Transdisciplinary Engineering Methods for Social Innovation of Industry 4.0
M. Peruzzini et al. (Eds.)

doi:10.3233/978-1-61499-898-3-966

Approach for Preventive Maintenance Planning of Machine Tools

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Abstract. This paper addresses a common problem to manufacturing companies: the maintenance of machine tools and their components. Preventive maintenance has always been a great challenge for companies, due to the need of predicting failures or production shutdowns, which requires knowledge and resources. However, the planning of machine tools maintenance presents itself as an even more complex problem due to the distinct lifetimes of their components. Age-based preventive replacement and Block replacement models define optimal replacement intervals for one item based on associated maintenance costs. A machine tool can be seen as a serial system of components or items. The concepts of group technology and clustering can be used to group components together in order to define common preventive maintenance intervals and reduce the number of production stops. In the literature, some contributions are found. However, the defined groups are static as well as the preventive maintenance intervals. This paper presents a conceptual model for the definition of dynamic clusters and intervals. It also presents an application to record the inputs, data collected in real time, needed to group components and set up preventive maintenance intervals. The developed application is being implemented in a metalworking company.

Keywords. Maintenance management, Maintenance planning, metalworking, Preventive maintenance

Introduction

The concept of maintenance is as old as that of production. Due to the increased use of mechanization and automation of operations and increased trend of using the Just-in-Time concept, maintenance impact on performance such as productivity and profitability has increased [1].

The state of machine tools has a significant impact on quality of the manufactured product and, therefore, their maintenance should be planned in order to provide the desired output. A tool is a system with multiple components, with different lifetimes, which hinders maintenance planning. Thus, it is not cost-effective to stop the machine for tool maintenance whenever each one of the tool components ends its lifetime or

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when each component reaches its optimal replacement time (defined based on costs). The first strategy allows using each component until the end of life, which could be interesting in terms of component cost, but implies stoppages at unpredictable moments, a situation that entails higher costs than the component itself (costs of production loss, waiting labor costs, non-conforming production costs, delayed order costs, etc.). The second strategy optimizes the individual maintenance cost of each component, but does not optimize the overall maintenance cost of the tool since it implies frequent stoppages and therefore production loss.

Since a tool can be seen as a serial system of components (a component failure causes the tool to stop), cost optimization should be made at the system level and not at the component level since the failure of a component affects the whole system.

This paper proposes a strategy for planning of tools preventive maintenance activities, based on the study of components reliability, to settle down preventive replacement intervals as well as components groups to be replaced at the same time, in order to reduce costs.

Some studies point in the intended sense, that is, they define preventive maintenance planning intervals based on the reliability of the equipment combined with costs [2]. Other studies address the issue of planning preventive maintenance activities of tools using Group Technology (GT) concept and similarity coefficient to define components clusters [3], [4] and [5]. However, these approaches are static. The components groups are defined once as well as the preventive maintenance interval.

The novelty of the developed model over the others is its dynamic characteristic to take advantage of stopping times to carry out preventive replacements. Therefore, the interval between tool maintenance tasks rather than be constant over time, varies to minimize costs. Whenever a maintenance task due to a component is triggered, an algorithm defines a cluster of components to be replaced in this stoppage, in addition to that component.

This paper is organized into six sections. The first defines the scope and paper objective. The second section presents a literature review about Group Technology, parts replacement models and preventive maintenance planning. The problem, limitations, restrictions and motivations are exposed in the third section. The fourth section describes a computer application, developed to record the requested inputs for the model application. In section five, the proposed conceptual model of the project is explained. The last section presents the conclusions and points out the future works that will be developed.

1. Literature review

1.1. Replacement Policies

Preventive replacement presupposes the definition of a replacement policy. To reduce the number of failures, preventive replacements can be scheduled to occur at specified intervals. However, a balance is required between the amount spent on the preventive replacement and its resulting benefits, that is, reduced failure replacements [7].

