# Efficient Maintenance of Machine Tools –
# Adapted Maintenance Activities and Assembly-Specific Maintenance Intervals


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**Abstract**

Besides purchasing costs of modern production equipment, guaranteed availabilities and maximum costs over the expected time of usage become more important. In order to meet these required availability limits, maintenance represents a key function as low MTTR and high MTBF values depend on systematic maintenance measures. Looking at maintenance policy in today's industry, the responsibility for maintenance is not only the duty of the service department but also a task of the machines' operators, who can be trained for minor maintenance tasks. The division of the responsibilities between maintenance experts and operators depends on the complexity of the respective tasks.



**Keywords**:

Machine Tool, Maintenance, Service Engineering


## 1 INTRODUCTION AND MOTIVATION

Increasing costs for modern production equipment oblige operators to use their machines most efficiently [1]. From a technical point of view, availability is key in offering great potential [2, 3]. Availability could potentially be increased by carrying out regular and preventive maintenance activities in order to avoid machine downtimes [4].

## 2 OBJECTIVES

The project "Maintenance-friendly machine tools – simple and robust maintenance activities to increase availability" aims at increasing machine tool availability by adapting maintenance activities and specific maintenance intervals to operating conditions. Availability can thus be improved by increasing MTBF (Mean Time Between Failures) for maintenance activities and by reducing MTTR (Mean Time To Repair) for servicing and repair activities (figure 1). This leads to a more efficient outcome of maintenance activities and allows for the use of TPM (Total Productive Maintenance) [5, 6].

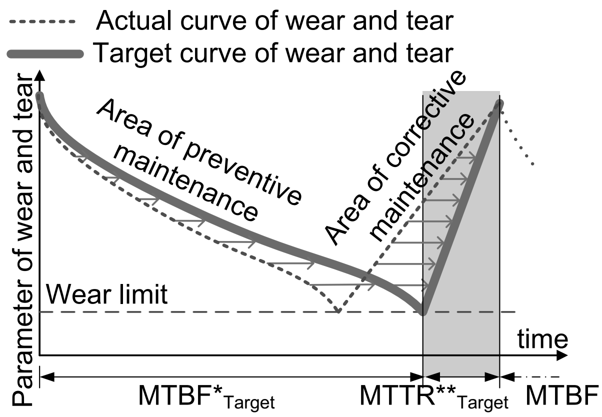


Figure 1: Objectives.

## 3 APPROACH

First of all, a modularisation approach for machine tools will be developed which takes into account how much effort is needed to carry out preventive and corrective maintenance activities for relevant components. This allows us to assess individual maintenance activities using the index for maintenance friendliness (IMF). The algorithm for the identification of collateral components (AIC) identifies components whose early replacement within upcoming maintenance activities is reasonable from an economic point of view. IMF and AIC were implemented into a software environment in order to simplify the application of these two methods. A detailed analysis of machine downtime causes during operation allows for the adaptation of the manufacturer's maintenance instructions to the respective operating conditions. The resulting measures for optimising preventive and corrective maintenance activities and intervals will be implemented into the machine control software. Furthermore, constant inspections monitor machine state and provide the basis for the calculation of a corrective maintenance index continuously assessing their efficiency. This model of intelligent maintenance can systematically increase availability (figure 2).

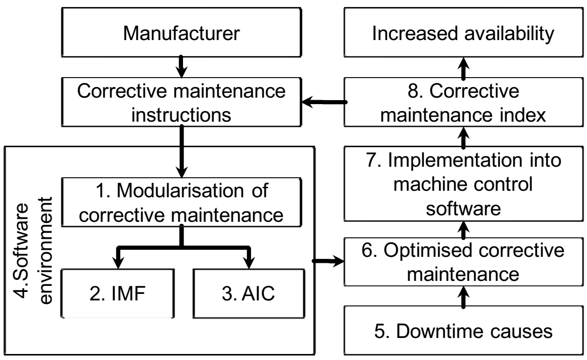


Figure 2: Approach.

