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KNOWLEDGE MANAGEMENT FOR MAINTENANCE, REPAIR AND SERVICE OF MANUFACTURING SYSTEM

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ABSTRACT

Manufacturing equipment, such as numerical controlled machines and assembly cranes, require constant maintenance and service in their operating lifecycle. Equipment maintenance plays an important role in ensuring production efficiency within manufacturing systems. Equipment conditions should be monitored so that unexpected failures can be avoided. During maintenance operations, much data is generated and stored in databases by human operators. It is essential for manufacturing companies to develop a system to integrate equipment condition monitoring, fault prediction and knowledge base to support maintenance decisions. A case study, carried out within a power generator manufacturing organisation, was conducted to understand what the maintenance process is and how maintenance knowledge is currently managed. It was concluded that maintenance process is less efficient, and maintenance records, stored within internal databases, are not consistent, which makes knowledge hard to share, learn from and reuse, not only within maintenance teams, but also between the maintenance teams and operators working on the shop floor. This paper proposes a Knowledge Management System for Maintenance, Repair and Service in Manufacturing Systems to support better maintenance decision and improve maintenance efficiency.

Keywords: maintenance, knowledge management, product lifecycle management.

1 INTRODUCTION

Many previous researchers such as Markeset and Kumar (2003) have pointed out that it is very challenging to design products or equipment which are expected to have extensive life without degradation over a certain period of time. The maintenance of such products or equipment is necessary to ensure continuous performance quality. Söderholm et al. (2007) defined maintenance as a series of operations, which apply techniques, administration and supervision to keep a unit in or renovate it to the required performance. In a manufacturing company, the quality of equipment and system maintenance significantly affects the company's profitability.

Manufacturing systems are used to produce physical products and the reliability of them should be ensured for efficient production through maintenance activities. Reported research (Eti et al., 2006) shows that costs relating to the maintenance of software and equipment, to ensure that manufacturing systems are operational, are extremely high – approximately 30-50% of direct business costs or 20-30% of a manufacturing plant's total operating costs (Sachdeva et al., 2008), which indicates the necessity to apply an improved maintenance strategy using previous maintenance information and knowledge.

Assembly lines are examples of typical manufacturing systems, which consist of essential components such as tools, operational fixtures and equipment, and other important components including material handling systems, human operators and computerised systems for cooperating and controlling the preceding components. One example of an assembly line is in the power generator manufacturing business, which has been explored in the case study detailed in this paper. The company designs and manufactures power generators called Gensets as its main line of products, which provide large buildings and construction sites with electric sources. Some equipment used in assembly lines is high valued, which should be kept in good working condition to ensure continuous production, but also to prevent large costs due to break downs. This calls for Condition-based maintenance (CBM) capturing real-time data, identifying and predicting the potential failure mode to improve the reliability of the equipment (Qiang et al., 2013). Equipment maintenance operation is a high-value process, which will generate maintenance information , such as mean time between failure, total working hours and mean time to repair (Hwang et al., 2007) and knowledge, such as how to conduct the maintenance. Within the manufacturing industry, the efficiency, correctness and timeliness of maintenance decisions is often beyond the skill set of a human operator to perform to a satisfactory standard. This leads to the requirement of maintenance knowledge as guidelines on how to complete more informed maintenance tasks.

Knowledge management has attracted manufacturers attention since it is able to support maintenance decisions with knowledge on how to complete tasks (Guerra-Zubiaga and Young, 2006). Knowledge is regarded as a critical resource within an organisation and resides in the minds of employees and is the result of human experience. The most commonly accepted classification in literature is that knowledge can be divided into either *explicit knowledge*, which is recorded formally, such as corporate reports and forms; or as lessons learnt for sharing and reusing by other people within the organisation, i.e., *tacit knowledge*, which is, on the other hand, embedded in the minds of employees and their movements and expressions (Borghoff and Pareschi, 1997). Through applying tacit knowledge to real business problems, explicit knowledge can be generated and recorded in lessons learnt, which can be shared and learnt easily by colleagues. Through learning and training of previous explicit knowledge, new tacit knowledge will be generated.