The well-known replacement policies "Age-based Replacement policy" and "Block replacement policy" aim at defining the best moment of part replacement. For the age-based replacement policy, the preventive replacement occurs according to a defined and fixed age of the part or when a fault occurs. For the block replacement policy, the replacement occurs at regular time intervals, regardless of the age, or when the failure occurs [8]. Based on these policies, replacement models have been developed. In order to minimize costs, the age-based replacement model and block replacement model aim to determine the optimal interval between preventive replacements to minimize the total expected cost of replacing the equipment per unit time [7].

The principal advantage of block replacement policy is its simple structure and administration because the time points of preventive replacements are fixed and determined in advance [8]. The block replacement policy is suitable to optimize interventions on systems with identical components or equipment, taking advantage of the simultaneous maintenance or replacement of the identical components. However, the block replacement policy results in a greater number of planned or failure interventions than age-based replacement policy [8] in a given time interval, which results in higher costs.

1.2. Clustering

The age-based model and block replacement model can be applied individually to each part of a system, obtaining the optimal replacement of each part. However, the system under study is a serial system, which means that failure or replacement of one of the components leads to the stop of the whole system, implying loss of production. Therefore, this solution increases costs because of the greater number of stops. Thus, to reduce costs, parts can be grouped to be replaced at the same stop. Grouping preventive maintenance activities to utilize simultaneous downtime can generate significant economic benefits [3]. Clustering can be defined from different techniques, and it is necessary to identify the assumptions for group definition.

Source [3] proposed a heuristic method for grouping non- identical equipment into blocks within a series system to perform preventive replacements based on group technology (GT) concepts [3]. The authors first defined a cost model for determining the optimal preventive maintenance interval for individual groups based on the block model presented in [9]. Then, the authors defined a similarity coefficient based heuristic to generate candidate grouping of similar machines whose time to failure was assumed to follow a Weibull distribution. The features selected to form the group were: the Weibull shape and scale parameters, the ratio between the corrective and preventive maintenance cost of the individual equipment and the optimal preventive maintenance interval for the individual equipment. The concept of group technology is not new, it has been reported in [6], which has a taxonomic review framework for GT. GT is a manufacturing philosophy that has attracted a lot of attention because of its positive impacts in the batch-type production [5]. GT defines groups of products or processes for the formation of cells of manufacture in order to reduce production costs. This concept has been applied in other areas, including preventive maintenance. One of the methodologies used in GT to define clustering algorithms is based on similarity or dissimilarity methods [3,4]. One of the methods of dissimilarity is the Minkowaski metric, which defines the cluster by calculating the distance between objects, in order to reduce total maintenance costs [3].

Most of the preventive maintenance planning models considers a cost-based approach. Das et al. [2] present a multi-objective model for maintenance planning of machines in a cellular manufacturing system that combines cost and reliability. The model aims to optimize maintenance costs by administrating a group maintenance policy subject to a desirable machine reliability threshold.

2. Problem description

This project was conceived having the metalworking industry as background. Therefore, it is being developed in two Portuguese metalworking companies, to test and validate the proposed solution.

This industrial sector has an important feature: in addition to the maintenance of production machines, it requires the maintenance of rapid wear tools, which are incorporated into those machines. Figure 1 shows a typical tool of a progressive stamping process, whose main components are punches and die inserts. Progressive Stamping is a machining method that can involve punching, coining, bending and other ways of modifying metal raw material, combined with an automatic feeding system to obtain a finished part.

