

## **An expert system machinability data bank (ESMDB) approach**

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### **ABSTRACT**

The selection of appropriate cutting parameters to ensure efficient and safe machining has long been a technological obstacle, especially to operation programmers and technicians and for those involved in manufacturing processes. Parameters selection is usually based on specialists, past experience or on recommended levels from conventional machinability handbooks. A machinability handbook lists machining operations, cross referenced with a broad list of material types to enable a machinist to find a starting point for speeds and feeds for machining. However, while these suit general or conventional machining and maintenance operations where many production objectives are sacrificed or considered unimportant, this is not the case in modern and advanced machining situations where a continuous in-process monitoring and control is an essential feature. The major objective of the current approach is to assess the selected cutting parameters considering the specifications of the available resources, production objectives and constraints. This is carried out through advanced detection, or prediction, of the levels of different outputs of the machining process, such as edge wear, cutting force, part surface quality and cutting vibration at any stage of its history. This is to avoid or minimize any possible failure consequences during the in-process stages that usually lead to the breakage of one or more of the manufacturing elements or which jeopardize the operator's safety.

Rather than retrieving and listing information, the proposed approach performs some experience and judgment procedures through pre-specified technically relevant rules and criteria to help the user make the decision whether to accept the proposed preliminary parameters or to modify them. The approach consists of two main features: time-varying mathematical models, and logic algorithm as well as a group of technical advisory rules. The expert system (ES) technique is used as a programming tool to manipulate data, to extract technical information from models according to the inputted data, and to provide users with some technical advisory and judgment information.

**Keywords:** Expert systems; In-process monitoring and control; Machinability data bank (base) systems; Time-varying mathematical models.

## INTRODUCTION

Machinability refers to the ease of machining or the relative resistance of a workpiece to deform during machining. According to the familiar technological rule, "not all cutting speed and feedrate combinations suit all work and tool materials". In other words, each process needs a certain, and maybe unique, machining condition (speed, feed, and depth of cut). At earlier stages, human experience and skill were always considered a major source of machinability data. Later, laboratory testing and experimentation were considered to be a trusted machinability reference. However, the continuous development in machining systems and the introduction of tougher and harder materials have demanded the necessity for data's direct and easy arrangement in what is called "Machinability Database Systems (MDS)". Machinability Handbooks (Metcut Research Associates 1980) represent a conventional approach by which judgment is attributed to data offered by the handbook used.

In the mid 60's and after the introduction of analogue computers to users, "Machinability Data Bank (MDB)" (Claycomb & Sullivan 1976) was developed. A computerized machinability data bank (CMDB) is a system for the efficient and fast selection of the most appropriate and economical machining parameters. Different types of CMDB were evolved, such as Data Storage and Retrieval; Generalized Empirical Equation Systems; and Mathematical Model Systems.

In Data Storage and Retrieval systems, machinability data are usually gathered from the shop floor, human skills, machinability handbooks and literature provided by manufacturers of tools, materials or machines. Collected information is stored in plain word-like computer files to be reviewed when the need arises. Although this approach produces an easier softwired machinability reference suitable for mass production where system consultation is less frequent, it is still far behind that required for today's sophisticated machining systems that usually require continuous monitoring and control actions. Additionally, it suffers from a lack of flexibility in data manipulation and in maintenance.

In the Generalized Empirical Equation systems, huge amounts of data are reduced to a general form which can be exploited in more visualized patterns such as charts, graphs and contours, or even monographs. A typical example of such system is the conventional (Taylor 1907), or the extended (Friedman & Field 1974) Taylor's equations. Difficulty in updating empirical equations, inaccuracy when it is applied to different machining combination from that for which it was intended, and excessive consumption of time and materials in experimentation usually degrade the performance of the system.

In the Mathematical Model type, an equation is built for a narrow and concentrated set of data. The difference between the Mathematical Model type and the Empirical one is that in the former, the developed model is more concise

and compact in that it closely matches and represents a pre-specified domain of operating parameters. Generally, if approximate parameters are required, the Empirical Equation may be used. More precise outcomes, however, can be obtained if a mathematical model type is manipulated instead. Balakrishnan & DeVries (1983) claimed that, in contrast to the empirical type, maintenance of the mathematical model type is simple since the recommended cutting conditions are only indirectly related to the data through the coefficients' values. Therefore, an experienced engineer need not perform sophisticated maintenance and suitable formulation software for someone less experience may do the task.

However, there are still some unsolved problems that affect the development of a practical and universal approach. Some of the common problems are:

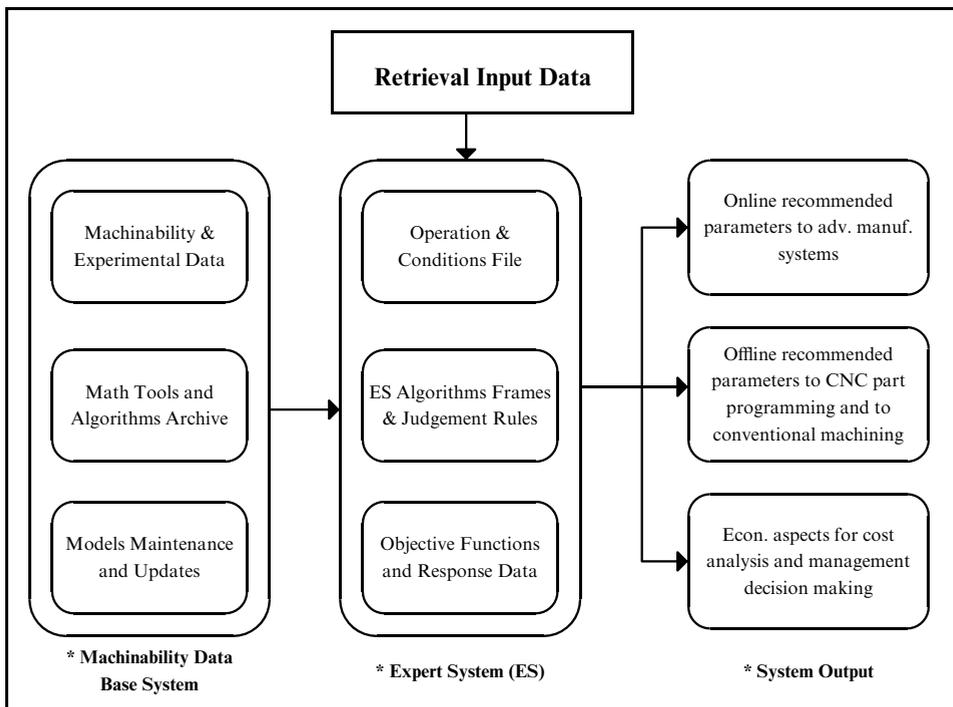
- The extent of applicability concerns the validity of the developed fixed-variable models to be used in actual time-varying process parameters. These models provide machinability information data in the forms of recommended initial values of feed, speed, and depth of cut to start with. As machining goes on within the initial recommended parameters, wear develops on tool edges and it is escalated by the inherent friction and high temperature. This violates expected nominal values of almost all machining outputs (responses) such as cutting forces and consumed power, surface finish and dimensional accuracy, and system dynamic characteristics and machining stability (Oraby & Hayhurst 1991). Unfortunately parameters modification at this late stage is impossible without a sophisticated in-process and adaptive control techniques. This fact narrows the validity of the conventional techniques so that they are applicable only to the selection of the theoretical initial parameters where any further variability cannot be detected, causing enormous practical problems.
- Further response variability emerges when the same tool is employed in successive operations with different cutting parameters. In such a situation, tools wear in different attitudes leading to a qualitative and quantitative variability of almost all process outputs (Oraby 1959). Time-varying models, therefore, are necessary as a prediction scheme to extract a global process profile that provides information about all possibilities.
- There is a lack of adaptability with advanced manufacturing systems and in-process monitoring techniques. In Computer Numerical Control (CNC) part programs, speed and feed once selected are never altered, whatever the variation in system performance. This is due to the absence of an on-line interface between the system and the machinability data source. This is required in order to facilitate the newly developed adaptive control (AC) systems in which speed and feed are continuously in-process modified to suit any emerged system variability. However, these systems are always characterized by their high cost, in addition to inherent instrumentation

complication and inaccuracy when they are used in a hostile machining environment. Therefore, an offline adaptive approach is proposed here to achieve some of the in-process system tanks and, at the same time, to avoid some of its problems in terms of replacing some hardware with a softwired routine with low level computing language.

Generally, more effort and elaborate searches are required before an integrated, universal, and technically accepted machinability data approach is reached. The current work is an attempt to contribute to the problem via the use of time-varying mathematical models with an expert judgment system.

### EXPERT SYSTEM BASED MACHINABILITY DATA BANK

The main object of the current approach is to supply users within the design stage with machinability information about process behaviour during the incutting stage. Moreover, the approach is set to generate simultaneous technical judgments according to pre-specified practical rules and criteria to assist in the early determination of the best operating parameters so as to achieve production objectives under system constraints. Figure 1 indicates the main structure of the proposed approach where it consists of three related and associated stages:



**Fig.1.** Machinability Data System Based on Expert System Shell

### i) Machinability Data Base System

This stage involves the performance of three main tasks. First, data are gathered from different possible practical sources such as laboratory experiments, human experience, machinability handbooks, shop floor performance, and recommended data by tool and materials manufacturers.

