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Web-based process planning for machine tool maintenance and services

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Abstract

Providing maintenance and services for high value complex products would extend manufacturers' responsibilities and benefits to the products' whole usable life, and provide the opportunities to re-use or re-manufacture some failed parts. Sophisticated Computer Numerical Control (CNC) machine tools in modern manufacturing systems are special products in that they are also used to manufacture other products, and their operation performance directly affects the quality of the manufactured parts as well as the performance of the entire manufacturing system. To ensure CNC machine tools' consistent performance, appropriate and efficient maintenance and services are essential and this is more challenging as technologies become more sophisticated and the environment is more dynamic. Previous research was mainly focused on maintenance strategy and maintenance scheduling. Very little effort was devoted to providing operational guidance for maintenance process execution, i.e., providing service suppliers with detailed information about resources needed for maintenance such as tooling, consumables, materials and spare parts, as well as service steps including disassembly and assembly of the serviced products. In this project, planning maintenance operation sequences, schedules and resource allocation are the three main tasks for generating final maintenance plans. This paper will present a Collaborative Maintenance Planning System (CoMPS) which will manage information and knowledge to support decision making in maintenance process planning.
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*Keywords:*Product Service System; CNC Machine Tools; Maintenance Process Planning; Product Lifecycle Management (PLM); Knowledge Management

1. Introduction

Product service is an important phase in a product's entire lifecycle, and is more important for long life complex products, such as aerospace, railway and automotive products and high-value machining tools. It was stated that the cost of product maintenance and service is 15% to 60% of the total production cost, with the maximum being experienced for complex products [1]. CNC machine tools are high value and complex products in manufacturing systems normally used to manufacture high precision parts at high speed. The faults and failures of any machine component would affect the machining accuracy and efficiency, leading to reduced part quality and profits. In order to improve machine tools' performance and capability, industrial product service systems (iPSSs) have been proposed. An example iPSS for CNC machine tools was reported by Zhu et al. [2]. Some researchers proposed the concepts of e-maintenance and maintenance oriented product lifecycle management (PLM) [3]. Few of the previous maintenance related research made maintenance process plans that include detailed procedures, actions, materials and instructions to guide engineers to conduct maintenance tasks more effectively and efficiently for CNC machine tools. This research aims to develop an e-maintenance system that integrates product information, previous knowledge and best practices, to help manufacturing and maintenance engineers predict and plan maintenance operations, so as to improve machining performance with full and consistent capabilities. The maintenance management process between different stakeholders and the knowledge within the maintenance process will be captured and represented using formal modelling methods.

2. Literature review

2.1. Product service systems

There are various definitions of product service systems

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(PSSs). Goedkoop et al. [3] defined a product service system as a system of products, services, network partners and supporting infrastructure that is economically feasible, competitive and satisfies customer needs. A PSS not only contains product and service, but also includes stakeholders throughout the product lifecycle and the supporting technologies, and information/knowledge which makes the product suppliers more competitive, the customers more satisfied, and the society more sustainable. PSSs can be classified into three categories: product-oriented, use-oriented, and result-oriented [4]. Zhu et al. [2] developed a Product Service System for Machine Tools. They considered both hardware and software aspects of implementing the architecture. There are research projects on PSS in other areas, for example, a use-oriented PSS for aviation products [4]and a lifecycle based method for technical product service system design was proposed and implemented on heavy road construction machines [5].

2.2. Machine maintenance strategies

Maintenance is defined as a process of operations that can keep an item in or recover it to the designed performance by applying technologies, supervision and administration [6]. According to the time relationship between maintenance actions and machine breakdowns, machine tool maintenance can be divided into four categories [7]: (1) corrective maintenance – conducted after machine breaks down, also known as reactive maintenance, repair, or run-to-failure maintenance; (2) preventive maintenance – also known as scheduled maintenance or routine maintenance. It is done every certain period to prevent machines' degraded conditions; (3) predictive or condition-based maintenance – through monitoring machines' current conditions, the machines' potential faults and remaining useful life can be predicted, thus maintenance can be adopted to prevent any potential failures; (4) design-out maintenance – also known as design improvement. Engineers should improve the machines' reliability and maintainability during the design and development phase, so that maintenance efforts can be reduced, maintenance requirements can be minimized.

Total productive maintenance (TPM) is currently a well-known method to improve productive quality by improving equipment reliability in manufacturing systems. It is a total maintenance strategy which requires all employees to participate in the maintenance work such as routine maintenance, corrective maintenance, preventive maintenance and predictive maintenance [8]. However, this method is only used within manufacturing systems. It does not consider all the stakeholders outside manufacturing systems to solve problems, and it has limitations in giving feedback to the machine tool manufacturer to improve product design.