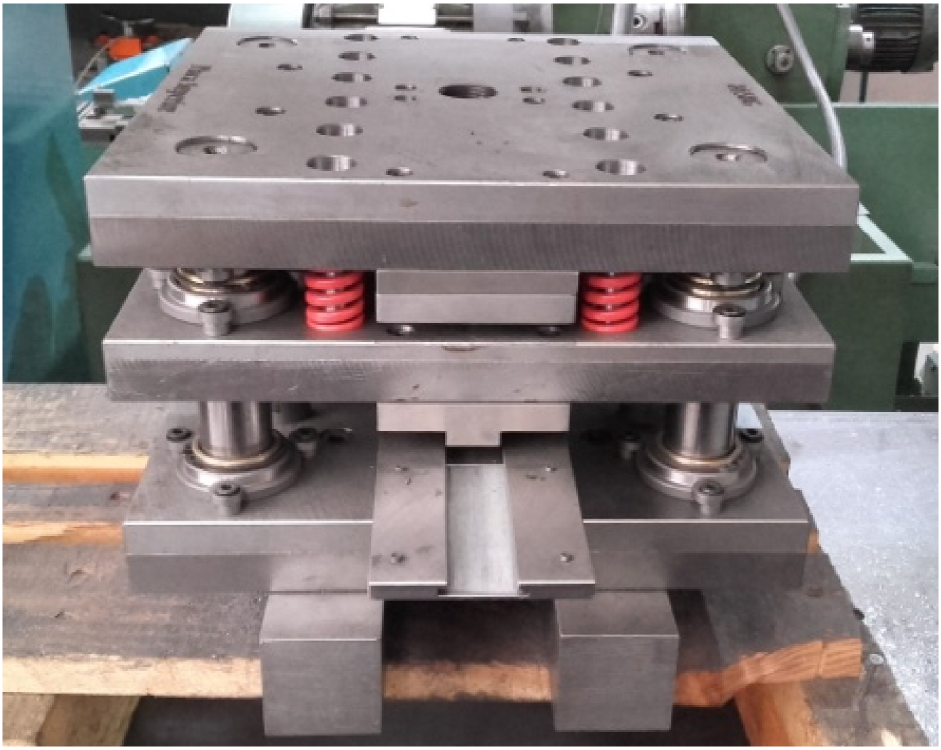

Figure 1. Progressive stamping tool.

Through performed audits to companies of this sector, it was observed that a considerable part of them does not plan the tools maintenance or does it empirically. The lack of planning has many downsides:

- Most interventions are generated after detecting tool failure, which can result in production of defects and more severe tool or machine damage.

- Tool failure is an unexpected event and may occur in inopportune moments, leading to resource underutilization, longer production shutdowns and/or late deliveries.
- Due to poor stock management of tool components, stock out may occur frequently, resulting in longer interventions since the failed components have to be rectified or, worse, new components have to be manufactured.
- Interventions may not be optimized since they are mainly focused on correcting the components associated with the failure, leaving untouched other components which may be near their lifetime end, leading to more than necessary stoppages.
- The intervention quality is highly dependent on the empirical experience of the technicians (especially elder staff).

The conceptual model presented in this paper aims to correct the issues listed above, through a preventive planned approach. Although this project was intended to be applied in the metalworking industry, it can be used in any industry with tools that can be seen as a serial system of components with distinct lifetimes.

In order to record the necessary input for the model and to support its execution, a computer application was developed.

3. Computer application

The computer application for data collection records the necessary data for the planning of maintenance actions and, in the future, will incorporate an algorithm, according to the conceptual model, to plan such actions. The data recorded in the application will allow to know the age of each tool component in a given moment and also to determine components failure time distribution and reliability for a given period of time.

Furthermore, this application is intended to monitor the technicians and operators' works and compute performance indicators, in order to improve the maintenance and operation processes. Therefore, there is, at least, one record desk in each of the two areas: maintenance and operation.

Starting with the operation desk, the application displays the operation module, where the operator records the assembly or disassembly of a given machine tool and communicates to the maintenance area the need for corrective intervention.

On the other hand, regarding the maintenance desk, the application displays two separate modules: tool maintenance and components maintenance. In these modules, the technician records the maintenance activities performed, respectively, on the tool and on the components.

The separation of maintenance modules implies a paradigm shift in this area: technicians should be able to act on the tool simply by replacing components with the respective ones available in stock; whereas repair of the replaced components should only be done after the tool is closed and ready to operate again. Thus, the productivity loss due to production shutdown is reduced.

Figure 2 presents the Use Case diagram of the tool maintenance module, to illustrate the user and system interactions.

As shown by the diagram, the technician has the possibility of starting, resuming, pausing and ending maintenance interventions for which part/component changes are recorded, allowing to know the age of each tool component. The user, besides being able to record the corrective or preventive replacement of components, has the possibility of recording the removal and addition of components with different characteristics to the tool. This possibility covers the situation that occurs in the case study company that consists in using the same tool to produce slightly different products, which implies adding new components and removing existing ones.

The application interface for the tool maintenance module is presented in Figure 3. To differentiate between corrective and preventive replacements, the tool maintenance module presents a different section for each.

