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Abstract

This paper demonstrates the value of applying heuristics to knowledge systems of business processes in a manufacturing company to resolve strategic issues and enable the attainment of strategic business goals. The manufacturing company was losing market share through not being able to get its new products to market quickly enough. The research illustrates the 'location' and use of information systems in a manufacturing context. The researchers collected the specific business process knowledge in the company and developed a knowledge management system and then applied heuristics to the 'AS IS' manufacturing process to determine better models of manufacturing that would enable faster to market product development and thus enable better strategic alignment between company expectations and realisation of market share. The paper highlights the strategic use of information systems as a means of directly solving business problems.

Keywords

Business Strategy, knowledge management, business process modelling, heuristics

INTRODUCTION

The paper focuses on the strategic role that business process analysis and the analytical evaluation of the relationships between repeated processes in business can play in resolving strategic business problems. The research illustrates the 'location' and use of information systems in a manufacturing context. 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 1991, 1993). Product development is one means of strategically gaining business advantage. Customisation in product development is used strategically to differentiate core products to suite different requirements. This can help business gain competitive advantage in the market (Nicholls & Eady 2008). For an organization to perform well in the product development process, it requires particular expertise from specific groups of people inside and outside the organization, that particular expertise often involving tacit knowledge. Effective manufacturing of customised products is not simply a knowledge problem but rather is one of knowledge management (Nicholls & Cargill 2006) and of appropriate and targeted analysis of that knowledge in systems (Kanjanabootra 2011). The knowledge-based theory of the firm (Grant 1996; Grant & Baden-Fuller 2004; Nickerson & Zenger 2004) argues that having useable knowledge in an organization is the basis for sustainable competitive advantage. This paper reports research that demonstrates that this useable knowledge can be identified through measurement and analysis based on consistent application of algorithms to organisational knowledge, located within the organisation's systems.

BUSINESS PROCESS MINING

Empirical studies of business process mining have shown that it can identify actual phenomena embedded in process logs and suggest possible solutions to improve those processes and enable the attainment of strategic business goals. Kim and Ellis (2007) proposed a number of workflow mining techniques to cover various kinds of processes. The purposes of these are to find the actual flow of information in the office, identify inconsistency and suggest possible restructuring to solve the problem (Kim & Ellis 2007). Fusun et al. (2009) proposed such analysis can approximate target workflow (Fusun, Tim & Mark 2009). Cordova et al. (2008) have applied business process mining to an underground mining process to improve mining productivity (Cordova et al. 2008). (Prashant Reddy, Kumanan & Krishnaiah Chetty 2001) applied a similar analysis to minimize costs in project management. Febbraro and Sacco (2004) adopted it to improve traffic flow (Febbraro & Sacco 2004).

In the semiconductor industry wafer scanner machines play an important role in the chip-making process. The wafer scanner machines operate by using a lithographic method, similar to how images are printed on film in a camera (Martijn, Barend van den & Frits 2006). The machine is used to make circuit patterns to appear on a wafer which was a slice of silicon (Mans et al. 2009). The patterns on the microchip were very small. The assemblies of the wafer scanner machines are very precise and exactly the same. Misalignment of any parts in the machine results in microchip production failure. Wafer scanner machine testing was a time consuming process. Testing too many times results in a long make-span which leads to competitive disadvantage from increased make-span costs. Insufficient testing processes can result in machine malfunction. Rozinat et al. (2007) applied heuristic process mining to this problem by using ‘The Heuristic Miner’ to optimize the wafer scanner testing time. This heuristic process mining was used to analyse the processes to see which repetitive processes were indispensable for the testing process. This analysis showed that problems affecting outputs are identified and can then be resolved improving the competitiveness of the company in the marketplace.

In the health care industry pressure has been put on hospitals by many stakeholders involved in the industry (Fred et al. 2009). The stakeholders were concerned with financial management, government policy and action, patients, insurance companies, hospital competitors and with technology. For the hospital to be able to encounter these pressures they had to perform their processes well and fast. The ways different disciplines work together to carry the data and service is complex and flexible. The time patients spend in a hospital from admission to discharge is called a ‘careflow’. Health care applications have been developed to ease hospital processes such as managing beds and operating rooms. Mans et al. (2009) applied heuristic process mining techniques to mine event logs recorded for business purposes from a hospital in the Netherlands. The purpose of using a heuristic process mining technique was to discover the ‘careflow’ paths and look at how individual patients have been treated in the care path compared with the procedure, enabling the hospital to meets its operational and strategic targets. The Public Works Department in the Netherlands also applied heuristic process mining techniques to their work processes (van der Aalst et al. 2007). The department provided services for construction and maintenance of road and water infrastructures. The resultant workflow derived from the analysis was a lot simpler, reducing costs and enabling better capacity to meet strategic goals.