2.3. Maintenance process planning

A typical maintenance process management system includes four basic stages: Performance Examination, Maintenance Planning, Maintenance Execution and Feedback [9]. The purpose of Performance Examination is to test machine's performance during operation. Continuous or periodically monitoring can be used so as to obtain the machine's health condition and requirement for maintenance and services. Maintenance Planning determines maintenance operations, procedures, resources, and time scales. It is the decision making phase based on the information of current machine health condition obtained during performance monitoring, maintenance requirements based on stakeholders, and information of available tooling and parts. The plan details include where, when and how to maintain the machine, with the supportive resources such as tooling and materials, experienced personnel, and maintenance documentation. The results of execution phase can then be taken as the input into performance examination phase and process planning phase to guide the monitoring scheme or to modify/upgrade the next process planning. In the Feedback phase, the knowledge obtained during Maintenance Execution phase will be fed back for improving Performance Examination, Maintenance Planning and Maintenance Execution. In the literature, for performance examination, Tran and Yang [10] developed a condition-based maintenance management system for rotary machine. Geramifard et al. [11] proposed an approach based on hidden Markov model to improve the fault detection and diagnosis accuracy on synchronous motors faults, which is useful for the fault prediction and maintenance planning. Boutros and Liang [12] improved the fault detection and diagnosis speed and accuracy of bearing and cutting tool. For maintenance planning, some researchers investigated maintenance planning or scheduling between different machines or with production together [13]; Some researchers provided methods to utilize maintenance resources [14], and select maintenance strategies [15]. For Feedback, some researchers [16] developed frameworks to generate new knowledge from experts or past experiences to improve the maintenance activity decision making for future applications.

2.4. Current trend and limitations

Regarding the three types of PSS applications, most reported work was about product-oriented PSS. However, in recent years, researchers are moving towards use-oriented and result-oriented PSS [5]. The maintenance and service of machine tools can be seen as use-oriented PSS, because the purpose of maintenance and service is to keep or restore the capability of machine tools. While in the service design and delivery, most researchers focused on providing service solutions, fewer researchers focused on service job instructions [17]. Job instructions include guidance of steps, resources utilization including consumables and tools, materials and spare parts, manpower, and times. The second limitation is that the product service decision making lacks the use and integration of knowledge in all phases of a product's lifecycle, which leads to low efficiency of maintenance plan making. For example, the core of maintenance plan making is to generate maintenance procedures such as disassembly, inspection and assembly steps which rely much on the product model in the product development phase. The basis for maintenance planning is the diagnosis results, i.e., failure patterns based on the monitored conditions from the product use phase. Besides, maintenance planning is a knowledge intensive activity, which needs to check previous maintenance experiences and knowledge from product service phase of the lifecycle to support planning new maintenance activities. The third limitation is that PSSs have been applied in various fields, such as aviation and automotive industries, but rarely in manufacturing systems. Human factors are also important. It is the maintenance engineers who conduct maintenance service, and contribute to the most possible factors leading to maintenance errors. According to Dhillon [18], 30% of electronic equipment failures are caused by operation and maintenance errors. Six categories of maintenance errors were concluded as memory failures, recognition failures, knowledge-based errors, rule-based slips, violation errors. Of all the maintenance errors, omissions of the procedures are the mostly likely (50%) to happen in human related maintenance errors [18]. Therefore, the availability and high quality of maintenance work instructions are very important to avoiding maintenance faults and improving machine capability and productivity.

3. The proposed maintenance planning system

Machine tools maintenance and servicing involve four main stakeholders: machine tool (M/T) manufacturers, manufacturing system operators, maintenance and service suppliers, and suppliers of M/T parts. The responsibility of the M/T manufacturer is to provide machine tools (products) to manufacturing systems. When a machine tool breaks down, a manufacturing system engineer requests for maintenance and service from the M/T manufacturer, who will assign the request to a service provider, which might be the internal maintenance department or a third-party service provider. The service provider will start maintenance and services work with the manufacturing system engineer. Meanwhile, the service provider will request for materials and spare parts from the M/T manufacturer as and when needed. The M/T manufacturer will order parts from part suppliers who will deliver parts directly to the service provider. Maintenance related information and knowledge will be represented in this system, for different maintenance types: predictive maintenance, corrective maintenance and scheduled maintenance; machine's failure mode, machine operators information and so on. The maintenance and servicing process will be managed by the proposed Collaborative Maintenance Planning System (CoMPS) as shown in Fig. 1.