Second, data are reduced to time-varying mathematical models in which machining responses such as cutting forces, tool wear and tool life, system dynamic characteristics, surface roughness, etc. are related to main machining parameters: cutting speed ( $V$ ), feed ( $F$ ), and depth of cut ( $d$ ), in addition to the cutting time ( $t$ ). Moreover, some responses are related to each other to detect their mutual interaction. Appropriate formulation tools have reduced the number of testing specimens (Oraby & Hayurst 1991). Non-linear regression analysis using the SPSS Ver. 10 computer program (Barr *et al.* 1990) is used to develop time-varying models in the general forms:

$$R(t) = \beta_0 V^{\beta_1} F^{\beta_2} d^{\beta_3} t^{\beta_4} \quad (1)$$

or;

$$R(t) = \alpha_0 V^{\alpha_1} F^{\alpha_2} d^{\alpha_3} + \beta_0 (W)^{\beta_1} t^{\beta_2} \quad (2)$$

where ( $R$ ) is the instantaneous level of process output (response) at any time interval ( $t$ ), and ( $W$ ) is instantaneous wear level while ( $\alpha$ 's) and ( $\beta$ 's) are the model coefficients to be estimated using available data in association with non-linear fitting procedures. Information about workpiece and tool specifications in addition to testing design and used time-varying models are listed in Appendix I. More details can be found in Orgby & Hayhurst (1991).

### ii) Expert Systems (ES)

One of the most important developments in today's technology is the "Artificial Intelligence" (AI) approach. AI is a part of computer science dealing with designing intelligent computer systems, that is, systems that exhibit the characteristics associated with intelligence in human behaviour - understanding languages, learning, ability of reasoning, solving problems, providing logical decision making and so on (Jackson 1999, and Barr *et al.* 1990).

Among the several technological implementations of AI is the expert system (ES) technique. The term "expert system" is often applied today to any system that uses "expert system technology". This technology may include special

languages and programs designed to aid in the development and the execution of an ES (Giarratano & Riley 1998, Skott *et al.* 1991, Waterman 1985, and Almeshai 2000). The basic concept of ES is that the user supplies facts or information to the system, and then receives expert advice in response.

In order to achieve more strategic flexibility, an expert system shell is found most appropriate. A language called Flex (SPSS Manual, Flex Expert system Toolkit 1996, and Win-Prologtt Reference 1995) is selected to perform the proposed approach. Such an ES shell offers the required capability as well as ease of use and compatibility. In addition, since it is developed from Prolog, the user can use Prolog syntax while coding in the Flex language. This flexibility gives the advantages of both languages. In addition, it runs under Microsoft Windows<sup>TM</sup>.

Generally, the shell is arranged as several files that can execute a step-by-step procedure until the programming stage reaches a satisfactory stage. As shown by Fig. 2, the proposed expert system utilizes a forward chaining inference scheme that starts by getting initial values of the operating parameters from conventional machinability sources in terms of cutting speed ( $V$ ), feed ( $F$ ) and depth of cut ( $d$ ) as well as information about work diameter ( $D$ ). These parameters are validated at any interval ( $t$ ) as the ES algorithm works away through the time varying mathematical models (Appendix I), and judgment rules (Table 1). While models provide information about the expected level of process output, judgment rules make available to the user help, technical warnings and suggestions. At this consultation session it is up to the user to take a decision whether to go on with the selected parameters or not considering data obtained from the ES system in association with process objectives and constraints. Process objectives are usually for minimizing tool wear and its rate (maximizing tool life); improving surface quality grade, ensuring the system stability state state or even maximizing the metal removal rate through feed and speed. Process constraints are usually the maximum allowable force and consumed powder and the wear criterion limit. However, different weights may be attributed to process objectives in accordance to general production circumstances.

Technical judgment rules (Table 1), play an important role to help the qualified user take the appropriate decision whether or not to modify the presumed cutting parameters. Such a user has to be able to interpret the information generated by the ES algorithm and extract the most significant data he needs from the generated massive amount of information. Advanced programming and computing skills are not required.

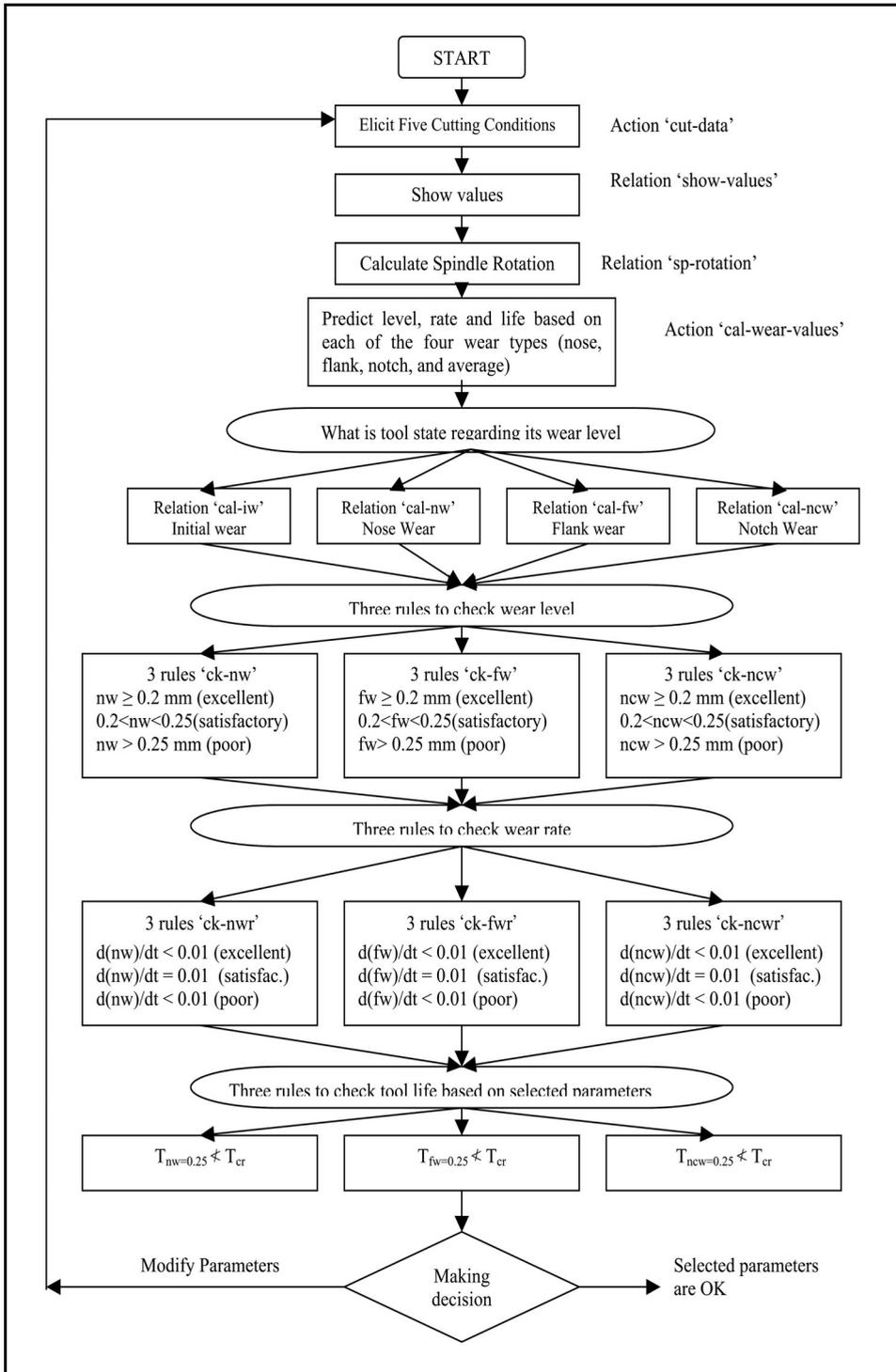


Fig.2. Sample schematic diagram for ES system for tool wear

**Table 1.** Used technical rules, judgment criteria, and constraint limits

Process Response	Rule Definition & Relation	Limits and Constraints
Tool Wear(W), Wear Rate [d(W)/dt] and Tool Life (T)	* $d(W)/dt < 0.01$ mm/min * $W \geq 0.2$ mm (Excellent) * $0.2 < W (0.25)$ (Satisfactory) * $W > 0.25$ mm (Poor)	$W_{cr} \neq 0.25$ mm $T_{0.25} \neq T_{cr}$
Cutting Forces (F)	* $d(F)/dt < 5$ N/min	$F(t) \neq 2F_i$
Surface Roughness (Ra)	* $Ra < 0.5$ $\mu$ m (Fine) * $0.5 < Ra < 1.0$ $\mu$ m (Finish) * $1.0 < Ra < 2.0$ $\mu$ m (Semi Finish) * $2.0 < Ra < 3.0$ (Rough)	$Ra > 0.4$ $\mu$ m (Inaccurate)

A sample schematic diagram of the proposed ES system regarding tool wear is illustrated in Fig. 2. The consultation session starts with cut-data action where five pop-up questions have to be answered by the user. These include three questions about initial levels of parameters - speed (V), feed (F), and depth of cut (d), another regarding workpiece configurations represented by its diameter (D) in addition to the cutting instance (t) at which the process is to be checked (t). However, in order to get useful practical information, the selected time should be related to the value of total machining time or the completion point, since it is expected to have the most adverse conditions. This is important if the use of a single edge is a compulsory objective or if the "one product one setting" rule is not to be sacrificed. A step is followed to list the inputted data via the relation "show-values" to confirm that they are the intended parameters. This is followed by the calculation of the recommended spindle speed via "sp-rotation" relation and according to the inputted speed and workpiece diameter. Then system predicts the levels of the different wear types on the cutting edge after interval (t). This is done via the linked time-varying wear models.