RESEARCH METHODOLOGY

This study involved the iterative design and building of a KMS. The system development framework was created by application of a Design Science paradigm (Markus, Majchrzak & Gasser 2002; McKay, Marshall and Heath 2010) as the intent was to create new knowledge about a system development (Vaishnavi & Kuechler 2008). ‘The fundamental principle of Design Science research is that knowledge and understanding of a design problem and its solution are acquired in the building and application of an artefact’ (Hevner & Chatterjee 2010a, p. 5). Design Science and then Action Research are used here together, using Design Science to build the artefact (IS system) and using Action Research as a strategy to evaluate it.

The research methodology was built on the Design Science principles suggested by Hevner et al. (2004) and Arnott and Pervan (2010): a viable artefact had to be developed; the problem had to be relevant; the design had to be evaluated for utility, quality and efficacy; the research had to make a significant contribution and be rigorous, based on an iterative research process, to enable the artefact to be readily understood and able to be used by both technicians and management. Using these principles, the study developed initially from uncovering company and engineering perspectives on requirements for the system, operationally and strategically. The IS developer then undertook an iterative process of artefact development through building, and evaluation. At stages through this process the engineers and the researchers together built and modified a systems architecture based on a shared understanding of the domain knowledge of refrigeration engineering. Three versions of a KMS were built using iterative testing, evaluating and then applying outcomes through 6 applications of action research cycles. Each cycle followed the process described by Baskerville and Wood-Harper (1996). Collecting the data was a research process using that data first to enable system development, secondly through action research, evaluating the models and then using research algorithms to mine the knowledge in the system to resolve the business problem identified in the company. The outcome was the provision of research-based systems and research driven set of solutions for a strategic business problems.

Data was collected by using multiple techniques including structured, and sometimes serendipitous interviews, shadowing, observation of meetings, observation of laboratory testing and embedded the IS developer into the work of the engineers over a 5 month period (Kanjanabootra et al., 2010). Data in various forms of artefacts, plans, laboratory testing data, drawings, standards documents and interview transcripts were classified, cross-referenced and stored in the KMS. The engineers involved were integral to the design and development process used in building, changing, adopting, using and re-changing the KMS. In this study, the researchers and the host-organization were working together intentionally to solve particular problems (Hart and Bond, 1995). In the evaluation of the knowledge system six cycles of action research and evaluation were interlinked until the problem was solved. In this study the initial product was a KMS built on an ontology derived from the expert knowledge of one of the researchers, a mechanical engineer, and a team of engineer end users. Ontologies are rarely, if ever, created or used in business to classify and store created tacit knowledge, and have seldom played that important role (Boh 2007; Milton, Keen & Kurnia 2010). Ontology offers a means to classify that interaction and collaboration with the elements of both tacit and explicit knowledge in a codified format. The IS developer used multiple versions of both the ontology and the developing KMS through feedback between the engineers and the IS developer to gain as complete as possible an understanding of the effectiveness of the artefact, applied in the engineering workplace. However such systems alone don't solve strategic issues. The information/knowledge embedded in information or knowledge systems has to be evaluated systematically to modify, change, and measure impacts through analysis. In this study the application of heuristics to the stored knowledge located in the information system, provided the business solution the company needed.

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 turnaround 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. 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.

THE STRATEGY CASE STUDY – APPLYING HEURISTICS

The idea for the application of heuristic process mining (HPM) in this research developed from Van Der Aalst et al. (2003). Heuristic process mining was derived from a more formal approach called the α-algorithm. This algorithm has been used in process mining in various applications (Weijters & Van der Aalst 2003). The intention was to gain understanding of the event in a process perspective which can help the researcher answer 'How?' question about the process. The algorithm will ascertain the causality of sequences and extent of the ordering of tasks in the process. It has been shown that the α-algorithm can reveal what is hidden in workflows (van der Aalst, Ton & Laura 2004; Weijters & van der Aalst 2003). This research examined the heuristic order of tasks in the workflow nets derived and mapped from the products testing processes used in the Company, stored as knowledge in the knowledge-based system. Workflow nets are a subset of Petri Nets and is a low level form of a Petri net which models a workflow process definition (van der Aalst 1998).