The stakeholders will interact with the proposed system in different ways: the M/T manufacturer will manage their product models and associated knowledge including spare parts in the system; the service provider will obtain maintenance knowledge from the system and make maintenance plans, and request spare parts according to the product model provided by the M/T manufacturer. The manufacturing system engineer will request maintenance and service through the system. In order to make the maintenance service instructions, several concepts have been proposed, such as "maintenance type" and "product maintenance process template".

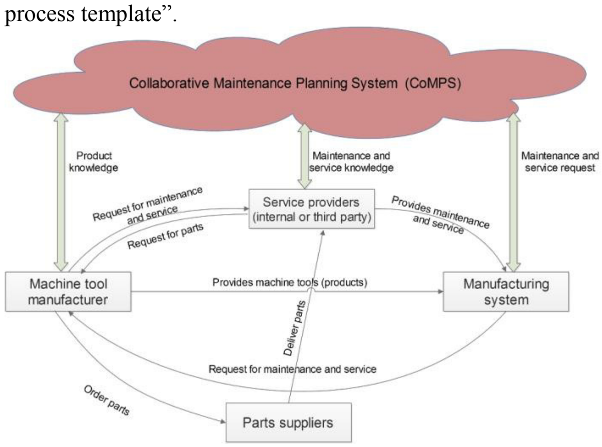

Fig. 1.The machine tool maintenance management process supported by the proposed Collaborative Maintenance Planning System (CoMPS).

Maintenance type is taken as the unique characteristics of the maintenance task, so as to identify maintenance requirements and retrieve stored knowledge and reuse maintenance knowledge. Maintenance knowledge can be retrieved for reuse in the future, which includes failure modes, reasons, and maintenance solutions. The product maintenance process template is a template for detailed solutions against maintenance requirements. It is a set of formalised knowledge including maintenance resources (tools and consumables, materials and spare parts, people and time) allocation and maintenance steps for the disassembly and assembly of products. By applying the newly created concepts and related knowledge, the collaborative machine tool maintenance management process can be represented through a cross-functional flowchart as shown in Fig. 2.

The starting point of the flowchart is that the M/T manufacturer provides M/T to the manufacturing system, thus M/T product model and associated knowledge can be shared through the CoMPS system. In order to keep the machine tool's machining capability, the manufacturing system engineer monitors the machine tool's condition and inspects the manufactured parts that can reflect the machine tool's performance. If any problems are identified that need to be corrected, the request will be sent to the M/T manufacturer. The M/T manufacturer will then assign the maintenance and service request to the service provider who may be internal maintenance department or an third party.

After receiving the assignment, the service provider will analyse, diagnose and predict the maintenance and service requirements based on the monitored data and inspection results, and compare with the previous signals and failure patterns. Then the maintenance context can be generated representing the characteristics of problems encountered, which include failed components and possible failure modes.

After obtained the maintenance requirements, a maintenance plan can be made according to three main knowledge resources: maintenance context, maintenance specifications from the M/T manufacturer, and previous cases. The maintenance context can be regarded as the maintenance requirements for the maintenance decision making. Maintenance specifications are from the M/T manufacturer, which provide good references for the maintenance solutions. The previous cases made for previous problems are regarded as important guidance for the making the new plan. Then the maintenance plan can be described in the format defined in the product maintenance process template, which includes maintenance time, materials, spare parts, engineers, and maintenance steps instructions.

Due to the fact that machine tools have production tasks, the maintenance plan should consider machine tools' workload. In addition, the plan is limited to meeting the maintenance requirements and referencing the maintenance specifications provided by the M/T manufacturer. However, the maintenance specifications are general guidelines for all machine tools of the same type. The situation of a specific machine tool may be different from others, and these differences have already been recorded as previous knowledge. Thus the maintenance plan should be revised according to the two main knowledge resources: scheduled M/T workload, and previous knowledge.