In each section, the technician records the tool components that have been replaced, the supplier of the replacing components and if the replaced components are meant to be scrapped or later rectified. Finally, he sends the tool to the warehouse or back to the operation workstation.

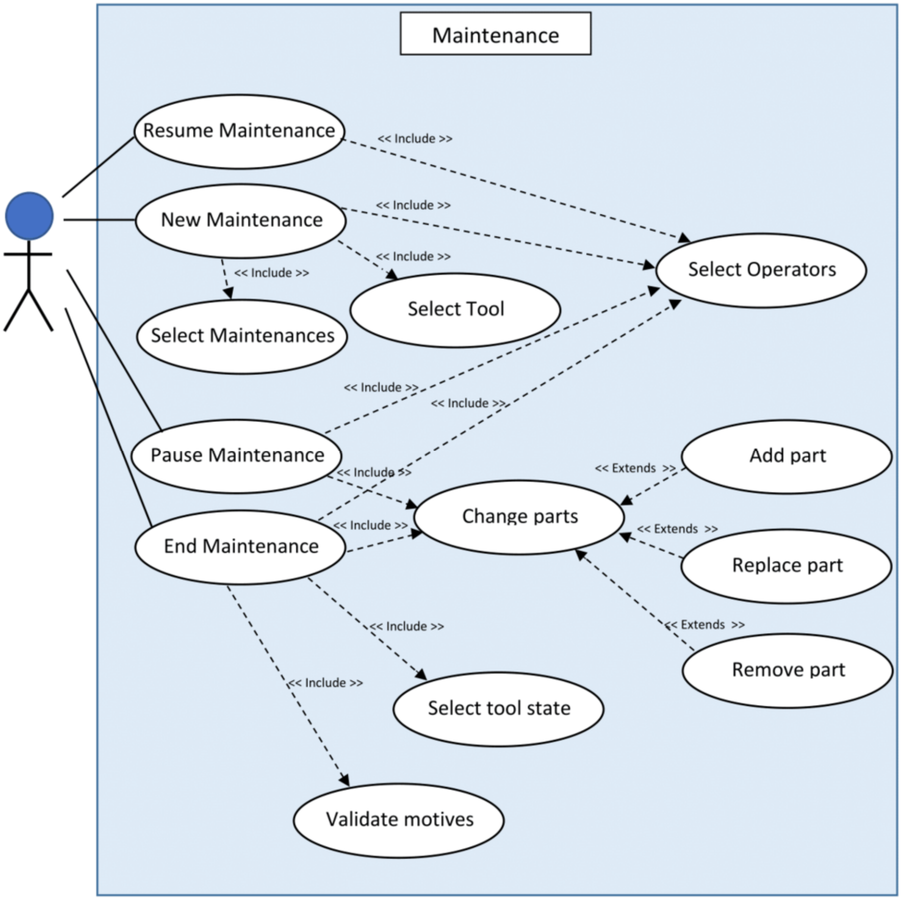

Figure 2. Use Case diagram of the tool maintenance module.