At this point the data base stage ends and the expert stage begins considering the specified technical rules (Table 1), where three interrelated rules are applied:

- 1 - to compare predicted wear levels with the criterion of allowable standard values,
- 2 - to examine wear attitude to ensure that the selected parameters do not lead to escalated wear rate, and
- 3 - to ensure that the predicted tool life based on the selected parameters is well within that specified by manufacturers or researchers.

Accordingly, the selected cutting parameters are either to be approved or modified. Similarly, procedures continue processing other responses-force, roughness, and vibration-ending with a complete run. At this stage, the overall assessment is carried out to decide whether to accept or modify parameters. Although proposed judgment rules (Table 1) may help in this modification procedure, human skills are also required, as will be explained later. The entire algorithm format is shown in Appendix II.

### OUTPUT, RESULTS AND DISCUSSION

An output example is shown in Table 2 where it begins by listing the input data, fed interactively by the user, along with technical data and specifications of tool and workpiece for which the mathematical models were developed. This is followed by the calculation of the recommended spindle speed. Next, wear levels at the different edge sites are predicted and assessed at the cutting time of 20 minutes using the relevant models (1-5) in Appendix I-iv-a. Results judgment is performed based on technical rules specified in Table 1 to indicate how close the developed wear level is to the criterion value of 0.25 mm. Moreover, wear increase percentage is considered as an indication of the relative wear progress:

$$W\% = \left[ \frac{W_t - W_0}{W_0} \right] \tag{3}$$

**Table 2.** Output from MDBES system

<b>A: System Input Data</b>	
Cutting speed is = 100 m/min	
Feed rate is = 0.25 mm/rev	
Depth of Cut is = 2 mm	
Cutting Time is = 20 min	
Workpiece Diameter is = 100 mm	
Tool: Multi-Coated Carbide Inserts SPUN 120312	
-Sandvik GC435- [6 deg , 5 deg , 0 , 60 deg , 90 deg]	
Workpiece: Alloy Steel 709M40	
<b>B: Proposed Spindle Speed - N -</b>	
Spindle Rotation-N- is = 318 rpm	
<b>C: Wear Response</b>	
<b>i) Wear levels at specified cutting time</b>	
Nose wear - NW - = 0.2219 mm	Rate at satisfactory level
Flank wear - FW - = 0.1923 mm	Rate at excellent level
Notch wear - Ncw - = 0.1875 mm	Rate at excellent level
Initial Wear - W <sub>0</sub> - = 0.1116 mm	
Average Wear - Aw - = 0.1921 mm	

**Table 2.** Output from MDBES system (cont'd)

<p><b>ii) Wear percentage increase</b></p> <p>Nose Wear percentage is = 98.84 %            Flank Wear percentage is = 72.31 %            Notch Wear percentage is = 68.01 %            Average Wear percentage is = 72.13 %</p>
<p><b>D: Wear Rate Response at Specified time</b></p> <p>Nose wear rate - NW<sub>r</sub> - = 0.0055 mm/min      Rate at excellent level            Flank wear rate - FW<sub>r</sub> - = 0.004 mm/min      Rate at excellent level            Notch wear rate - Nc<sub>wr</sub> - = 0.0038 mm/min      Rate at excellent level            Average wear rate- Aw<sub>r</sub> - = 0.004 mm/min      Rate at excellent level</p>
<p><b>E: Tool Life Response</b></p> <p>TOOL LIFE AT A CRITERION WEAR LEVEL OF 0.25 mm            TOOL LIFE with respect NOSE WEAR is - T<sub>nw</sub> = 64.08 min            TOOL LIFE with respect FLANK WEAR is - T<sub>fw</sub> = 143.01 min            TOOL LIFE with respect NOTCH WEAR is - T<sub>nw</sub> = 149.02 min            TOOL LIFE with respect AVERAGE WEAR is - T<sub>aw</sub> = 81.06 min            * Suggestion - check manufacturer specifications for individual wear</p>
<p><b>F: Cutting Force Response</b></p> <p><b>i) INITIAL VALUES AT ZERO WEAR-SHARP EDGE</b></p> <p>Initial Force in X axis - F<sub>xi</sub> - is = 421 N            Initial Force in Y axis - F<sub>yi</sub> - is = 1265 N            Initial Force in Z axis - F<sub>zi</sub> - is = 399 N            Initial Resultant Thrust Force - F<sub>xzi</sub> - is = 580 N</p> <p><b>ii) Instantaneous values of force components at the specified time</b></p> <p>Feed Force - F<sub>x</sub> - is = 507 N            Power -Main- Force - F<sub>y</sub> - is = 1356 N            Radial Force - F<sub>z</sub> - is = 521 N            Thrust Force - F<sub>xz</sub> - is = 728 N</p> <p><b>iii) Rate of change of force values at the specified time</b></p> <p>Rate of increase of Feed Force - F<sub>x/t</sub> - is = 4.3 N/min Excellent machining            Rate of increase of Power Force - F<sub>y/t</sub> - is = 4.55 N/min Excellent machining            Rate of increase of Radial Force - F<sub>z/t</sub> - is = 6.1 N/min Good machining            Rate of increase of Thrust Force - F<sub>xz/t</sub> - is = 7.4 N/min Good machining</p>
<p><b>G: Workpiece Initial Surface Roughness</b></p> <p>Initial Surface Roughness -RI- is = 3 micron rough machining            Surface Roughness at the specified time ability -RA- is = 3 micron            The RA value given shows a fair level - rough machining -</p>
<p><b>H: Cutting Vibration Response</b></p> <p>EXPECTED VIBRATION LEVEL AT THE CUTTING VICINITY AT PRE-SPECIFIED TIME [WITH RESPECT TO TOOL NATURAL FREQUENCY VALUE ]</p> <p>Initial Amplitude value is - A<sub>ci</sub> - = 220125.5593            Critical Amplitude is - Acc - = 568316312387840</p>

where  $W_t$  is the instantaneous wear at time (t) while ( $W_0$ ) is the initial wear. Results indicate that the nose area is the most affected followed by flank area and finally notch. Since the nose area usually governs the workpiece dimensional accuracy and quality, it is up to the user to consider the consequences if dimensional accuracy is one of the process priorities. More wear results and judgments are produced in terms of wear rate ( $dW/dt$ ) and expected tool life ( $T_{0.25}$ ). Practical considerations to assess wear and its rate are usually associated with edge per capita, part dimensional accuracy, nature of the process - continuous vs, interrupted, etc.

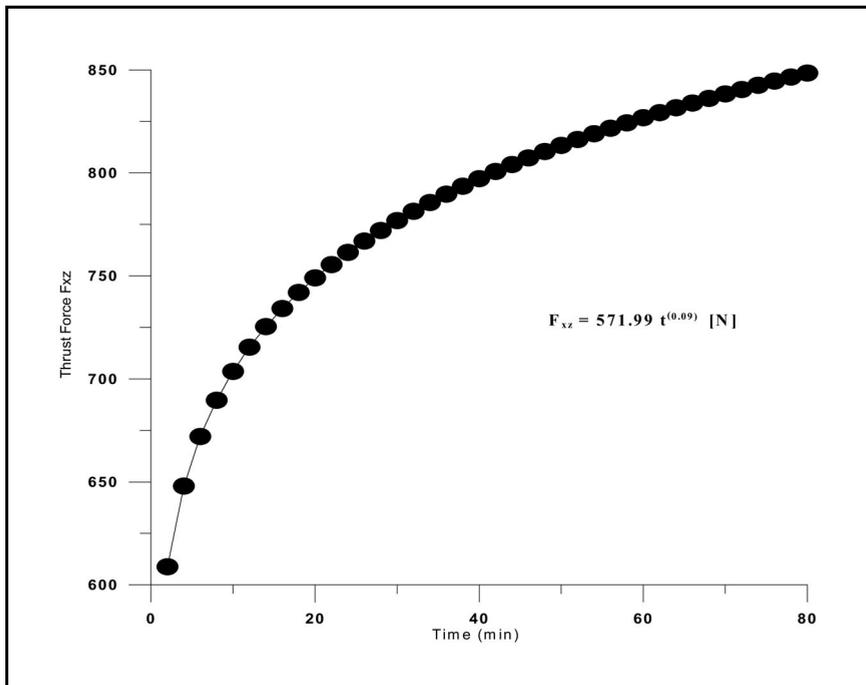
Procedures continue to predict and analyze the resulting cutting forces response. Forces estimation importance stems from the fact it is a crucial constraint that determines system safety and power requirements. In most situations, force is wear dependent, which is characterized by its variability as shown by the results (Table 2, section F). There is always a large deviation between force value at time (t) and that representing the initial state when the tool is sharp. This may justify the use of the time-varying models instead of conventional data base machinability approaches that use the fixed-variable (initial) models. Figure 3 signifies the topic where the deviation history of the thrust force  $F_{xz}$  is predicted throughout the full tool life span based on the case under study (Table 2). This is based on the following combined model:

$$\begin{aligned}
 F_{xz} &= 55354V^{(-0.484)}F^{(0.236)}d^{(0.715)}t^{-0.173}AW^{(1.099)} \\
 &= [55354V^{(-0.484)}F^{(0.236)}d^{(0.715)}t^{(-0.173)}] \\
 &\times [.00762V^{(0.577)}F^{(0.168)}d^{(0.248)}t^{(0.245)}]^{(1.099)} \\
 &= 260.164V^{(0.15)}F^{(0.42)}d^{(0.98)}t^{(0.09)} \\
 &= 571.99t^{(0.09)} \tag{4}
 \end{aligned}$$

As shown by Fig. 3, an approximate 40% increase in the force value resulted at the end of tool life, and it is clear that process design based on fixed models may jeopardize both operator and machine safety in addition to having possible economic consequences.