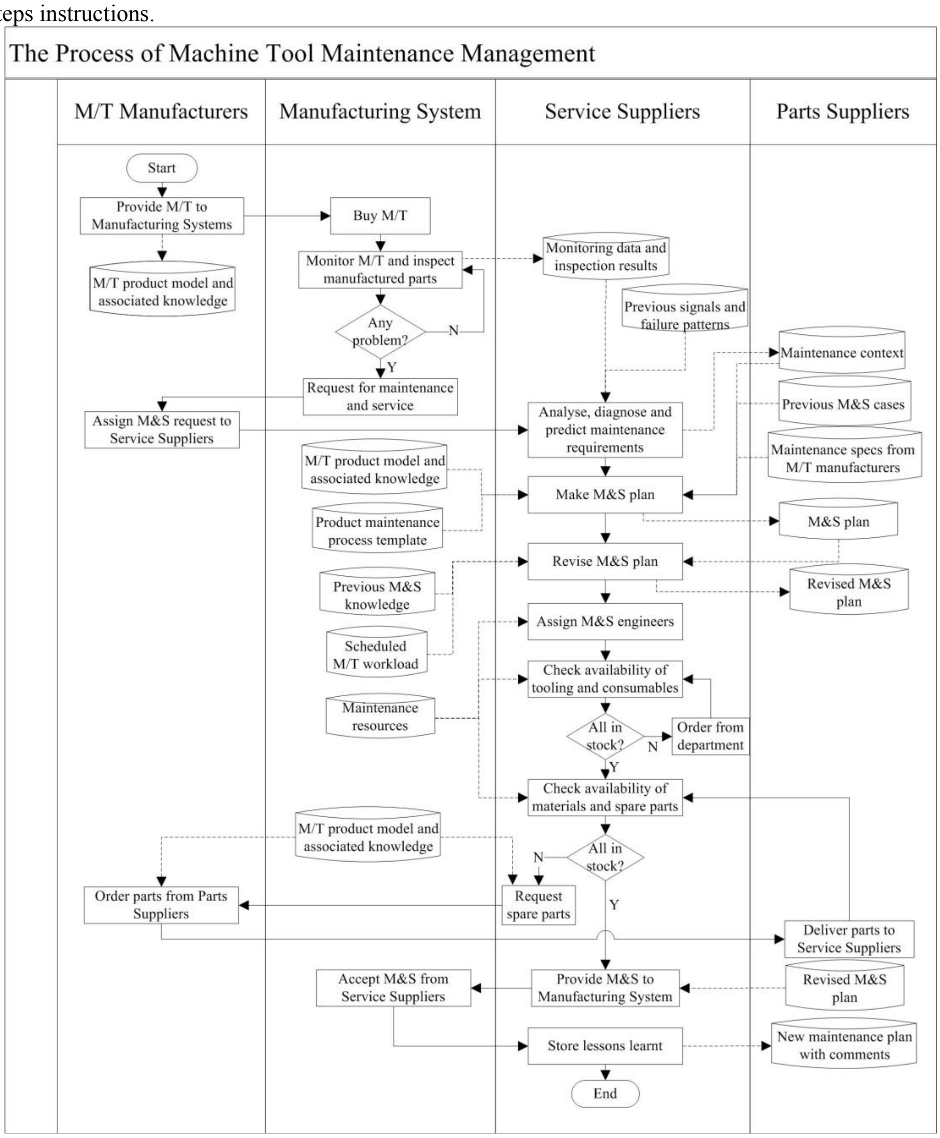

Fig. 2.The collaborative machine tool maintenance management process.

According to the revised maintenance plan, maintenance resources should be ensured available. If there is a lack of tooling and the request should be sent to the M/T manufacturer. The request should refer to the product model and associated knowledge to avoid wrong parts ordered. Once receiving the request, the M/T manufacturers will pass the order to part suppliers which are either in-house or third-party suppliers. After the service provider got parts and other resource ready, they will carry out the maintenance and service to the manufacturing system based on the guidelines on the revised plan. After that, lessons learnt from the maintenance execution will be stored as new maintenance knowledge and used as "previous" knowledge when next maintenance plan is to be made.

4. The machine tool centred information and knowledge

The product model is the core of the information and knowledge for maintenance and service planning. Fig. 3 is the structure of the product centred information and knowledge that supports maintenance planning.

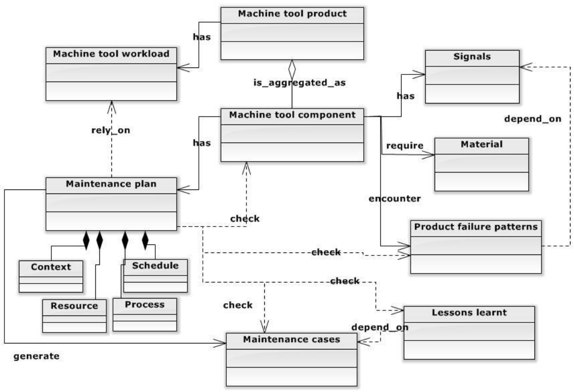

Fig. 3.The structure of product centred information and knowledge.