### 3.1 Modularisation of maintenance activities

A modularisation approach for machine tools was elaborated which takes into account how much effort is needed to carry out preventive and corrective maintenance activities for relevant components [7]. Maintenance instructions that were provided by the manufacturer with delivery can thus be assigned to three machine tool levels: components, assemblies and the machine as a whole. The interdependence of components and assemblies in the event of replacement is taken into account. The time needed for identifying collateral components and replacing them at a subsequent point in time can thus be determined. The required time will either be determined by experts or, in terms of activities carried out regularly, by established time measurement methods such as MTM [8] or REFA (German Association for work design, industrial organisation and company development) [9].

### 3.2 Index for maintenance friendliness (IMF)

In order to identify potentials to increase maintenance friendliness, an index for corrective maintenance friendliness was elaborated (IMF) [10, 11]. The IMF allows for assessing the maintenance friendliness of an individual activity, component, assembly or the machine tool as a whole. The outcome of this assessment is a numerical value ranging from 0 % (maintenance-unfriendly) to 100 % (maintenance-friendly).

### 3.3 Algorithm for the identification of collateral components (AIC)

The AIC is used to identify so called collateral components. According to maintenance instructions, these components do not have to be replaced yet, but from an economic point of view it might be reasonable to replace them ahead of schedule when replacing a neighbouring component. The time needed for another dismantling of the assemblies sitting above these two components is calculated. Not only needs the primary time needed for carrying out the actual maintenance activity to be taken into account, but the secondary time as well. This is the time needed to remove components sitting above the elements to be replaced, such as covers for example. As opposed to [12, 13, 14], this approach takes the existing interdependence of components and assemblies into account when replacing them as part of regular maintenance activities. Another aspect to be taken into account when identifying collateral components is, besides additional time and staff needed, the respective remaining value of the component, which is left unused when replacing it ahead of schedule [7].

### 3.4 Software environment

Existing data from various sources are used for the application of this method (e.g. corrective maintenance instructions, spare parts lists, life-cycle specifications). A software environment was thus developed in MS Visio, in order to ensure a simple and rapid implementation of the steps presented above [15].

### 3.5 Downtime causes

Based on a field data analysis of machines' operating behaviour assemblies and components are identified according to [16], whose failure behaviour is key to machine availability. The aim is to improve the failure behaviour of these components by adapting corrective maintenance instructions to the operating conditions in place and thus to increase machine availability. Analyses of downtime causes based on these results and the identification of potential improvements provide, together with individual experiences of servicing and maintenance staff for the analysed machine type, the basis for optimised maintenance activities.

| ABC-analysis II: Frequency as per component | | ABC-analysis I: Total downtime as per component — A: serious / significant | B: medium | C: low |
|---|---|---|---|---|
| A | frequent | 1. Significant total downtime & Frequent occurence | 2. Medium total downtime & Frequent occurence | 3. Low total downtime & Frequent occurence |
| B | Not too frequent /several times | 4. Significant total downtime & Several donwtimes | 5. Medium total downtime & Several donwtimes | 6. Low total downtime & Several donwtimes |
| C | rare | 7. Significant total downtime & Rare occurence | 8. Medium total downtime & Rare occurence | 9. Low total downtime & Rare occurence |

Figure 3: Pareto approach.

The Institute of Production Science (wbk) developed an pareto chart based on 2D ABC analysis that can be used to introduce the results into a matrix and compare them. The ABC analysis categorises downtime along the horizontal axis and downtime frequency along the vertical axis (figure 3).

A component is considered to be significant in its impact on availability if it figures in at least one of the two ABC analyses in class A and in none of the two ABC analyses in class C. In the ABC 2D analysis this corresponds to the fields 1, 2 or 4.

| ABC-analysis II: Frequency [times] | | ABC-analysis I: Total downtime [h] — A: serious / significant | B: medium |
|---|---|---|---|
| A | frequent | ▪ Tooling system [3193,6h; 717]<br>▪ Machine control [2101,0h; 580]<br>▪ Turret [2053,1h; 326]<br>▪ Limit switch, sensor, proximity switch [1518,9h; 624]<br>▪ Feeding device [1919,4h; 316] | ▪ Chip conveyor [1121,9h, 318]<br>▪ Coolant supply [907,3h; 277] |
| B | Not too frequent, several times | ▪ Lines, fittings [1426,2h; 180] | |

Figure 4: Results of the pareto.