There were assumptions that had to be made about the process in its application in their study. These assumptions were that only complete workflow logs and noise free workflow logs are useable. Complete in this sense means the actual tasks in the log records have been executed and have been recorded correctly without any omissions. Noise free logs were process logs where everything has been registered correctly and contain sufficient information (van der Aalst, Ton & Laura 2004). This approach then examined the heuristic order of tasks in workflow nets. Workflow net is a subset of Petri Net (Pnina, Maya & Yair 2008; Weijters & Van der Aalst 2003). The workflow net structure is simpler and requires a smaller set of construction. However, the expressiveness is high and can precisely represent the workflow (van der Aalst, Ton & Laura 2004).

In workflow nets, if any given task A happens then task B always happens immediately; this is likely to mean that task A has a dependency relationship with task B (Weijters & Van der Aalst 2003). The α-algorithm focuses on the four kinds of ordering relationships between task A and task B in a workflow log. These relationships can be seen in the workflow log (Weijters & Van der Aalst 2003). The relationships between tasks in workflow are one or other among these four types:

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

However, noise free and complete logs are difficult to find in reality. Sometimes system operators miss recording one or more steps during the process. Sometimes operators mistakenly record some steps more than they actually occurred. Noise and incompleteness in the log can affect the validity of an α-algorithm result. Heuristic mining techniques have been developed to be less sensitive to noise and incompleteness (Weijters & Van der Aalst 2003). However, complete and noise-free workflow is the ideal.

This research adopted the heuristic mining technique from (van der Aalst, Ton & Laura 2004). There are three steps in the heuristic process mining. Firstly, dependency and frequency table construction is undertaken. Secondly, reduction of dependency and frequency graphs occurs and lastly workflow net from D/F graph is generated. This process was applied to the problem of reducing the make-span in the Company product development process.

First step: Generally workflow logs contain information about the process (Schimm 2004). The information mentioned is a set of events (Aubrey 2006; Kwanghoon 2009; van der Aalst & Weijters 2004; Weijters & Van der Aalst 2003) which occur at the beginning of the process followed by subsequent events and it keeps continuing until the process is finished (van der Aalst et al. 2007; Weijters & Van der Aalst 2003). The notations in developing the dependency and frequency process are:

i. $\# A$ is the overall frequency of task A
ii. $\# B < A$ is frequency of task A directly preceded by another task B
iii. $\# A > B$ is relationship of task A directly followed by another task B
iv. $\$ A \rightarrow^{L} B$ is a heuristic rule that use to construct local metric that identify the strength of the dependency relation between task A and another task B. Local metric IV can be defined as

$$\$ A \rightarrow^{L} B = \frac{(\# A > B - \# B > A)}{(\# A > B + \# B > A + 1)}$$

The frequency of the order of task A and tasks B has to be counted and recorded. Then the algorithm is used to calculate D/F values. This results in a dependency metric between task A and task B. The value of dependency and frequency value (D/F) is between -1 to 1. The value of $\$ A \rightarrow^{L} B$ approaching 1 means the relationship between two tasks is very strong and it is plausible that task A is the cause of task B. A sample of using this heuristic will be shown in a later section: Methodology and Analysis of Product development process at the Company. Frequencies of pairs of tasks have to be identified because the heuristic approach can show how certain the relation is between tasks A and task B (Weijters & Van der Aalst 2003). The frequency of an occurrence of events can be used as a factor to identify the certainness of phenomena. One example from the case study is shown in Fig 1. Each T value is a specific task defined from the 41 tasks collected and then classified by the researchers from analysis of documents and observation of actual work in the company.