The way of how to manage maintenance knowledge is a relatively new research field, compared with Information Communication Technologies (ICT). Computerised Maintenance Management Systems (CMMS), as an ICT system, are most typical and widely used in enterprises to record maintenance data on equipment usage, faults or failures, performances on the asset and inventory control. However, if a maintenance decision, such as maintenance regularity or maintenance operations, is to be made, it relies on the intellectual analysis of historical data. CMMS do not necessarily have the functionality, which is important for managing the increasing amount of information which is being generated within an organisation (Björling et al. 2013). Integrating knowledge management can assist CMMS with the management of maintenance instructions, decision support and experience management.

2 MAINTENANCE DATA AND KNOWLEDGE DISCOVERY

During equipment maintenance operations for an advanced manufacturing system, such as the collaborative power generator manufacturer, data and information stored in maintenance management systems are often not utilised fully to make informed maintenance decisions (Jia et al. 2013). Managers do not always know how to extract and formalise previously obtained knowledge, if there is an abundance of data collected, which makes decision making less efficiency. Therefore, a formalised maintenance knowledge base is necessary to establish. Meanwhile, trends in equipment failure rates should be discovered in historic equipment condition database, when real time equipment condition is applied to trends model, potential equipment faults can be obtained for better maintenance scheduling and operation planning.

The requirement of capturing patterns of knowledge, gaining rules between different data and generating new knowledge, with an abundance of data in databases, creates the research field of Knowledge Discovery in Databases (KDD), which aims to generate statements that describe ‘real-world objects, concepts, and regularities’ (Klösgen and Zytkow, 2002). KDD includes several steps, within which, Data Mining (DM) is seen as an essential step and composes of data handling and discovery algorithms. DM can be categorised according to various criteria, such as database mined, knowledge mined, technique utilised and application fields. According to knowledge to be mined, DM can be grouped into 'descriptive' and 'predictive'. Within manufacturing research, which has been applied data mining, Choudhary et al. (2009) stated that only 8% of studies were related to the field of maintenance.

Jia et al. (2013) recognised that there are typically two major components of maintenance data, i.e., maintenance records and maintenance support records. Maintenance records include information on equipment, maintenance information, failure information and consumable material information. Maintenance support records include details of maintenance support staff and funding.

Managers who oversee the maintenance process within the collaborating company focus mainly on failure type, failure rate, maintenance action, the cost of each breakdown and measurement of it. Therefore, through applying KDD, which displays history data, the next potential failure can be predicted, including the type and pattern. Feasible maintenance operations can also be provided according to the previous actions to failures, which help decision makers schedule maintenance tasks in advance, which avoid unnecessary losses in production.

3 CASE STUDY INVESTIGATION

The following case study investigation was carried out within a leading global power generator supplier based in the UK, known forth as 'The Company'. The Company has four business units, which are design, manufacture, distribute and service engines, and related technologies. To further understand knowledge management, equipment maintenance, repair and overhaul process within The Company, an industrial investigation was conducted from October 2013 to March 2014. The investigation captured the views of employees and was split into six parts, including general information about the interviewees, communication methods/tools within the department or with other departments (if applicable) or with other sites (if within their role), new product development process, ICT tools, knowledge management methods and maintenance operations. In total, 17 employees were selected for face-to-face interviews covering both professional level and leadership level. The interviews were conducted as an informal audio-recorded interview with each of them lasting between 60 to 90 minutes. Following each interview, the audio recordings were transcribed to capture what was said during the interviews and shared within our research group. The 17 employees interviewed had an average employment of 9 years within The Company, ranging from 2 years to 15 years by the time of interview.

3.1 Results of the Investigation

The Company deals with both soft maintenance and operations maintenance activities. Soft maintenance relates to maintenance activities for general lighting, ground and buildings, whereas operations maintenance refers to the monitoring of machines, cranes, rollers and test cells. The maintenance team employs approximately 15 people. Electric works are undertaken according to The Company's low voltage safety electrical rules - Electricity Work Regulations.

The maintenance of large operating equipment is completed by third-party organisations, who are preferred suppliers to The Company. Soft maintenance is completed by the on-site maintenance team dependent on resources and current work load. A Total Preventive Maintenance (TPM) schedule is utilised for each piece of equipment that is stored onsite. Equipment components are checked daily and weekly under the TPM plans.