Also, this approach presents some information and judgment about force performance and its rate where process performance is judged through force rate of increase. Also, a limiting point for a firm rejection of parameters is when force value exceeds twofold of its initial value.

More information about other cutting responses are generated by the system as indicated in Table 2 for surface roughness (section G), and cutting vibration, (section H). A comparison should be made between initial and final values, and a technical decision is taken accordingly.



**Fig.3.** Thrust force variation along tool life span

Although it is not a system necessity, a technically qualified user is preferred in the modification stage where basic human knowledge is needed. Rules governing the interrelation and the correlation between each of the operating parameters and the process response can reduce computation time. For instance, at lower wear levels, cutting force is in direct proportion to feed and depth, while it is not affected by speed. Attitude changes at higher wear levels where force is related directly to speed where friction prevails. An almost opposite attitude is expected for tool wear and its life. However, workpiece surface roughness is found (in a previous study by the authors) to improve as wear increases. Therefore, in order to get faster convergence of the system, logical suggestions are required at the modification stage.

Generally, the proposed approach provides users with an advance simultaneous overview of the process before it begins. Obtained information helps in the process performance optimization through the selection of the most appropriate cutting parameters and in accordance to its objectives and constraints.

The proposed system can be updated easily to include further relevant data and models of other responses such as cutting temperature, acoustic emission, residual stresses and subsurface damage, etc.

## CONCLUSIONS

An offline adaptive system in the form of a machinability data base approach is proposed bearing in mind the assessment of the overall process performance throughout its different stages: initial, customized, and final. The main object is the selection of the proper parameters that usually save cutting edge, increase productivity, increase safety levels, improve part surface quality, and minimize machining via reducing the stop intervals.

Time-varying mathematical models in association with an interactive expert system strategy is arranged to establish an integrated machinability software by which much of interrelated and simultaneous technical information is generated. Many consulting rules and judgment criteria are included to assist in the evaluation stage where the most appropriate cutting parameters are selected.

Compatible sets of computer programs and ready computational packages, such as SPSS, FLEX, and PROLO formats, could improve a system's response time and, therefore, its ability to be linked to an integrated adaptive control system by which cutting parameters are selected on-line and modified according to process behaviour.

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## APPENDICES

## Appendix I: Experimental Data

- i - **Workpiece:** En19 (hardened and alloy steel 709M40) with 355HV hardness, 933 N/mm<sup>2</sup> tensile stress, and 610 N/mm<sup>2</sup> shear stress.
- ii - **Tool:** Sandvik GC435 - SPUN 12 03 12 multi-coated carbide inserts.
- iii - **Cutting parameters:**

Test No.	Speed (V) m/min	Feed (f) mm/rev	D.O.C (d)mm
1	72	0.12	2.00
2	145	0.3	2.00
3	145	0.12	2.50
4	72	0.30	2.50
5	104	0.20	2.25
6	104	0.20	2.25
7	145	0.12	2.00
8	72	0.30	2.00
9	72	0.12	2.50
10	145	0.30	2.50
11	104	0.20	2.25
12	104	0.20	2.25
13	206	0.20	2.25
14	50	0.20	2.25
15	104	0.20	2.25
16	104	0.60	2.25
17	104	0.06	3.00
18	104	0.20	1.50
19	206	0.20	2.25
20	50	0.20	2.25
21	104	0.60	2.25
22	104	0.06	2.25
23	104	0.20	3.00
24	104	0.20	1.50

iv - **Used time-varying models**a - **Wear Models**

$$\text{Initial Wear } (W_0) = 0.0093 V^{0.5133} F^{0.0059} d^{-0.0597} D^{0.0371} \quad [mm] \quad (1)$$

$$\text{Nose Wear } (NW) = 8.873 \times 10^{-3} V^{0.559} F^{0.174} d^{0.159} t^{0.259} \quad [mm] \quad (2)$$

$$\text{Flank Wear } (FW) = 7.205 \times 10^{-3} V^{0.585} F^{0.145} d^{0.165} t^{0.226} \quad [mm] \quad (3)$$

$$\text{Notch Wear } (NCW) = 9.08 \times 10^{-3} V^{0.506} F^{0.165} d^{0.325} t^{0.234} \quad [mm] \quad (4)$$

$$\text{Average Wear } (AW) = 7.62 \times 10^{-3} V^{0.577} F^{0.168} d^{0.248} t^{0.245} \quad [mm] \quad (5)$$

b - **Cutting Force Models**

$$\text{Initial Feeding Force Component } (F_{xi}) = 318.62 F^{0.33} d^{1.062} \quad [N] \quad (6)$$

$$\text{Initial Power Force Component } (F_{yi}) = 2344.9 V^{-0.064} F^{0.729} d^{0.993} \quad [N] \quad (7)$$

$$\text{Initial Radial Force Component } (F_{zi}) = 699.2 V^{-0.146} F^{0.359} d^{0.88} \quad [N] \quad (8)$$

$$\text{Feeding Force Component } (F_x) = 22248 V^{-0.45} F^{0.24} d^{0.93} t^{-0.15} \\ NW^{0.45} FW^{0.41} NCW^{0.13} \quad [N] \quad (9)$$

$$\text{Power Force Component } (F_y) = 8403.8 V^{-0.18} F^{0.63} d^{0.863} t^{-0.05} \\ NW^{0.18} FW^{0.15} NCW^{0.03} \quad [N] \quad (10)$$

$$\text{Radial Force Component } (F_z) = 6618 V^{-0.05} F^{0.25} d^{0.51} t^{-0.2} \\ NW^{0.69} FW^{0.41} NCW^{0.14} \quad [N] \quad (11)$$

$$\text{Thrust Force Component } (F_{xz}) = 47525 V^{-0.47} F^{0.24} d^{0.77} t^{-0.17} \\ NW^{0.54} FW^{0.41} NCW^{0.13} \quad [N] \quad (12)$$

c - **Combined Models**

$$\text{Average Wear - Force } (AW_F) = 0.132 F^{0.58} d^{0.35} + 0.35 \left[ \frac{F_z}{F_y} \right]^{1.147} \quad [mm] \quad (13)$$

$$\text{Nose Wear - Force - Vibration } (NW_{FAC}) = 1.36 \times 10^{-4} AC^{-0.015} F_{xz}^{0.847} t^{0.172} \\ V^{-0.423} F^{-0.088} d^{-0.987} \quad [mm] \quad (14)$$