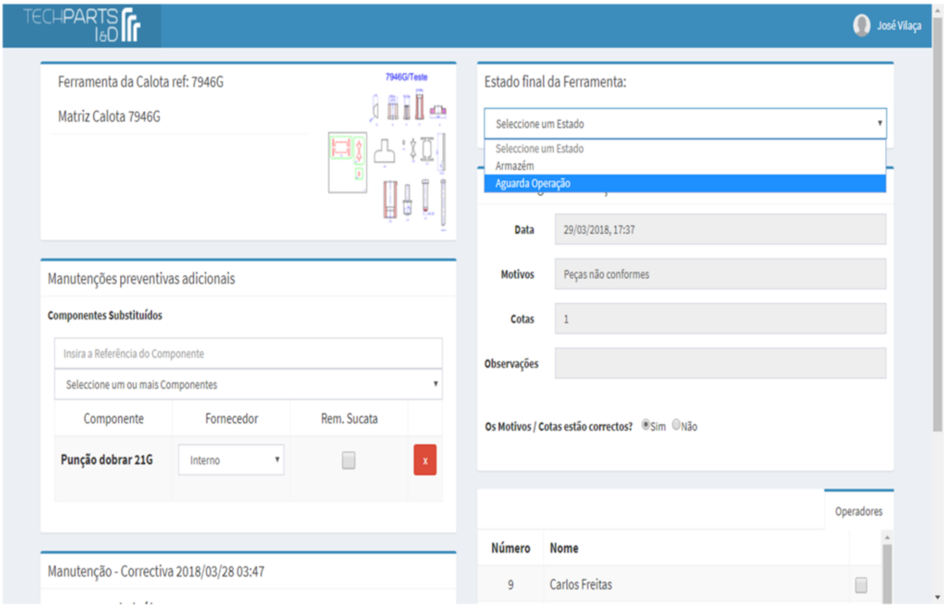

Figure 3. Interface of the application's tool maintenance module.

4. Conceptual Model

The models for preventive maintenance of series system proposed in the literature are static since they define only once the preventive maintenance interval for groups as well as the corresponding groups of equipment. Machine downtime due to a component failure can be used to perform preventive maintenance or replacement, possibly avoiding a future stop for this purpose. Therefore, the components to be replaced preventively during this stop should be determined when the failure is detected and the information should be transmitted to the technician. In addition, the time interval to the next intervention should be determined. Since it is intended to replace the components based on its age, the computer application will periodically update the number of manufacturing product by the tool and, based on this information, will also update the age of the respective components.

To exemplify the proposed approach, the possible scenarios, which differ mainly in the event that triggered the intervention, were defined and presented in Figure 4.

The following scenarios were considered:

1 - Occurrence of a failure during a production order (PO): the tool is sent to maintenance area for performing a corrective maintenance, information that is recorded and transmitted by the application. A clustering method is used to define the components to be replaced.

2 – Stop for performing preventive maintenance during a PO: the computer application gives an alert for performing preventive maintenance based on the defined preventive interval and the record of the number of manufacturing products. Clustering starts and the group of components to be replaced is defined.

3 - End of a PO followed by the start of a new PO with the same tool: components to be replaced preventively are defined and indicated to the technician.

4 – End of a PO followed by a new PO with a different tool: components to be replaced preventively are defined and indicated to the technician. The tool is stored in the warehouse until the start of a new PO.