Maintenance information and knowledge is currently managed within a type of CMMS called Maximo. The process of how maintenance information and knowledge is generated is: Once human operators on the assembly lines detect an issue, they raise a ticket on the system. If there is a safety issue, the operators will raise a T-card (bespoke to The Company), which is recorded on the Maximo system as a "ticket". A T-card is a card shaped like letter 'T', which is completed by the operator who identifies the problem and is then placed into a production board on shop floor. The maintenance team will then view all T-cards raised on a daily basis and input the data into the Maximo system. Within Maximo, maintenance team employees can input the data into separate text fields. Information captured include: line in which the fault was found, area, asset number (if known) and a brief description of the problem e.g. "crane does not work because it only goes up, but does not come down". When the information reaches the maintenance support team, the maintenance engineers will liaise with the operator who raised the T-card for further in-depth understanding of the incident. They will then collaboratively decide on what the maintenance engineers can deal with and what they cannot and which need outsourcing to a third-party supplier. For those out of scope, they will liaise with external suppliers for solutions, which are provided within a time period of 3 hours. Figure 1 illustrates the maintenance process when a problem is encountered through Cross Function Flowchart.

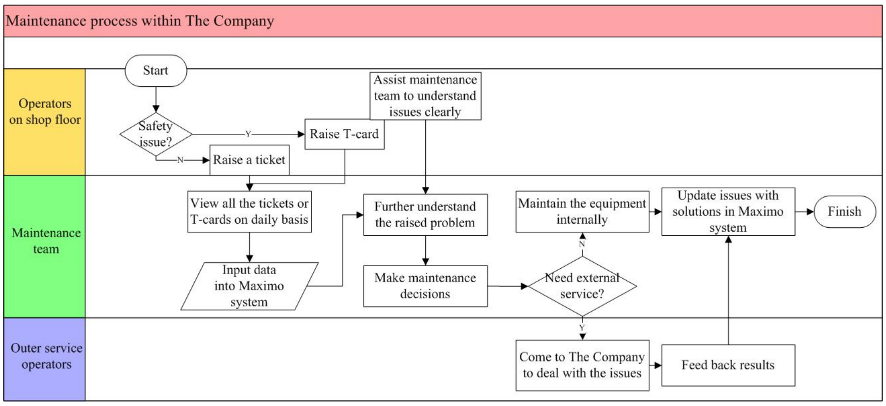

Figure 1: The Maintenance Process within the Company.

3.2 Discussion

During the investigation, it was recorded that nearly one thousand T-cards were raised in the Maximo system during the previous year when safety issues occurred on the shop floor, which indicates that the safety issue from operating equipment should attract more attention and be solved more quickly. However, according to Figure 1, there is no monitoring mechanism on the equipment to avoid failures, equipment is repaired only when encountering a problem on shop floor. Although suppliers of the operating equipment conduct a preventive maintenance service for the equipment every 3 months, equipment condition can not be predicted during this period. The suppliers have to come for a corrective maintenance service when The Company encounters a large problem, which leads to low efficiency of maintenance and high delay cost when equipment stops working.All maintenance records are stored within the Maximo system, such as equipment type, location, problems, break down time, causes, maintenance time, maintenance operations, maintainers etc. Maintenance records can be retrieved as lessons learnt if the maintenance team encounters another or similar problem. To improve maintenance operations and to capture the relationship between a problem and a cause, a reasoning mechanism is required by The Company. Lessons learnt are currently stored in an inconsistent format as operators currently use varying methods to input their experiences and tacit knowledge. This is often not beneficial when it comes to the sharing, learning and training of employees within the maintenance team and the improved understanding of problems by operators on the shop floor, who are not always knowledgeable in the maintenance field.

Furthermore, another problem is that once an operating equipment fault has been repaired, the human operator, who raised the ticket in Maximo, does not receive detailed feedback on the solution, which can be reflected through Figure 1. They can only see that the problem has been fixed and do not, therefore, receive explicit knowledge on how to fix such problems by themselves in the future. This current situation leads to poor sharing, learning and reusing of maintenance knowledge. If improved knowledge sharing took place, operators working on the shop floor could help the maintenance team or suppliers with standard maintenance tasks. Meanwhile, if operators received more detailed feedback, they could be more aware of the matters which need attention during daily operations.