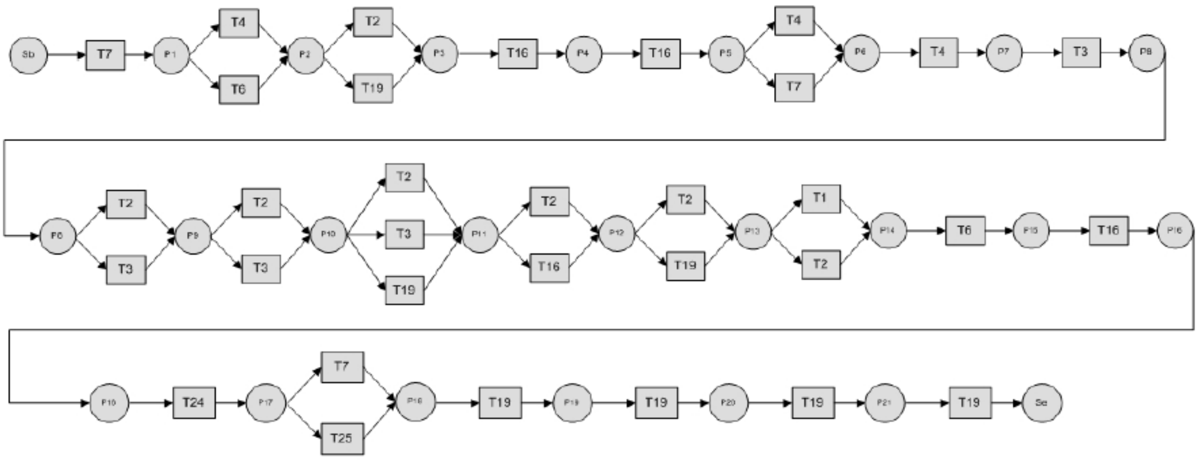

Figure 1 GLR 12 DAC workflow net

Second step: reduction of the dependency and frequency graph. In this step the D/F values are placed in the workflow. The result is a representation of an existing workflow, complete with D/F values between tasks. For the example shown in Fig 1 this analysis is applied to that example and the outcomes are shown in Fig 2.

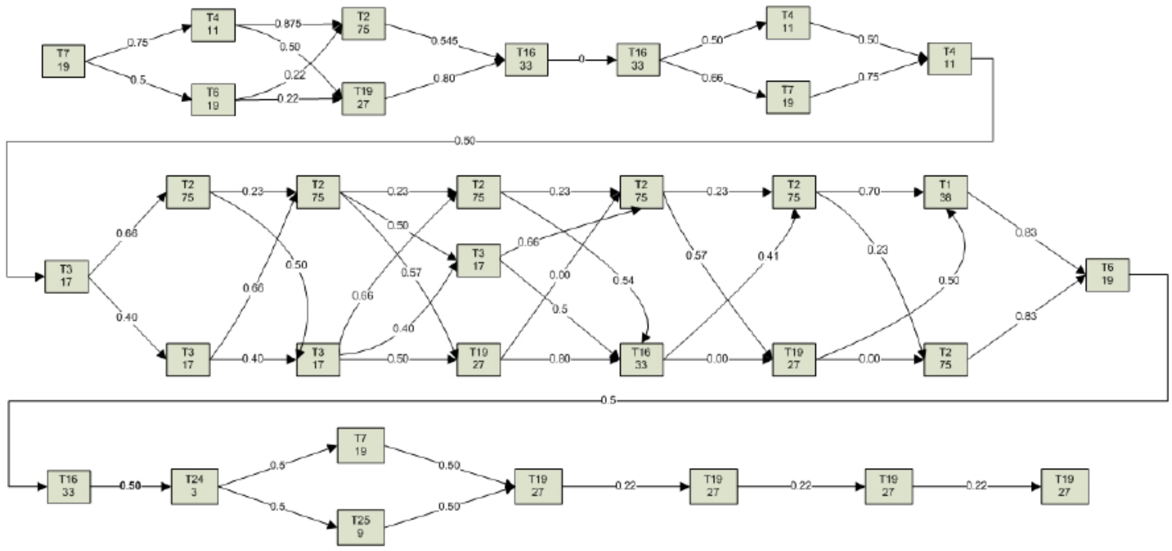

Figure 2 GLR 12 DAC workflow net – modified by application of between task relationships measurements

Third step: New workflow net generation. This is the process of generating the new workflow net in which only high D/F values between tasks are contained. The new workflow net can then reflect simpler processes and be more optimal as shown in Fig 3.