The results shown in figure 4 stem from 33 lathes of the same type that are in operation in a single company. In the following these are seen as a single machine with a single period of operation. The resulting overall period of operation is based on the sum of individual periods of operation and therefore amounts to 193.64 years. Due to this company's shift schedule the theoretic overall period of operation of all machines amounts to 145.40 years. The overall downtime of all assemblies (27259h, app. 3 years) equals 100%. This is the result of 5860 error messages.

### 3.6 Optimised maintenance

The identified components are assessed according to their potential for optimisation (figure 5). The aim is to increase the availability of the whole machine by optimising the maintenance of these components. Every component is thus examined for its potential for optimisation along the lines of the four basic measures of machine maintenance which are preventive maintenance, inspection, corrective maintenance and improvement [17]. Based on their potential for optimisation components are analysed on whether it is reasonable for example to optimise them rather within the framework of preventive maintenance or as part of other basic corrective maintenance activities. Components can be classified into electronic and mechanical components. Electronic components (machine control, limit switch, sensor, proximity switch) usually offer less potential for optimisation than mechanical components. One reason is the failure behaviour of electronic components which is often referred to as digital and which represents an unpromising starting point for improvement. In practice, this can often be ascribed to the insufficient predictability of downtimes.

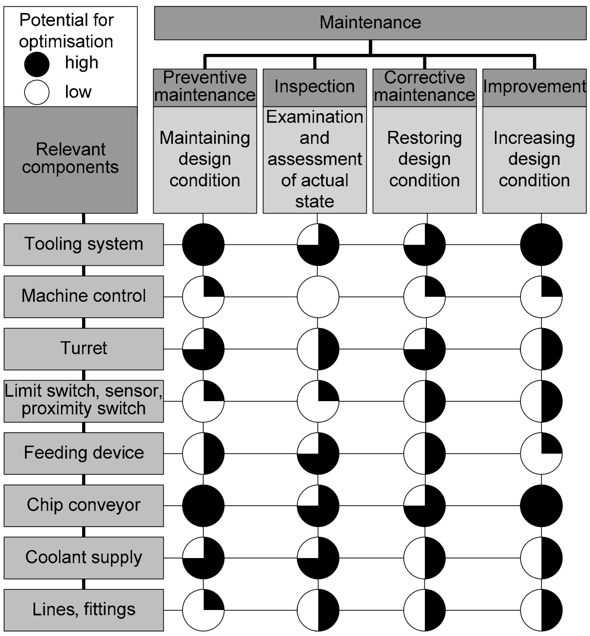


Figure 5: Potential for optimisation of relevant components.

The Institute of Production Science (wbk) developed a classification system in order to analyse the relevant components according to their downtimes. Potential causes for downtimes are restricted to the four most relevant downtime causes in terms of machine maintenance.

- **Soiling** is seen as part of an unintentional machine malfunction caused by a foreign object, e.g. chips.
- **Operating errors** include all downtime causes resulting form incorrect machine operation, e.g. incorrect CNC programming.
- **Consequential damage** occurs when downtime is caused by another component, e.g. by a defective pneumatic hose line (component: lines, fittings). This can lead to palletisation downtime (component: tooling system)
- **Tear and wear** includes surface abrasion of a component through frictional, grinding, rolling, smiting, scratching, chemical and thermal strain.
- Should error messages occur that cannot definitely assigned to a specific failure, these are assigned to the position "**no classification**". This position, however, should only be used in emergency cases.

A cluster analysis visualises the results (figure 6). The abscissa shows downtime causes, whereas the ordinate displays components. The frequency of downtime causes for each component (in percent) is indicated by bubble diameter. The operating behaviour documented above is based on a sufficient amount of field data and thus provides the basis for optimising existing instructions.