All of the issues described above occurred within The Company and this means that there is an urgent requirement to improve the capturing of hidden knowledge from databases and generate new knowledge for improved maintenance decision making. This will improve the efficiency and assist in the predicting of future operating equipment problems.

4 THE PROPOSED SOLUTION

Due to the issues discussed in section 3.2, there is a necessity to develop a knowledge management system that integrates equipment condition monitoring, condition prediction and maintenance decision making, to identify equipment degrading condition, avoid failure in time, share and reuse knowledge. Take CNC machine centre as an example, Figure 2 shows the basic idea of a proposed Knowledge Management System (KMS) for Maintenance, Repair and Service (MRS) of Manufacturing System.

The first step is to establish a Maintenance, Repair and Service Knowledge Base (MRSKB) which is used for supporting decision making and knowledge sharing within the company. Related maintenance, repair and service information or knowledge will be collected from different sources; After that tacit knowledge should be discovered, and explicit knowledge should be classified, structured and modelled, so that the knowledge can be represented in a standardized way for learning, reusing and sharing easier. KDD technology is required to achieve functions above.

Secondly, real time data and signals are collected through sensors and probes from the machine, which helps to identify the machine condition that needs MRS operations. Historic machine condition data will be stored in database and the typical machine condition models can be generated. Through applying typical machine condition models, potential fault or the conditions requiring maintenance can be recognized and predicted, by matching real time data with the typical machine condition models, then potential faults and remaining life of the equipment will be generated;

After that, based on MRSKB established during the first step, and the predicted results that generated at the second step, a recommended solution including what, how and when to act will be given. Users can get that recommended solution through user interface to guide maintenance, repair and service on machine, and MRS knowledge supports the usage of the framework at the same time. Through the MRS operations, there generates actual methods, tools and parameters, and lessons learnt and advices for the improvement as well. And this kind of knowledge may different with the recommended solutions and can also be used for the next MRS operations, so they can update the current MRSKB.

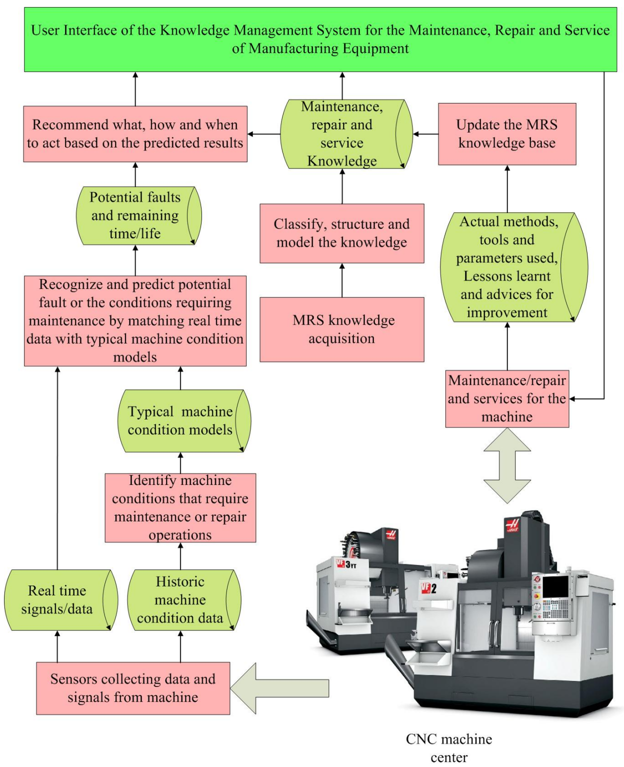

Figure 2: The Proposed Knowledge Management System for Maintenance, Repair and Service of Manufacturing System

5 CONCLUSIONS AND FURTHER WORK

Maintenance, repair and services (MRS) of manufacturing systems plays an important role in ensuring manufacturing operations. In order to avoid unexpected failures, real time equipment conditions should be monitored to match with historic equipment condition database so that the degraded equipment condition can be predicted. To support MRS decision making and manage lessons learnt, MRS knowledge base should be established and updated during each MRS operations. Therefore, a knowledge management system for MRS of Manufacturing System is to be developed in which knowledge discovery technology is one of the key technologies.

The development of each stage within the proposed system should be studied in detail as future work. Besides, an investigation within other manufacturing industries will be conducted to better understand the problems experienced with regard to maintenance decision making on operation equipment.

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