## Appendix II

### (a) A Sample Program for Force Calculation

```

%Calculation of initial cutting forces
%-----
relation cal_i_fx
if lookup(q_frate, global, F)
and lookup(q_dcut, global, D)
and writet(' INITIAL VALUES AT ZERO WEAR -
SHARP EDGE-') and newl and newl and newl
and FX = 318.62 * (F^0.33) * (D^1.062)
and roundi( FX, FXI ) and writet(' Initial Force in X axis -
Fxi - is = ') and nwritet( FXI ) and writet(' N ')
and newl and newl
and new_slot(fxi, cut_cond, FXI).
relation cal_i_fy
if writet('something happened to the calculation of initial
cutting forces') .
relation cal_i_fy
if lookup(q_vcut, global, V)
and lookup(q_frate, global, F)
and lookup(q_dcut, global, D)
and FY = 2344.9 * (V^-0.064) * (F^0.729) * (D^0.993)
and roundi( FY, FYI ) and writet(' Initial Force in Y axis -
Fyi - is = ') and nwritet( FYI ) and writet(' N ')
and newl and newl
and new_slot(fyi, cut_cond, FYI).
relation cal_i_fz
if writet('something happened to the calculation of initial
cutting forces') .
relation cal_i_fz
if lookup(q_vcut, global, V)
and lookup(q_frate, global, F)
and lookup(q_dcut, global, D)
and FZ = 699.2 * (V^-0.146) * (F^0.359) * (D^0.88)
and roundi( FZ, FZI ) and writet(' Initial Force in Z axis -
Fzi - is = ') and nwritet( FZI ) and writet(' N ')
and newl and newl
and new_slot(fzi, cut_cond, FZI).
relation cal_i_fxz
if writet('something happened to the calculation of initial
cutting forces') .
relation cal_i_fxz
if lookup(fxi, cut_cond, FXI)
and lookup(fzi, cut_cond, FZI)
and FXZ = ((FXI^2) + (FZI^2))^0.5
and roundi( FXZ, FXZI ) and writet(' Initial Resultant
Thrust Force - Fxzi - is = ') and nwritet( FXZI ) and writet
(' N ')
and newl and newl
and new_slot(fxzi, cut_cond, FXZI)
and writet('-----')
and flash('Please check Initial Forces values') and newl and
newl.
relation cal_i_fxz
if writet('something happened to the calculation of Trust
force') .
%Calculation of cutting forces with time variable
%-----
relation force_fx
if lookup(q_vcut, global, V)
and lookup(q_frate, global, F)
and lookup(q_dcut, global, D)
and lookup(q_mtime, global, T)
and lookup(nwear, cut_cond, N)
and lookup(fwear, cut_cond, FW)
and lookup(ncwear, cut_cond, NCHW)
and writet(' RATE OF CHANGE OF FORCE
COMPONENTS TILL THE TIME SPECIFIED ') and newl
and newl and newl
and FXT = 22248 * (V^-0.45) * (F^0.24) * (D^0.93) * (T^-
0.15) * (N^0.45) * (FW^0.41) * (NCHW^0.13)
and roundi( FXT, TFX ) and writet(' Feed Force - Fx - is =
') and nwritet( TFX ) and writet(' N ')
and newl and newl
and new_slot(fx, cut_cond, TFX).
relation force_fy
if writet('something happened to the calculation of cutting
forces') .
relation force_fy
if lookup(q_vcut, global, V)
and lookup(q_frate, global, F)
and lookup(q_dcut, global, D)
and lookup(q_mtime, global, T)
and lookup(nwear, cut_cond, N)
and lookup(fwear, cut_cond, FW)
and lookup(ncwear, cut_cond, NCHW)
and FYT = 8403.8 * (V^-0.18) * (F^0.63) * (D^0.86) * (T^-
0.05) * (N^0.18) * (FW^0.15) * (NCHW^0.03)
and roundi( FYT, TFY ) and writet(' Power -Main- Force -
Fy - is = ') and nwritet( TFY ) and writet(' N ')
and newl and newl
and new_slot(fy, cut_cond, TFY).
relation force_fz
if writet('something happened to the calculation of cutting
forces') .
relation force_fz
if lookup(q_vcut, global, V)
and lookup(q_frate, global, F)
and lookup(q_dcut, global, D)
and lookup(q_mtime, global, T)
and lookup(nwear, cut_cond, N)
and lookup(fwear, cut_cond, FW)
and lookup(ncwear, cut_cond, NCHW)
and FZT = 66138 * (V^-0.5) * (F^0.25) * (D^0.51) * (T^-0.2)
* (N^0.69) * (FW^0.41) * (NCHW^0.14)
and roundi( FZT, TFZ ) and writet(' Radial Force - Fz - is
= ') and nwritet( TFZ ) and writet(' N ')
and newl and newl
and new_slot(fz, cut_cond, TFZ) .
relation force_fz
if writet('something happened to the calculation of cutting
forces') .
relation force_fxz
if lookup(q_vcut, global, V)
and lookup(q_frate, global, F)
and lookup(q_dcut, global, D)
and lookup(q_mtime, global, T)
and lookup(nwear, cut_cond, N)
and lookup(fwear, cut_cond, FW)
and lookup(ncwear, cut_cond, NCHW)
and FXZT = 47525 * (V^-0.47) * (F^0.24) * (D^0.77) * (T^-
0.17) * (N^0.54) * (FW^0.41) * (NCHW^0.13)
and roundi( FXZT, TFXZ ) and writet(' Thrust Force - Fxz -
is = ') and nwritet( TFXZ ) and writet(' N ')
and newl and newl
and new_slot(fxz, cut_cond, TFXZ)
and writet('-----')
and flash('Please check Cutting Forces values') and newl and
newl .
relation force_fxz
if writet('something happened to the calculation of resultant
thrust force') and newl .
%Calculating force rates
%Force rate in X direction
%-----
relation force_rate_fx
if lookup(fx, cut_cond, FX)
and lookup(fxi, cut_cond, FXI)
and lookup(q_mtime, global, T)
and writet(' RATE OF FORCE VALUES ') and newl and
newl and newl
and RFX = ( FX - FXI )/T

```

```

and roundt( RFX, FXR ) and writeit( ' Rate of increase of
Feed Force - Fx/t - is = ' ) and nwriteit( FXR ) and writeit( '
N/min ' )
and newl and newl
and new_slot(fxr, cut_cond, FXR) .
relation force_rate_fx
if writeit( 'something happened to the calculation of force rate
in x direction' ) and newl .
relation ck_rate_fx
if lookup(fxr, cut_cond, FXR)
and FXR = and writeit( ' Excellent machining ' ) and newl and
newl
and writeit('-----')
and newl and newl and newl .
relation ck_rate_fx
if lookup(fxr, cut_cond, FXR)
and FXR = and writeit( ' Good machining ' ) and newl and
newl
and writeit('-----')
and newl and newl and newl .
relation ck_rate_fx
if lookup(fxr, cut_cond, FXR)
and FXR = and writeit( ' Bad machining - Stop cutting
operation ' ) and newl and newl
and writeit('-----')
and newl and newl and newl .
relation ck_rate_fx
if writeit( ' Operation passes safe limits ' ) and newl and newl
and writeit('-----')
and newl and newl and newl .
%Force rate in Y direction
%-----
relation force_rate_fy
if lookup(fy, cut_cond, FY)
and lookup(fyi, cut_cond, FYI)
and lookup(q_mtime, global, T)
and RFY = ( FY - FYI )/T
and roundt( RFY, FYR ) and writeit( ' Rate of increase of
Power Force - Fy/t - is = ' ) and nwriteit( FYR ) and writeit( '
N/min ' )
and newl and newl
and new_slot(fyr, cut_cond, FYR) .
relation force_rate_fy
if writeit( 'something happened to the calculation of force rate
in y direction' ) and newl .
relation ck_rate_fy
if lookup(fyr, cut_cond, FYR)
and FYR = and writeit( ' Excellent machining ' ) and newl and
newl
and writeit('-----')
and newl and newl and newl .
relation ck_rate_fy
if lookup(fyr, cut_cond, FYR)
and FYR = and writeit( ' Good machining ' ) and newl and
newl
and writeit('-----')
and newl and newl and newl .
relation ck_rate_fy
if lookup(fyr, cut_cond, FYR)
and FYR = and writeit( ' Bad machining - Stop cutting
operation ' ) and newl and newl
and writeit('-----')
and newl and newl and newl .
relation ck_rate_fy
if writeit( ' Operation passes safe limits ' ) and newl and newl
and writeit('-----')
and newl and newl and newl .
%Force rate in Z direction
%-----
relation force_rate_fz
if lookup(fz, cut_cond, FZ)
and lookup(fzi, cut_cond, FZI)
and lookup(q_mtime, global, T)
and RFZ = ( FZ - FZI )/T

```

```

and roundt( RFZ, FZR ) and writeit( ' Rate of increase of
Radial Force - Fz/t - is = ' ) and nwriteit( FZR ) and writeit( '
N/min ' )
and newl and newl
and new_slot(fzr, cut_cond, FZR) .
relation force_rate_fz
if writeit( 'something happened to the calculation of force rate
in z direction' ) and newl .
relation ck_rate_fz
if lookup(fzr, cut_cond, FZR)
and FZR = and writeit( ' Excellent machining ' ) and newl and
newl
and writeit('-----')
and newl and newl and newl .
relation ck_rate_fz
if lookup(fzr, cut_cond, FZR)
and FZR = and writeit( ' Good machining ' ) and newl and
newl
and writeit('-----')
and newl and newl and newl .
relation ck_rate_fz
if lookup(fzr, cut_cond, FZR)
and FZR = and writeit( ' Bad machining - Stop cutting
operation ' ) and newl and newl
and writeit('-----')
and newl and newl and newl .
relation ck_rate_fz
if writeit( ' Operation passes safe limits ' ) and newl and newl
and writeit('-----')
and newl and newl and newl .
%Thrust Force rate
%-----
relation force_rate_fxz
if lookup(fxz, cut_cond, TFXZ)
and lookup(fxzi, cut_cond, FXZI)
and lookup(q_mtime, global, T)
and RFXZ = ( TFXZ - FXZI )/T
and roundt( RFXZ, FXZR ) and writeit( ' Rate of increase of
Thrust Force - Fxz/t - is = ' ) and nwriteit( FXZR ) and
writeit( ' N/min ' )
and newl and newl
and new_slot(fxZR, cut_cond, FXZR)
and flash('Please check Rate Forces values') and newl and
newl .
relation force_rate_fxz
if writeit( 'something happened to the calculation of force rate
in z direction' ) and newl .
relation ck_rate_fxz
if lookup(fxZR, cut_cond, FXZR)
and FXZR = and writeit( ' Excellent machining ' ) and newl
and newl
and writeit('-----')
and newl and newl and newl .
relation ck_rate_fxz
if lookup(fxZR, cut_cond, FXZR)
and FXZR = and writeit( ' Good machining ' ) and newl and
newl
and writeit('-----')
and newl and newl and newl .
relation ck_rate_fxz
if lookup(fxZR, cut_cond, FXZR)
and FXZR = and writeit( ' Bad machining - Stop cutting
operation ' ) and newl and newl
and writeit('-----')
and newl and newl and newl .
relation ck_rate_fxz
if writeit( ' Operation passes safe limits ' ) and newl and newl
and writeit('-----')
and newl and newl and newl .
%Calculating Average Wear
%-----
relation diff_wear
if writeit( ' DIFFERENT TOOL WEAR LEVELS AT
SPECIFIED CUTTING TIME ' ) and newl and newl and
newl