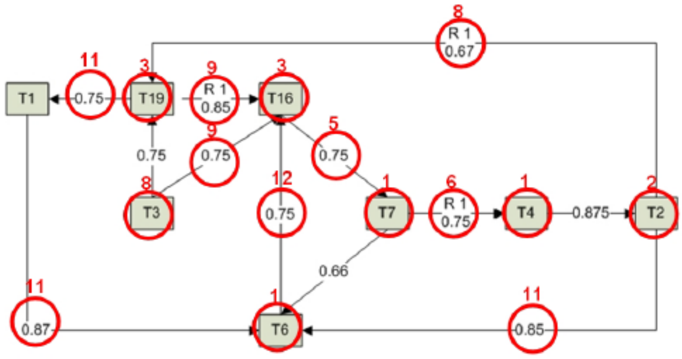

Figure 3 GLR 12 DAC workflow net modified for efficiency

However, statistically one exemplar is insufficient for any valid analysis. As a result the researchers undertook 13 such product business analyses, aggregating the results iteratively until a point of no change was reached. The major result from expanding the amount of cases and instances in the application of the process mining was improvement in both dependency and frequency values for many of the paired relationships. The researcher then used the D/F values for links in each example and built a complex model which reflected all links between tasks of values greater than 0.6. How this was done can be explained in this way: in GLR 12 MTC there is a relationship between T6 to T3 at 0.75; in the inducted form of GLR 12 DAC there is no relationship between T6 and T3. Therefore the researcher added this link to a cumulative model from T6 to T3 and then repeated this process through all links in the model for GLR 12 MTC resulting in the more complex model shown in Fig 4. This model is derived from eliminating all relationships in the business design and build process that are insignificant, keeping only those with values that demonstrate significant value add to the process. This model demonstrates those tasks that alone need to be performed and in what order to make the process more efficient and increase the speed of delivery of new products to market.

As part of the research process, the researchers tested these new relationship propositions with the design engineers involved. Their testing of the outcomes confirmed the applicability of the model the analysis produced.

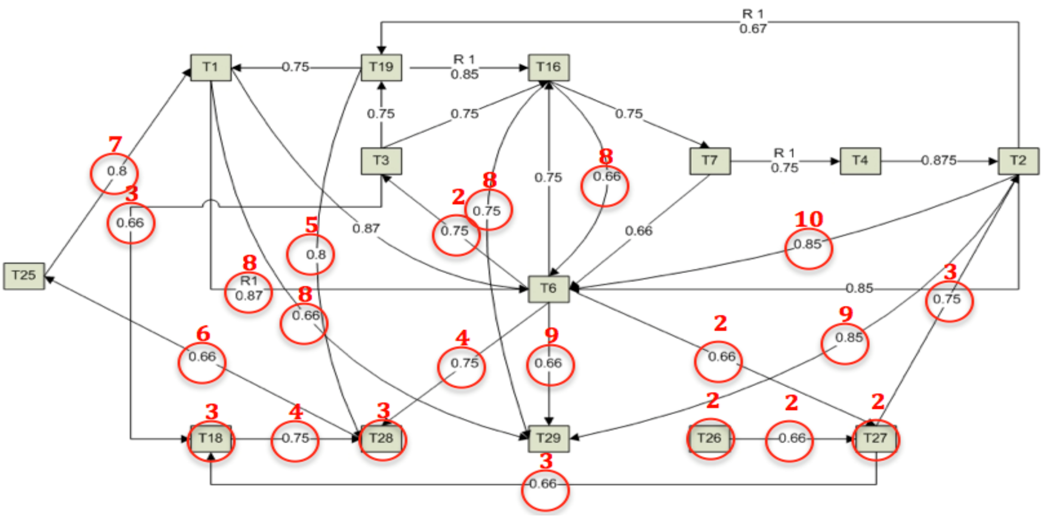

Figure 4 Inducted workflow models of both GLR 12 DAC and GLR 12 MTC.