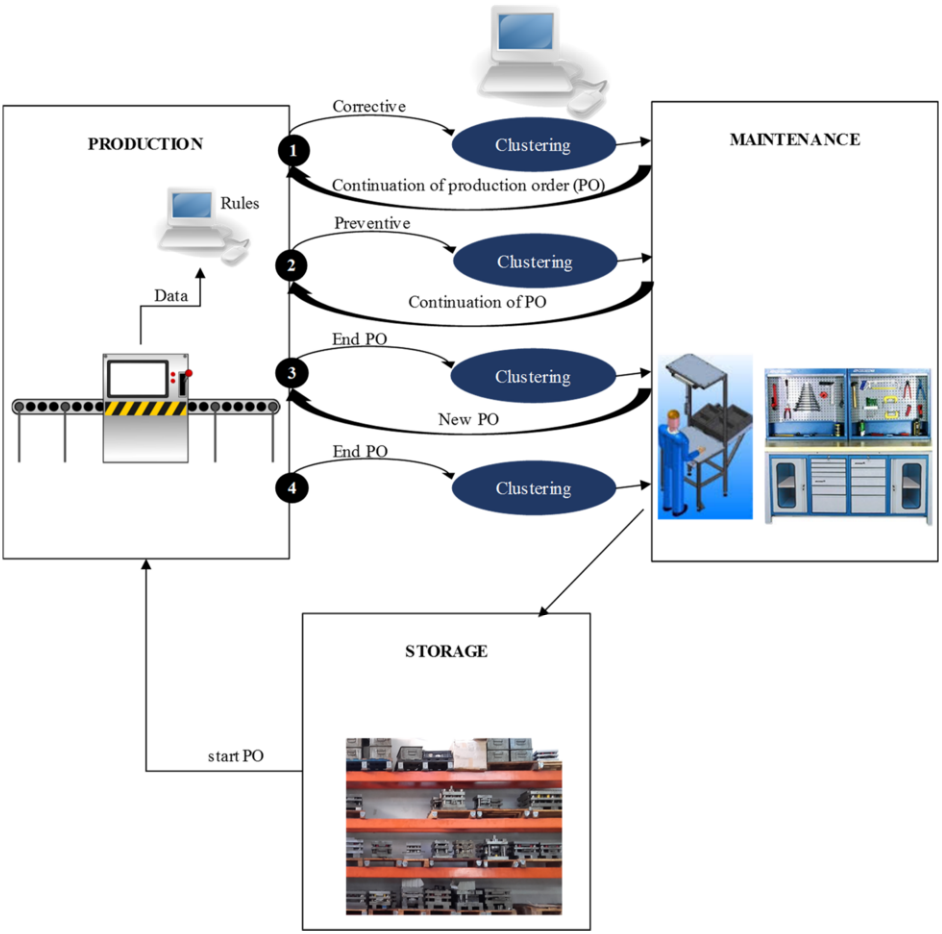

Figure 4. Conceptual model.

Therefore, to adopt the proposed approach, the following should be defined:

- The preventive maintenance interval considering the reliability of the tool: this interval will be defined based on the age-based replacement model adapted to a series system (see equation 1).

$$C(t) = \frac{C_f \cdot F_s(t) + C_p \cdot R_s(t) + \sum_{i=1}^{n} C_i}{t \cdot R_s(t) + F_s(t) \cdot M(t)} \quad (1)$$

Where:
$C(t)$ – Total cost per unit of time;
C_p – Cost of corrective maintenance;
C_f – Cost of preventive maintenance;
C_i- Cost of component i replaced at the stop;

n- Number of components preventively replaced at the stop;
$F_s(t)$ - Cumulative distribution of the time to failure of the series system (tool);
$R_s(t)$ - Reliability function of the series system;
M(t) - mean of the probability distribution (of the failure times) truncated at t

- The components to be preventively replaced during a stop: group technology and similarity coefficient that has been applied in [3] for this purpose is not adequate in the proposed approach since the approach aims to be dynamic and the selection of components to be preventively replaced in the same stoppage depends on the system condition at that instant, i.e., the age and therefore reliability (or probability of failure) of the components involved, and on the cost of each component. An algorithm will be defined to select the components to be replaced. The algorithm will first sort the components based on their estimated remaining useful life and, then analyze the impact of replacing or not replacing the component during the considered stop.

5. Conclusion

The maintenance of rapid wear tools, despite being a critical area for the performance of manufacturing processes, typically lacks planning. This situation leads to many problems, such as production of defects, severe tool damage, resource underutilization, longer and frequent production shutdowns and ultimately to delays in deliveries. To address these issues, this paper presents a conceptual model based on a preventive maintenance approach.

Since a tool is a set of multiple components with distinct lifetimes, preventive maintenance planning becomes a challenge. Nevertheless, a tool can be seen as a serial system of components, where failure of one component means tool stoppage.

To take advantage of tool stoppages, intended for instance to carry out corrective interventions, for reducing overall costs, clustering can be used to group components together in order to define common preventive maintenance intervals. While the proposed grouping methods found in the literature are static, this paper presents a conceptual model that intend to dynamically define clusters and respective maintenance intervals. A mathematical model will be defined based on this approach, in order to define clusters and preventive intervals that minimize costs, and will be tested in real environment, in order to be validated.

The application described in this paper to collect the inputs used by the model was implemented in a company. Hereafter, the model will be incorporated into this application to automatically indicate to the user the time to perform a tool preventive maintenance and the components to be replaced preventively. Preventive replacement of components is also possible whenever the tool stops, due to a failure or the end of a production order, and will also be supported by the application that will indicate the components to be replaced.

This function added to the application will allow the company to move towards Industry 4.0 since the tool maintenance will depend less on technicians and will be based on recorded and real-time information. In addition, the outputs of sensors can also be considered in the future, included in the reliability function.

Acknowledgement

We would like to thank the companies that are involved in the project and express our appreciation for the commitment of the employees involved.

This work has been supported by Norte 010247 FEDER 017833 – TechParts I&D.

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