```

```

and lookup(nwear, cut_cond, NW)
and lookup(fwear, cut_cond, FLW)
and lookup(ncwear, cut_cond, NCHW)
and lookup(iwear, cut_cond, IW)
and writeit(' Nose wear - NW - = ') and nwriteit( NW ) and
writeit(' mm') and ck_nw
and writeit(' Flank wear - FW - = ') and nwriteit( FLW ) and
writeit(' mm') and ck_fw
and writeit(' Notch wear - Ncw - = ') and nwriteit( NCHW )
and writeit(' mm') and ck_ncw
and writeit(' Initial Wear - Wo - = ') and nwriteit( IW ) and
writeit(' mm') and newl and newl .
relation diff_wear
if writeit('where is the wear values') and newl.
relation avg_wear
if lookup(q_frate, global, F )
and lookup(q_dcut, global, D )
and lookup(fy, cut_cond, FY)
and lookup(fz, cut_cond, FZ)
and WA = (0.132 * (F^0.58) * (D^0.35)) + (0.35 * ((FZ/
FY)^1.147))
and roundt( WA, AW ) and writeit(' Average Wear - Aw - =
') and nwriteit( AW ) and writeit(' mm')
and newl and newl
and new_slot(aw, cut_cond, AW)
and writeit('-----')
and flash('Please check Wear values') and newl and newl .
relation avg_wear
if writeit('something happened to the calculation of average
wear') .
%Calculating Wear Percentage
%-----
relation nose_per
if lookup(nwear, cut_cond, N)
and lookup(iwear, cut_cond, IW)
and DNW = ((N - IW) / IW) * 100
and roundup ( DNW, NWD ) and writeit(' Nose Wear
percentage is = ') and nwriteit( NWD ) and writeit(' % ')
and newl and newl .
relation flank_per
if lookup(fwear, cut_cond, F)
and lookup(iwear, cut_cond, IW)
and DFW = ((F - IW) / IW) * 100
and roundup ( DFW, FWD ) and writeit(' Flank Wear
percentage is = ') and nwriteit( FWD ) and writeit(' % ')
and newl and newl .
relation nch_per
if lookup(ncwear, cut_cond, NC)
and lookup(iwear, cut_cond, IW)
and DNCW = ((NC - IW) / IW) * 100
and roundup ( DNCW, NCWD ) and writeit(' Notch Wear
percentage is = ') and nwriteit( NCWD ) and writeit(' % ')
and newl and newl .
relation avg_wear_per
if lookup(aw, cut_cond, AW)
and lookup(iwear, cut_cond, IW)
and DAW = ((AW - IW) / IW) * 100
and roundup ( DAW, AWD ) and writeit(' Average Wear
percentage is = ') and nwriteit( AWD ) and writeit(' % ')
and newl and newl
and writeit('-----')
and flash('Please check Wear Percentage values') and newl
and newl .
%Calculating Wear Rates
%-----
relation cal_nw_rate
if writeit(' WEAR RATE ACCELERATION VALUES AT
SPECIFIED CUTTING TIME ') and newl and newl and
newl
and lookup(nwear, cut_cond, NW)
and lookup(iwear, cut_cond, IW)
and lookup(q_mtime, global, T )
and RNW = (NW - IW) / T
and roundt( RNW, NWR )
and new_slot(nwr, cut_cond, NWR) .

relation cal_nw_rate
if writeit(' check Values of Nose Wear Rate ') and newl and
newl and newl .
%Checking NOSE WEAR RATE VALUE
%-----
relation ck_nwr
if lookup(nwr, cut_cond, NWR)
and NWR > 0
and NWR = 0.02
and NWR = 0.05
and NWR 0
and FWR = 0.02
and FWR = 0.05
and FWR 0
and NCWR = 0.02
and NCWR = 0.05
and NCWR 0
and AWR = 0.02
and AWR = 0.05
and AWR and writeit(' Rate at critical level ') and newl and
newl .
relation ck_awr
if flash('Dangerous level of AVERAGE wear rate, Stop the
cutting operation')
and writeit(' AVERAGE wear rate over the safe limit of 0.1 ')
and newl
and writeit(' At these cutting conditions the tool reached
dangerous level') and newl .
relation diff_wear_rate
if lookup(nwr, cut_cond, NWR)
and lookup(fwr, cut_cond, FLWR)
and lookup(ncwr, cut_cond, NCHWR)
and lookup(awr, cut_cond, AWR)
and writeit(' Nose wear rate - NWR - = ') and nwriteit( NWR
) and writeit(' mm/min') and ck_nwr
and writeit(' Flank wear rate - FWR - = ') and nwriteit(
FLWR ) and writeit(' mm/min') and ck_fw
and writeit(' Notch wear rate - Ncwr - = ') and nwriteit(
NCHWR ) and writeit(' mm/min') and ck_ncwr
and writeit(' Average wear rate- AWR - = ') and nwriteit(
AWR ) and writeit(' mm/min') and ck_awr and newl and
newl
and writeit('-----')
and flash('Please check Wear Rate values') and newl and
newl.
relation diff_wear_rate
if writeit('where is the wear rate values') and newl.
%Calculation of Amplitude values-Vibration of Nose Wear
%-----
relation force_fxz_life
if lookup(q_vcut, global, V )
and lookup(q_frate, global, F )
and lookup(q_dcut, global, D )
and lookup(tnwear, cut_cond, NWT)
and lookup(nwear, cut_cond, N)
and lookup(fwear, cut_cond, FW)
and lookup(ncwear, cut_cond, NCHW)
and FXZTL = 47525 * (V^-0.47) * (F^0.24) * (D^0.77) *
(NWT^-0.17) * (N^0.54) * (FW^0.41) * (NCHW^0.13)
and roundi( FXZTL, TFXZL )
and new_slot(fxztl, cut_cond, TFXZL) .
relation force_fxz_life
if writeit('something happened to the calculation of fxz tool
life') .
relation cal_ac_in
if lookup(q_vcut, global, V )
and lookup(q_frate, global, F )
and lookup(q_dcut, global, D )
and lookup(fxzi, cut_cond, FXZI)
and lookup(iwear, cut_cond, IW)
and IAC = (( 0.000136 * (FXZI^0.847) * (2^0.172) *
(V^0.423) * (F^-0.088) * (D^-0.987)) / IW)^(1/0.015)
and roundt( IAC, ACI ) and writeit(' Initial Amplitude
value is - AcI - = ') and nwriteit( ACI )
and newl and newl

```

```

and new_slot(acin, cut_cond, ACI) .
relation cal_ac_in
if writeit(' check Initial Amplitude calculation')
and newl and newl .
relation cal_ac_crit
if lookup(q_vcut, global, V )
and lookup(q_frate, global, F )
and lookup(q_dcut, global, D )
and lookup(tnwear, cut_cond, NWT)
and lookup(fxztl, cut_cond, FWT)
and VACC = (( 0.000136 * (FXZ^0.847) * (NWT^0.172) *
(V^0.423) * (F^-0.088) * (D^-0.987))/ 0.15)^(1/0.015)
and roundt( VACC, ACCV ) and writeit(' Critical
Amplitude is - Acc - = ') and nwriteit( ACCV )
and newl and newl
and new_slot(acc, cut_cond, ACCV)
and flash(' check Amplitude values') .
relation cal_ac_crit
if writeit(' check Critical Amplitude calculation')
and newl and newl .
relation show_final_data
if writeit(' Summary of all Expected - Predicted -
Machinability Data')
and newl and newl and newl
and lookup(q_vcut, global, V )
and lookup(q_frate, global, F )
and lookup(q_dcut, global, D )
and lookup(q_mtime, global, T )
and lookup(q_dwork, global, DW )
and lookup(tnwear, cut_cond, NWT)
and lookup(tfwear, cut_cond, FWT)
and lookup(tnchwear, cut_cond, NCHWT)
and lookup(tawear, cut_cond, AWT)
and lookup(fxi, cut_cond, FXI)
and lookup(fyi, cut_cond, FYI)
and lookup(fzi, cut_cond, FZI)
and lookup(fxzi, cut_cond, FXZI)
and lookup(fx, cut_cond, FX)
and lookup(fy, cut_cond, FY)
and lookup(fz, cut_cond, FZ)
and lookup(fxz, cut_cond, FXZ)
and lookup(fxr, cut_cond, FXR)
and writeit(' CS') and tab and writeit('FR') and tab and
writeit('DOC')
and tab and writeit('CT') and tab and writeit('WPD') and tab
and writeit('TLN') and tab and writeit('TLF') and tab and
writeit('TLNH') and tab and writeit('TLAW')
and newl and newl
and nwriteit( V ) and tab and nwriteit( F ) and tab and
nwriteit( D ) and tab
and nwriteit( T ) and tab and nwriteit( DW ) and tab and
nwriteit( NWT ) and tab
and nwriteit( FWT ) and tab and nwriteit( NCHWT ) and tab
and nwriteit( AWT )
and newl and newl and newl
and writeit(' Fxo') and tab and writeit(' Fyo') and tab and
writeit(' Fzo') and tab and writeit(' Fxzo')
and tab and writeit(' Fx') and tab and writeit(' Fy') and tab
and writeit(' Fz') and tab and writeit(' Fxz')
and tab and writeit(' Fxr')
and newl and newl
and nwriteit( FXI ) and tab and nwriteit( FYI ) and tab and
nwriteit( FZI ) and tab and nwriteit( FXZI )
and tab and nwriteit( FX ) and tab and nwriteit( FY ) and tab
and nwriteit( FZ ) and tab and nwriteit( FXZ )
and tab and nwriteit( FXR )
and newl and newl and newl .
relation show_final_data
if writeit(' Check Final Summary of Machinability Data')
and newl and newl and newl .
relation show_final_values
if lookup(fyr, cut_cond, FYR)
and lookup(fzr, cut_cond, FZR)
and lookup(fx zr, cut_cond, FXZR)
and lookup(nwear, cut_cond, NW)