The analysis of the design and build process for the 13 exemplar products made and sold by the Company across all of its range showed that there were, in total, 41 modification tasks that were performed by the design engineers. Some of the Company workflow instances were procedural. These tasks were static and required to meet required Australian Standards. Most of them have sequences that they have to follow. However, the ordering of the instances is dynamic. These tasks could be executed at any time in the process without sequential restriction. Practically the engineers performed modification task A and then they had 41 modification choices to select from for task B, including repeating task A again. If we considered only one single modification task per procedure the possibility to choose task B and further would be 41! This is equal to 3.34^{49} process instances. This means there were far too many tasks to choose from in the process to modify the design of a new or re-engineered refrigerated cabinet. This did not include multiple modification tasks that often occurred in one day and happened many times during the whole process. The engineers noted that in their practice the maximum number of the multiple modifications per day was five tasks. The number of the process instances was even bigger. However, the engineers argued that they knew by experience that if they did task A, they knew what task B will be. However, they could not describe that. Further evidence lies in the mapped workflow nets illustrated in this chapter. There were a large number of different processes task A and task B that may, or may not, follow each other. This resulted in the testing logs showing that what they had been doing was unsystematic.

The possible solutions to these issues can be found in the models developed in this research, based on the heuristic mining algorithm used. This process defined the dependency relationships between Task A and B in any sequence. The assumption made was that if the value was high, then Task A would cause Task B to be adopted. The higher D/F value meant the more significant the dependency of the modification relationship. On the other hand, if the D/F value between tasks A and B was low, it was plausible that A has got little to do with B. This meant that if the new testing process, based on the modelling undertaken, contained only relatively high D/F values, the engineers did not have to waste their time performing tasks that were not related, or did not contribute any effect to the end product of designing and testing the various cabinets. The new cabinet testing process contained the highest D/F value throughout the process. This can be assumed as the best possible candidate process which reflected the shortest possible design and testing time.

An example of the new possible design/testing process showed that the engineers often started the testing process with task 2: 'modify cut out temperature'. Data from the collective model derived from the analysis showed that if the engineers started the cabinet design/testing process with T2, the next best task B is T5 because it has the highest D/F value. Then T5 is now task A, and therefore the best next task B is T1 with the highest D/F value together with T5. T1 is now task A and the next task B is T6 with a D/F value 0.87 and this is repeated five times. T6 is now task A and the next task B is either T16 or T18 because they have the same value. For example, if task T16 is selected as the next task in this process, T16 is now task A. Therefore T1 becomes 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. Selecting T18 as task B on the sixth step of the process, T18 now becomes task A and task B becomes T28; T28 is now task A and the next task B becomes T2. Up to this stage the task T2 is now repeated as it has been done in the first step of the process. Therefore, the new testing process is ended. These two best possible solutions derived are shown in Figure 5 below.

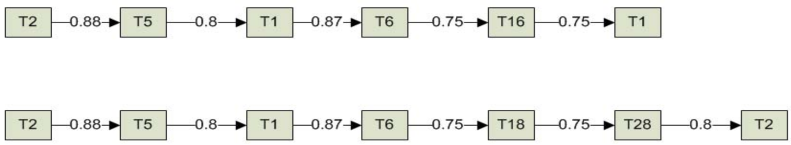

Figure 5 Examples of best possible solutions.

Using this same logic, there are other possible solutions that can be extracted from the D/F matrix, depending on the model being developed and the product purpose of the model. For instance changing the starting step in the process to other task will give different results from the first 2 examples (Fig 5). Such variation is necessary as the start point will vary by model but the dependency relationship should not change so the start point will then determine the following sequence of tasks (Fig 6).