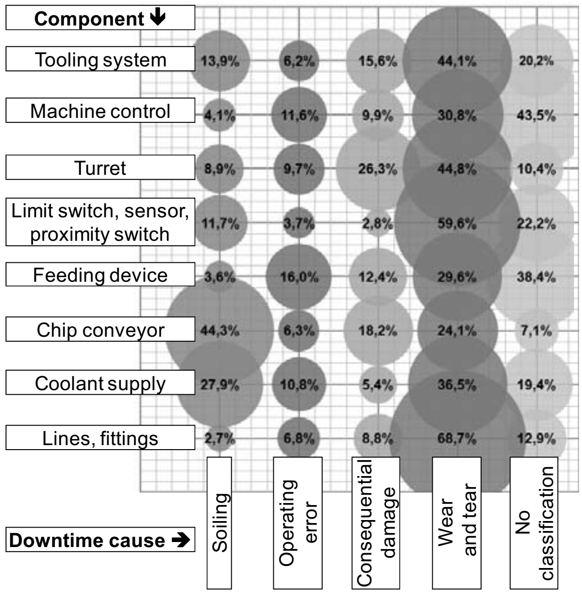


Figure 6: Downtime causes of the relevant components

The endeavour is to efficiently increase machine tool availability by adapting maintenance activities to operating conditions. The downtime causes "soiling" and "tear and wear" in particular can lead to changes in maintenance activities and intervals. Based on these findings and after consultation with the operator and the manufacturer, the respective instructions were elaborated. Optimised preventive and corrective maintenance instructions include the following information:

1. Activity: short description of the measure to be taken
2. Number: consecutive numbering of instructions

Table 1: Optimised preventive and corrective maintenance instructions sheet

<table>
<tr><td colspan="3" rowspan="3">1. Activity</td><td>2. Number</td></tr>
<tr><td>3. Classification</td></tr>
<tr><td>4. Machine operating mode</td></tr>
<tr><td>5. Interval</td><td>6. Duration</td><td>7. Number of persons</td><td>8. Service group</td></tr>
<tr><td>9. Caution!</td><td colspan="3">specific aspects of this instruction</td></tr>
<tr><td>10. Place</td><td colspan="3">place of activity to be carried out</td></tr>
<tr><td>11. Instruction</td><td colspan="3">1.</td></tr>
</table>

3. Classification: preventive maintenance, inspection or corrective maintenance [17]
4. Machine operating mode: Distinction of On – Set-up mode – Off
5. Interval: time specification for interval duration in min – h – a
6. Duration: time specification for duration in min – h – a
7. Number of persons: the number of persons needed for carrying out maintenance activities
8. Service group: in charge of maintenance activity depending on the level of difficulty: untrained employee, machine operator, maintenance staff (mechanics), maintenance staff (electrics), and hybrids [10].
9. Caution: consideration of specific framework conditions
10. Place: indication of the place where the activity is to be carried out
11. Instruction: description of the activity

The written instructions focus on a consistent documentation that is easy to understand for the employee in charge (table 1). Instructions may be completed by graphics and technical drawings.

### 3.7 Implementation into machine control software

In order to ensure that maintenance activities are carried out at the scheduled time, the optimised instructions were implemented into a software, which allows for a visualisation of maintenance instructions on the machine control screen. As part of the TPM maintenance concept, machine operators shall be increasingly included in machine maintenance by carrying out maintenance-friendly activities. As opposed to [18, 19], the Siemens user interface was designed in analogy to the 840D control interface (figure 7), in order to facilitate machine introduction and training for the user.

The user interface contains the same information as shown in table 1. In order to do justice to the TPM approach, a signal using the traffic light colours red – yellow – green was created which is shown on the control interface at all times within the machine operator's sight. This signal indicates, depending on the time required for issuing a maintenance warning for specific activities, which activities are to be carried out on the machine next.