```

```

and lookup(fwear, cut_cond, FW)
and lookup(ncwear, cut_cond, NCW)
and lookup(iwear, cut_cond, IW)
and lookup(aw, cut_cond, AW)
and lookup(nwr, cut_cond, NR)
and lookup(fwr, cut_cond, FR)
and lookup(ncwr, cut_cond, NCR)
and lookup(awr, cut_cond, AWR)
and lookup(tnwear, cut_cond, NT)
and lookup(tfwear, cut_cond, FT)
and lookup(tnchwear, cut_cond, NCT)
and lookup(tawear, cut_cond, AWT)
and lookup(aci, cut_cond, AIV)
and lookup(acc, cut_cond, ACV)
and tab and writeit(' Fyr') and tab and writeit(' Fzr') and tab
and writeit(' Fx zr')
and tab and writeit(' Nw') and tab and writeit(' Fw') and tab
and writeit(' New')
and tab and writeit(' Iw') and tab and writeit(' Aw')
and newl and newl
and tab and nwriteit( FYR ) and tab and nwriteit( FZR ) and
tab and nwriteit( FXZR )
and tab and nwriteit( NW ) and tab and nwriteit( FW ) and
tab and nwriteit( NCW )
and tab and nwriteit( IW ) and tab and nwriteit( AW )
and newl and newl and newl
and tab and writeit(' Nwr') and tab and writeit(' Fwr') and
tab and writeit(' Ncr') and tab and writeit(' Awr')
and tab and writeit(' Tn') and tab and writeit(' Tf') and tab
and writeit(' Tnc')
and tab and writeit(' Taw')
and newl and newl
and tab and nwriteit( NR ) and tab and nwriteit( FR ) and tab
and nwriteit( NCR ) and tab and nwriteit( AWR )
and tab and nwriteit( NT ) and tab and nwriteit( FT ) and tab
and nwriteit( NCT )
and tab and nwriteit( AWT )
and newl and newl and newl
and tab and writeit(' Ai') and tab and tab and writeit(' Ac')
and newl and newl
and tab and nwriteit( AIV ) and tab and tab and nwriteit(
ACV ) and newl and newl and newl .
relation show_final_values
if writeit(' Check Second Final Summary of Machinability
Data')
and newl and newl and newl .

```

## (b) A Sample Program for Results

```

%This part for performing cutting condition analysis
%-----
action cutting
stratm( TITLE, 'MACHINIBILITY DATA RESULTS')
and wcreate( result, text, TITLE, 0, 0, 600, 350, 0)
%do textpl %system display phase-1 message
and newl and writeit(' Machinability Response Data - Bank
System') and newl
and writeit(' -----') and newl and newl
and cut_data
and show_values
and sp_rotation
and cal_wear_values
and cal_wears_avg
and writeit(' C: Workpiece Initial Surface Roughness ') and
newl and newl and newl
and cal_surf_rough
and ck_sfrh
and cal_sr_variable
and ck_sfrhv
and writeit(' D: Cutting Force Response ') and newl and newl
and newl
and cal_cut_in_forces

```

```

and cutting_forces
and force_rates
and writeit(' E: Wear Propagation Response ') and newl and
newl and newl
and show_wear_values
and writeit(' F: Tool Wear Percentage Response ') and newl
and newl and newl
and cal_wear_percent
and writeit(' G: Wear Rate Response ') and newl and newl
and newl
and cal_wear_rates
and diff_wear_rate
and writeit(' H: Tool Life Response ') and newl and newl and
newl
and cal_tool_life
and newl and newl
and writeit('-----')
and newl and newl
and writeit(' I: Cutting Vibration Response ') and newl and
newl and newl
and cal_nw_vib
and writeit('-----')
and newl and newl
and writeit(' J: Summary Sheet ') and newl and newl and newl
and show_final_data
and show_final_values
and sum_short
%and check_forces
and ask_user_save and !.
%Gathering necessary cutting condition data
%-----
action cut_data
do ask_q_vcut
and do ask_q_frate
and do ask_q_dcut
and do ask_q_mtime
and do ask_q_dwork.
%Calculation of tool life
%-----
action cal_tool_life
do nw_tool_life
and fw_tool_life
and nchw_tool_life
and aw_tool_life.
%Calculating and Checking WEAR values
%-----
action cal_wear_values
do cal_nw
and cal_fw
and cal_new
and cal_jw.
%Calculation of initial Cutting Forces values
%-----
action cal_cut_in_forces
do cal_i_fx
and cal_i_fy
and cal_i_fz
and cal_i_fxz.
%Calculation of Cutting Forces values with time variable
%-----
action cutting_forces
do force_fx
and force_fy
and force_fz
and force_fxz.
%Calculation of Forces rates values with time variable
%-----
action force_rates
do force_rate_fx
and ck_rate_fx
and force_rate_fy
and ck_rate_fy
and force_rate_fz
and ck_rate_fz
and force_rate_fxz

and ck_rate_fxz.
%Show different wear values of cutting condition
%-----
action show_wear_values
do diff_wear
and avg_wear.
%Calculation of Wear percentage
%-----
action cal_wear_percent
do nose_per
and flank_per
and nch_per
and avg_wear_per.
%Calculation of Wear rates values with time variable
%-----
action cal_wear_rates
do cal_nw_rate
and cal_fw_rate
and cal_ncw_rate
and cal_aw_rate.
%Calculation of Nose Wear vibration values
%-----
action cal_nw_vib
do writeit(' EXPECTED VIBRATION LEVEL AT THE
CUTTING VICINITY AT PRE-SPECIFIED') and newl and
newl
and writeit(' TIME [ WITH RESPECT TO TOOL
NATURAL FREQUENCY VALUE ]')and newl and newl
and newl
and force_fxz_tlife
and cal_ac_in
and cal_ac_crit.
%Show values of cutting condition
%-----
relation show_values
if lookup(q_vcut, global, V )
and lookup(q_frate, global, F )
and lookup(q_dcut, global, D )
and lookup(q_mtime, global, T )
and lookup(q_dwork, global, DW )
and writeit(' A: System Input Data ') and newl and newl and
newl
and writeit(' Cutting speed is = ') and nwriteit( V ) and
writeit(' m/min ') and newl and newl
and writeit(' Feed rate is = ') and nwriteit( F ) and writeit('
mm/rev ') and newl and newl
and writeit(' Depth of Cut is = ') and nwriteit( D ) and
writeit(' mm ') and newl and newl
and writeit(' Cutting Time is = ') and nwriteit( T ) and
writeit(' min ') and newl and newl
and writeit(' Workpiece Diameter is = ') and nwriteit( DW )
and writeit(' mm ') and newl and newl and newl
and writeit(' Tool: Multi-Coated Carbide Inserts SPUN
120312') and newl and newl
and writeit(' -Sandvik GC435- [6 deg , 5 deg , 0 , 60 deg , 90
deg] ') and newl and newl
and writeit(' Workpiece: Alloy Steel 709M40 ') and newl
and writeit('-----
') and newl and newl
and flash('Please check Cutting Conditions').
relation show_values
if flash('Please check Cutting Conditions').
%Calculation of spindle Rotation value
%-----
relation sp_rotation
if lookup(q_vcut, global, V )
and lookup(q_dwork, global, DW )
and SP = (V * 1000) / (3.142 * DW)
and roundi( SP, N )
and writeit(' B: Proposed Spindle Speed - N - ') and newl and
newl and newl
and writeit(' Spindle Rotation-N- is = ') and nwriteit( N ) and
writeit(' rpm') and newl and newl and newl
and new_slot(spr, cut_cond, N)

