefore, the new testing process is ended. This 2 best possible solution is shown in Figure 5

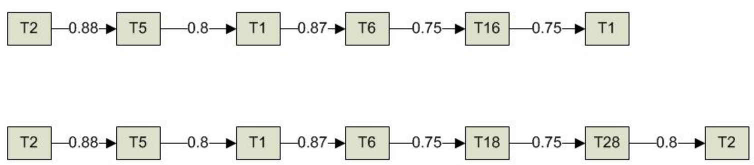

Figure 5 Examples of best possible solutions.

Figure 5 shows the 2 best possible solutions derived from heuristic process mining analysis for one example in product design and development. It can be seen that the difference between the original workflow in figure 1 and new workflow is significant. The cabinet testing process can be done in a simpler way which is shorter and a lot less complex. This means time spent in the cabinet testing process is now shorter and cost of production also cheaper. The efficacy of this process was verified by the practicing engineers involved.

This result is the outcome of using knowledge as a strategic business tool. There are other possible solutions that can be extracted form the D/F metric. In the research the 13 exemplar design development processes on average were 41. After HPM analysis the range varied from 6-15.

7 Conclusion

This paper has shown that ontology application can be of strategic use to companies trying to resolve business issues. Enabling business continuity through knowledge capture and improving make span issues is a key outcome of the application of ontology to knowledge in the first instance and then the application of heuristic process mining to that knowledge. In a dynamic business context where design, testing and building of new products is an essential component of the enablement of business continuity and the achievement of business strategy, there is a real role for structured overlays using ontology and structured analyses of the forms used in this research. The serendipitous nature of the dynamic environment and the lack of order can be addressed through flexible structures and the application of heuristics. The larger project associated with this research has shown that expertise in the forms of tacit knowledge becomes a fundamental aspect of both the achievement of business strategy in the long term and success in business continuity.

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