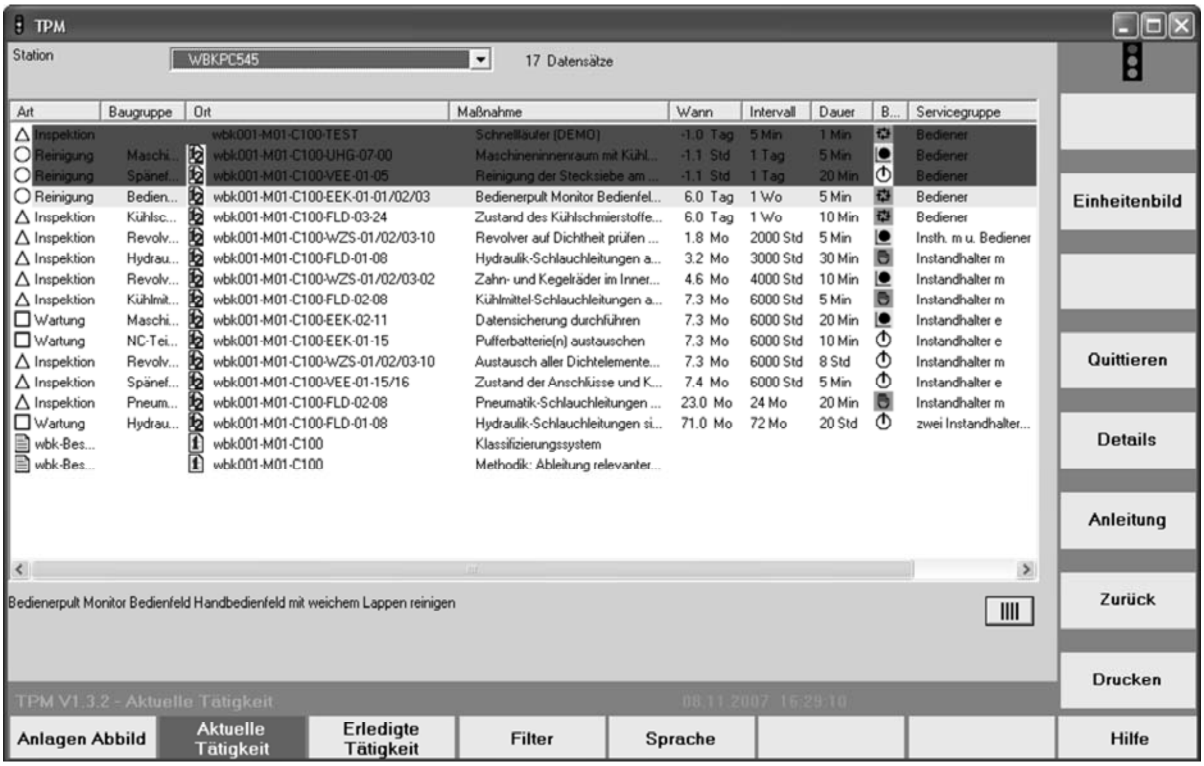


Figure 7: User interface Siemens MCIS TPM.

As long as the period of warranty applies, the manufacturer is particularly interested in the list of activities carried out on the machine in order to control the activities carried out by the operator in the event of damage. Furthermore, in analogy to individual service groups, user accounts are created in order to take corporate framework conditions into account. Among these figure for example adapting the interval and duration of an activity to the corporate framework conditions.

### 3.8 Corrective maintenance index based on operational behaviour

The efficiency of optimised preventive and corrective maintenance instructions in view of machine availability is assessed by an index. This represents a decisive step towards a reliable maintenance concept (RCM – Reliability Centered Maintenance) [20, 21]. The corrective maintenance index is the result of three essential criteria in order to assess the overall machine state:

- A. Availability: Machine availability is assessed for a specific period of time using downtime figures (i.e. by using production data acquisition systems such as SAP).
- B. Profitability: SAP determines machine tool costs for a specific period of time.
- C. Machine state assessment: the technical machine state is assessed as part of an inspection.

A scoring method for single criteria is used to determine the index. The targeted and continuous monitoring and assessment of the overall machine state enables us to carry out corrective maintenance activities no earlier than actually required, and this with a limited amount of risk (due to short machine monitoring intervals) and effort (i.e. through the targeted use of automated condition-monitoring-systems [22] in respective places). First observations, made by the wbk on a machine fitted with this software, provide very promising results.

## 4 SUMMARY

This article presented a method for intelligent machine tool maintenance. Based on a modularisation approach for corrective machine tool maintenance, the algorithm elaborated by the wbk enables us to assess machine tools' corrective maintenance friendliness with the IMF and to identify collateral components with the AIC. Both IMF and AIC were implemented into a software environment to allow for an easier application of both methods. Downtime causes of machine tools during operation were analysed in detail including the components that are relevant for machine tool availability. These figures provided the basis for adapting the corrective maintenance instructions issued by the machine manufacturer to the respective operational conditions and for optimising these instructions. These were implemented into the machine tool control software. The machine state is permanently monitored by inspection staff and its efficiency constantly assessed by the corrective maintenance index. The approach presented in this paper paves the way for systematically increasing overall machine tool availability by focusing on the targeted improvement of components relevant for availability.

## 5 ACKNOWLEDGMENTS

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