```

```

and writeit('-----
') and newl and newl
and flash('Please check Spindle Speed Value') .
relation sp_rotation
if flash('Please check Spindle Rotation') .
%Calculation of Initial Workpiece Surface Roughness
%-----
relation cal_surf_rough
if lookup(q_vcut, global, V)
and lookup(q_frate, global, F)
and SF = 211.2356 * ((F * 10)1.093178) * (V-1.109572)
and roundi(SF, RI)
and writeit(' Initial Surface Roughness -RI- is = ') and
nwriteit( RI ) and writeit(' micron') and newl and newl and
newl
and new_slot(sfrgh, cut_cond, RI)
and writeit('-----
') and newl and newl
and flash('Please check Initial Surface Roughness Value') .
relation cal_surf_rough
if flash('Please check Initial Surface Roughness Value') .
%Rules that set to check initial surface roughness
%-----
relation ck_sfrh
if lookup(sfrgh, cut_cond, RI)
and RI = 1
and RI = 2
and RI = 3
and RI = 1
and SRV = 2
and SRV = 3
and SRV = and writeit(' The RA value given shows a bad and
inaccurate machining ') and newl and newl
and writeit('-----
') and newl and newl and newl .
relation ck_sfrhv
if writeit(' The RA value exceeded the limits set the surface
too rough for turning operation ') and newl and newl
and writeit('-----
') and newl and newl and newl .
%Calculation of TOOL LIFE values with respect to diffrent
wear locations
%-----
relation nw_tool_life
if lookup(q_vcut, global, V)
and lookup(q_frate, global, F)
and lookup(q_dcut, global, D)
and writeit(' TOOL LIFE AT A CRITERION WEAR
LEVEL OF 0.25 mm ') and newl and newl and newl
and T = ( 0.3 * (V-0.559) * (F-0.174) * (D-0.159) /
0.008873 )(1/0.259)
and roundup( T, NWT ) and writeit(' TOOL LIFE with
respect NOSE WEAR is - Tnw = ') and nwriteit( NWT ) and
writeit(' min')
and newl and newl
and new_slot(tnwear, cut_cond, NWT) .
relation nw_tool_life
if writeit('see the above relation for tool life nose wear') and
newl.
relation fw_tool_life
if lookup(q_vcut, global, V)
and lookup(q_frate, global, F)
and lookup(q_dcut, global, D)
and T = ( 0.3 * (V-0.585) * (F-0.145) * (D-0.165) /
0.007205 )(1/0.226)
and roundup( T, FWT ) and writeit(' TOOL LIFE with
respect FLANK WEAR is - Tfw = ') and nwriteit( FWT )
and writeit(' min')
and newl and newl
and new_slot(tfwear, cut_cond, FWT) .
relation fw_tool_life
if writeit('see the above relation for tool life flank wear') and
newl.
relation nchw_tool_life
if lookup(q_vcut, global, V)
and lookup(q_frate, global, F)
and T = ( 0.3 * (V-0.506) * (F-0.165) * (D-0.325) / 0.00908
)(1/0.234)
and roundup( T, NCHWT ) and writeit(' TOOL LIFE with
respect NOTCH WEAR is - Tncw = ') and nwriteit(
NCHWT ) and writeit(' min')
and newl and newl
and new_slot(tchwear, cut_cond, NCHWT) .
relation nchw_tool_life
if writeit('see the above relation for tool life notch wear') and
newl.
relation aw_tool_life
if lookup(q_vcut, global, V)
and lookup(q_frate, global, F)
and lookup(q_dcut, global, D)
and T = ( 0.3 * (V-0.577) * (F-0.168) * (D-0.248) / 0.00762
)(1/0.245)
and roundup( T, AWT ) and writeit(' TOOL LIFE with
respect AVERAGE WEAR is - Taw = ') and nwriteit( AWT
) and writeit(' min')
and newl and newl
and new_slot(tawear, cut_cond, AWT)
and flash('Please check TOOL LIFE values') and newl and
newl
and writeit(' * Suggestion check manufacturer specifications
for individual wear ') and newl and newl and newl .
relation aw_tool_life
if writeit('see the above relation for tool life average wear')
and newl.
%Calculation of NOSE WEAR
%-----
relation cal_nw
if lookup(q_vcut, global, V)
and lookup(q_frate, global, F)
and lookup(q_dcut, global, D)
and lookup(q_mtime, global, T)
and N = 0.008873 * (V0.559) * (F0.174) * (D0.159) *
(T0.259)
and roundt( N, NW )
and new_slot(nwear, cut_cond, NW) .
relation cal_nw
if writeit('something happened to the calculation of cutting
conditions') .
%Checking NOSE WEAR VALUES
%-----
relation ck_nw
if lookup(nwear, cut_cond, NW)
and NW > 0
and NW = 0.2
and NW = 0.28
and NW = 0
and F = 0.2
and F = 0.28
and F = 0
and NCHW = 0.2
and NCHW = 0.28
and NCHW = and writeit(' Rate at critical level ') and newl
and newl .
relation ck_ncw
if flash('Dangerous level of Notch wear, Stop cutting
operation')
and writeit(' Notch wear is over the safe limit of 0.3 At these')
and newl
and writeit(' cutting conditions the tool is at dangerous levels')
and newl .
%Calculating INITIAL WEAR
%-----
relation cal_iw
if lookup(q_vcut, global, V)
and lookup(q_frate, global, F)
and lookup(q_dcut, global, D)
and lookup(q_dwork, global, DW)
and WI = 0.0093 * (V0.5133) * (F0.0059) * (D-0.0597) *
(DW0.0371)

```

```

and roundt( WI, IW )
and new_slot(iwear, cut_cond, IW).
relation cal_iw
if writeit('something happened to the calculation of initial
wear').
relation cal_wears_avg
if lookup(nwear, cut_cond, NW)
and lookup(fwear, cut_cond, FLW)
and lookup(ncwear, cut_cond, NCHW)
and AVG = ( NW + FLW + NCHW ) / 3
and roundt(AVG,WAVG)
and new_slot(wearavg, cut_cond, WAVG).
relation cal_wears_avg
if writeit(' check the three avg wear calculation') and newl and
newl .
action sum_short
do writeit(' CS :Cutting Speed in mm / min ,') and tab
and writeit(' FR :Feed Rate in mm / rev') and newl
and writeit(' DOC :Depth of Cut in mm ,') and tab and tab
and writeit(' CT :Cutting Time in min') and newl
and writeit(' WPD :Workpiece Diameter in mm ,') and tab
and writeit(' TLN :Tool life with Nose Wear in min') and
newl and newl
and writeit(' TLF :Tool life with Flank Wear in min ,') and
writeit(' TLNH :Tool life with Notch Wear in min') and newl
and writeit(' TLAW :Tool life with Average Wear in min ,')
and writeit(' Fxo :Initial force in X axis ,') and newl
and writeit(' Fyo :Initial force in Y axis ,') and tab and writeit
(' Fzo :Initial force in Z axis ,') and newl and newl
and writeit(' Fxzo :Initial Thrust force ,') and writeit(' Fx
:Force in X axis ,') and writeit(' Fy :Force in y axis ,') and
newl
and writeit(' Fz :Force in Z axis ,') and writeit(' Fxz
:Rsultant Thrust Force ,') and writeit(' Fxr :Rate Force in X
axis ,') and newl
and writeit(' Fyr :Rate Force in Y axis ,') and writeit(' Fzr
:Rate Force in Z axis ,') and writeit(' Fx zr :Rate Thrust Force
') and newl
%and writeit(' Nw :Nose Wear ,') newl
and writeit('-----
') and newl and newl .
relation ask_user_save

if ask q_user_save
and the answer to q_user_save is no and ! .
relation ask_user_save
if dirbox('FILES', 'Which file do you wish to save to.',
'a:*.ss', FILE)
and save_values(FILE)
and drive(c) and ! .
%These questions to gather cutting conditions
%-----
question q_vcvt
'What is the cutting velocity in m / minutes?';
input number
because 'The system requesting the cutting speed for the
machine'.
question q_frate
'What is the feed rate in mm / rev?';
input number
because 'The program inquiring the feed rate set by the
cutting machine'.
question q_dcut
'What is the depth of cut in mm?';
input number
because 'The system requesting the depth of cut for the work
piece'.
question q_mtime
'What is the machining time in minutes?';
input number
because 'The system inquiring the working period for the
cutting tool'.
question q_dwork
'What is the diameter of the workpiece in mm?';
input number
because 'The system eliciting the diameter of the workpiece'.
question q_user_save
'Do you wish to save the consultation and create project file?';
choose one of yes, no
because 'Please specify drive and file name for saved
consultation(file)'.
%This part where the data is kept
%-----
frame cut_cond .

```

## اقترح لإنشاء بنك لمعلومات التشغيلية باستخدام الأنظمة الخبيرة

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### خلاصة

إن اختيار ظروف وأحوال التشغيل المناسبة كانت دائماً عقبة تكنولوجية خاصة لأولئك المشرفين على برمجة العملية التشغيلية وعامة لكل المهتمين والمنخرطين في العمليات التصنيعية. فمن جهة، الاختيار الشعوائي أو المتحفظ للقيم يؤثر على اقتصاديات العملية وهو عامل مهم وأساسي، ومن جهة أخرى فإن التطورات الحديثة المتلاحقة للمواد المصنعة ونظم التشغيل تتطلب أنظمة اختيار ظروف التشغيل أكثر تطوراً من تلك المتوافرة في المصادر القديمة التقليدية. بالإضافة إلى ذلك فإن اختيار الظروف المناسبة تحتاج إلى أسلوب أكثر تطوراً ومرونة في البحث والاختيار.

لسوء الحظ فإن معظم مراجع التشغيلية الحديثة التي تستخدم الحاسب تعتمد على موديلات رياضية استاتيكية (غير متغيرة)، تعتمد على اقتراح قيمة ابتدائية تقريبية بصرف النظر عما قد يحدث من تغيرات في أي من عناصر النظام أثناء إجراء العملية.

في هذا العمل فقد تم التعامل مع العيبين السابق ذكرهما وتم بناء نظام تشغيلية دقيق وفي نفس الوقت يتميز بسهولة التعامل معه وذلك باستخدام موديلات رياضية متغيرة زمنياً وبالاعتماد على برمجيات الأنظمة الخبيرة.

لقد أمكن توقع مستويات معظم مخرجات عملية التشغيل مثل قوى القطع ومستويات التآكل والخواص الديناميكية لنظام التشغيل عند أي لحظة قبل إجراء العملية مما يوفر معلومات مهمة للوصول بالعملية التصنيعية للحالة المثلى حيث تكاليف متدنية وجودة عالية.