Semantic modelling method is used in this project to represent maintenance plans (MPLAN), which includes the Context in which a maintenance plan is made, maintenance Process including sequences and steps, Resources that the planned maintenance operations require, and Schedule for maintenance operations, i.e.,

$$\text{MPLAN} = (\text{Context}, \text{Process}, \text{Resource}, \text{Schedule})$$

All the contents included in the maintenance plan are machine tool (product) centred, e.g., the Context displays which M/T product or component requires maintenance – identified by product id or component id, what failure pattern and problem description is – obtained from monitored signals for each component. Since maintenance process includes disassembly, inspection, re-assembly, test and evaluation, and man hour for each stage, the product (dis-)assembly information and maintenance operation standard from product model will support the planning. The product model includes what material type the component or part is, such as worn parts and spare parts, so that the material can be ordered accordingly. Scheduling of maintenance not only relies on the machine tools' own routine maintenance arrangements, but also on the machine tools' workload so as to avoid conflicts. After maintenance operations are executed, historical maintenance cases are generated by updating the planned parameters with actual values. Lessons learnt can be obtained from the maintenance cases and comments. In return, maintenance plans can be revised according to previous maintenance cases, comments and lessons learnt.

5. System implementation

In order to implement the proposed system, an open source content management system (CMS) – Drupal has been chosen as the development framework. It is also taken as content management framework (CMF) which allows users to develop a website or web-based system quickly [19]. "Node" is a set of related information, and a collection of nodes – the data pool forms the base of the system; 'Module' as the functional plugin is used to either customise the data item or sort and display content; Blocks and menus can be used to determine the format of modules' output. User permissions are used to determine which roles are allowed to do what. The top layer is the Theme. Compared with other tools, Drupal provides a growing repository of contributed modules to extend the functionality as needed; It is Open Source thus making customization easy; Drupal modules provide a flexible way to achieve changeable function requirements; The Drupal core and hundreds and thousands of contributed modules that build on it, provide the developers a variety of choices and possibilities. In this project, several functional sections have been developed: 'Product', 'Requested services', 'Scheduled services', 'Service resources', 'Lessons learnt' and 'My account'. Each section includes subsections including the information and knowledge designed from Fig.3. Four user roles have been set: machine tool users, machine tool manufacturer, service suppliers and part suppliers. Fig.4 is one of the interfaces that logged as service suppliers. They can read the product structure provided by machine tool users, and add service schedules to the pre-set calendar. And service schedules cannot be overlapped with machining schedules, and they have been set with different legend colors. Due to the page limitation, other functions are not be described here.

6. Conclusion and further work

This paper represented a collaborative maintenance planning system through which different stakeholders along the machine tools lifecycle can contribute to the maintenance and service planning of CNC machines: machine tool manufacturers can provide machine tool product information and designed documents for maintenance; service suppliers can provide maintenance services for machine tools and obtain lessons learnt during daily operations and can give feedback to machine tool manufacturers for future improving product design from maintenance point of view; manufacturing system can request service through the system, and part suppliers would avoid providing wrong parts by referring to the machine tool product information provided by machine tool manufacturer. Further work will be carried out to implement the system and test it with industrial example.

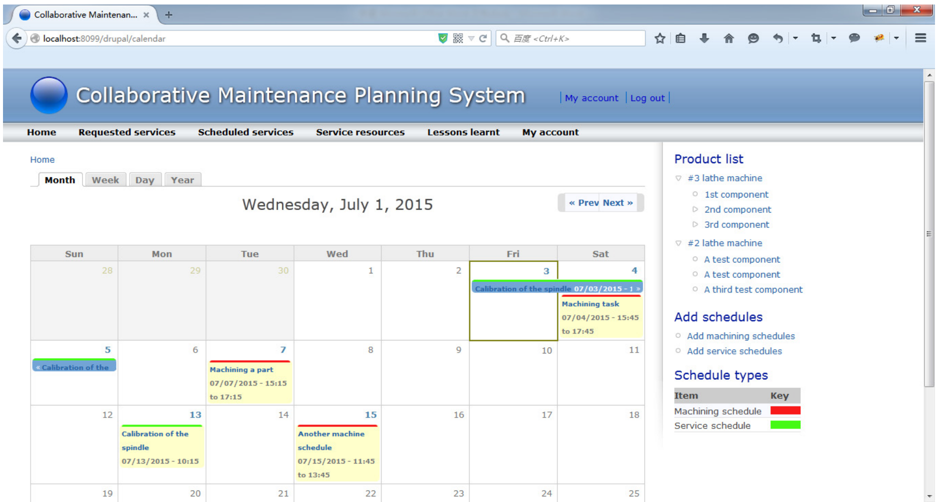

Fig. 4. One of the interfaces of the implemented system.

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