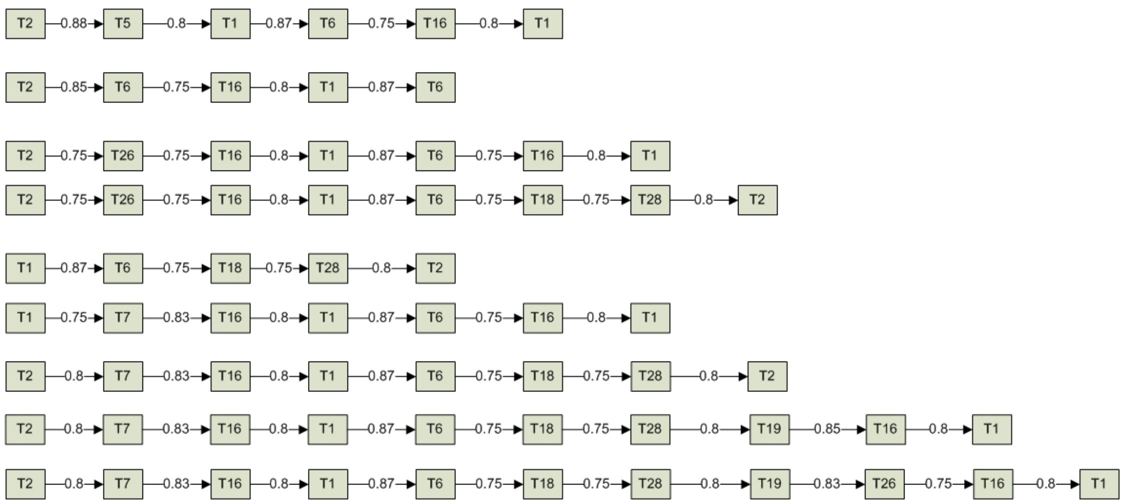

Figure 6 Examples of other possible solutions for new design/testing process.

This analysis of the Company workflow nets based on application of a heuristic mining process showed the potential solutions available to resolve the Company make-span problem by eliminating irrelevant tasks that the engineers perform. The analysis eliminated 22 out of 41 tasks that had little dependency relationships in the design/testing process. The analysis also showed that the numbers of relevant tasks that could be selected were therefore limited. For example, in the D/F matrix it showed that if the engineers performed T1 they would have only two tasks, which are T6 and T7, to choose from. Another example, T2 had seven relevant tasks B, which were T5, T6, T7, T14, T26, T29 and T35. This helped the engineers to make decisions more easily in their product development meetings. Instead of having the choice of another 41 tasks to perform, the D/F matrix developed here limited the number of tasks for them.

HPM allowed the researchers to identify dependency and frequency values between tasks in the workflows and then eliminate tasks with insignificant dependency and frequency. The application of the results means the engineers would only perform cabinet testing processes that contained relevant tasks. However the real results of the outcomes of the HPM analysis lay in its utility and applicability in the Company.

The analysis shows that the Company's make-span process can be reduced through an analysis of the tasks involved, identifying those tasks which are redundant or less significant to the actual process. The essential data for this analysis required the knowledge deposited and organised in the Company knowledge management system. The analysis identified a knowledge gap which needed to be addressed to resolve the strategy gap.

CONCLUSION

This paper shows that a targeted analysis of stored knowledge can be used for manufacturing make-span reduction and improved competitiveness. The researchers analysed the collected and organized knowledge located in the information system to find possible shorter cabinet design/testing processes. The application of a Heuristic Process Mining technique enabled the Company executives and engineers to see what knowledge was hidden or overlooked in the cabinet design/testing process. The analysis verified an early observation of the researchers that the engineers had been doing their job intuitively. The analysis enabled the engineers to gain a real understanding of what was actually going on in the cabinet design/testing process. The HPM analysis showed that there were irrelevant tasks being performed throughout the design/testing process. Results from the HPM analysis also identified patterns in their work which helped the engineers make decisions to eliminate irrelevant tasks from the process. Once the irrelevant tasks were eliminated and only relevant tasks were left to be performed by the engineers, the make-span for new products decreased. Interestingly this emerged as an indirect effect of the researchers working with the engineers, iteratively showing them what they were doing and then questioning them as to what their own knowledge processes were showing. In their words, 'operational effectiveness had increased' and enabled them 'to deliver new products to market in a shorter time'. The result emerged because the required knowledge was stored and located in a company information system, and was able to be extracted.

In future work the application of HPM also could be applied to other types of dynamic workflow logs. Industries often record their work logs. However, they rarely use what they have recorded strategically. The outcomes of this research would provide a useful model applied to other organizational workflow contexts. The previous research in HPM mostly applied this technique to static process, for example, business process, health care and public work. This research has shown that the technique is applicable to dynamic process such as cabinet testing processes. Future research could apply the technique to other dynamic processes. In future research, outcomes from HPM analysis should be quantitatively evaluated when applicable, especially in large scale operations. In this research, the Company's management problems, entry into receivership and eventually to cessation of operations, meant the researcher could only manage to qualitatively evaluate the outcomes of the HPM. In the future, the HPM technique also should be extending to cover the relation ship between set of more than two tasks.

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