INTELLIGENT AUTOMATIC IDENTIFICATION OF PROBLEMS IN PRACTICAL APPLICATIONS OF TURNING

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Abstract. *This paper presents a model for machining knowledge structuring, aiming to solve problems in a practical way. The source of the knowledge used is from literature and experience of hands on technicians and machining teachers and researchers. The knowledge is structured through the use of production rules that once identified some kind of problem, they propose potential solutions to overcome them. To do that, it was used the Expert System Development Environment called Kappa PC 2.3®. Through the use of the proposed system, the user provides basic information about a given turning operation such as ISO code of the tool that he pursuit to use, workpiece material and some technical information about machine too. The input information is stored in a plain text file (ASCII) and then the inference system detects if there is some trouble or probability of fault if the described operation is executed. The system output the probable faults and some orientations to overcome them. The ability of configure the knowledge stored by the system allows its implementation in several companies, specially in low size firms, where the technical knowledge is restricted and where there are no registries of passed experience. Therefore, solutions like the presented here may be an excellent aid for fault detection during the Planning Phase.*

Keywords*: Machining optimization, turning faults, artificial intelligence, process planning.*

1. Introduction

Machining is an essentially empiric manufacturing process. Thus, any attempt to solve certain practical problems or making optimizations will depend on experience and professional skills within the area. Beside this, the great quantity of involved parameters in machining, with a strong relationship among them, and the unknowledge of the consequences of modifying a given cutting parameters may cause serious prejudices for the process performance.

Despite the availability of technical information, mainly in technical catalogues (Iscar, 2000; Sandvik, 2001; Seco , 2000), in tables (ASM, 1995, Stemmer, 2001) and the technical support from tool providers (Sandvik, 1994), many of these data are not well systematized for correct application in industry. This fact leads to wrong decisions and loss of time when certain problems or faults arise having as a consequence low productivity and quality levels. This entire situation can generate a loss of competitiveness of the firm.

Another consequence of the aforementioned situation, is the knowledge evasion, when an experienced professional migrates to another company, and takes out all the technical knowledge, if the company did not systematize the technical knowledge is process planning and fault recovering, it will be necessary the recomposition of this technical skills and knowledge to maintain quality and productivity levels. This recuperation has to be made through investments in training or through the hiring of a new highly skilled professional.

The lack of systematized technical knowledge in manufacturing processes begins early in the professional education phases of mechanical engineers or technicians, where teaching of matters such as process planning or selection of appropriate cutting conditions is a difficult task. Assimilation of the interrelation among cutting parameters is hard to assimilate by the students.

Among the manufacturing processes, machining is an important technique for producing parts. It is known that approximately 80% of manufactured products have, directly or indirectly some machining operation (Dieter, 1981). In addition, it is known that nowadays the effective machining time is greater than the downtime one, the opposite of what happened some decades ago, when the cutting time was considered the minimum portion of the total time. That change occurred thanks to technological innovations. According to the paradigms of modern production, the economic and technical results of machining operations much depend on what happens during the effective cutting time (time where the tool is in effective contact with the piece) rather than the benefits obtained from improving unproductive phases. This fact leads to a great responsibility during machining process planning and the need of well-suited knowledge to avoid technical problems and to generate optimized solutions aiming at machining operations technical and economical satisfaction.

To make that possible, at least three prerequisites must be attained: equipment, tooling and knowledge. A great number of companies in the mechanical sector have a wide availability of such physical resources, mainly to meet the market requirements. Consequently, the third factor, technical knowledge, seems to be the problem. So that, unstructured technical knowledge or absence of systematization of the machining knowledge may cause misleading decisions in process planning or fault detection and recovery.

The solution, at least, must be the technical knowledge systematization, using production rules and structuring them in a knowledge base that could assist technicians and students in solving some practical machining problems, besides giving the possibility of making actualizations and expansions permanently. Wide availability of knowledge-systematization software at low costs, such as expert systems development shells, promotes the implementation of such solutions in a wide range of situations.

Thus, this work aims to propose a model of Expert System for users to solve machining problems of turning operation in an efficient, quick and easy way. For this goal, the machining knowledge has been collected and than it has been systematically structured in a computational database to help users by diagnosis to their machining problems.

2. Background

Machining is defined as a manufacturing process with material removal (Machado and Bacci da Silva, 1999). As it is well known, main manufactured products are made through some kind of machining process. In addition, many parts face high precision requirements. This fact makes the machining processes to be one of the most expensive in industry. Some surveys made in United States conclude that during 1995 more that 100 billions of dollars were expended in machining processes (ASM, 1995). This is one more argument to justifying the importance of knowing the problems in machining processes and how to solve them in an economic way.

Accordingly Taylor apud Stemmer (2001), the easiness that a material can be machined depends on, at least, 12 variables. Under a more practical point of view, it can be observed that many other related variables or parameters could be considered. Firstly, the tool geometry, its angles, vertices and noses have well defined functions. Therefore the selection or definition of those parameters depends on a series of factors, such as work piece material hardness, operation type, material removal rate, among others (Stemmer, 2001). The quality of the parameters selection process will define the fact if a certain machining operation will occur with a good performance or with some kind of faults.

Tool Material plays a crucial role in machining efficiency, especially from the point of view of tool wear. Material properties have to be considered facing different applications and situations, so that their selection must be made in a very careful way considering factors such as workpiece, machining process, machine state, tool geometry, tool cost, cutting conditions and operations conditions (Diniz et al., 2000).

The great variety and interrelated factors turns machining operations in perhaps one of the most difficult to plan manufacturing process. Also, the control of such operations is very complex and could be a highly empiric activity. Thus, aiming at enabling the work of machining practitioners, some cutting tool provider structured technical information to solve frequent operations problems in its tool catalogues (Sandvik, 2001), what constitutes the first step for total knowledge systematization in the area of machining processes. Besides the mentioned provider, others tool manufacturers are providing valuable technical information in machining processes aiming at overcoming troubles and faults, but in a less friendly format which make difficult its use in real situations.

Expert systems constitute a wide used approach for knowledge systematization and storing. Giarrantano and Riley (1994) define expert system as “computational programs that use knowledge and inference procedures to solve complex problems that need a very specific knowledge to its solution”. Expert system formalization is the computational representation of the knowledge in a given domain plus the implementation of the inference procedures needed to extract useful information or more knowledge from the system. Besides the knowledge base, an important section of the expert system is the user interface, which has to be focused on the specific domain. The representation of the knowledge, in synthesis, is the definition of attributes and values, and the writing of the decision rules within the domain where the expert system is operating (Consalter, 1999).

Considering machining operations, few have been published in applications of Experts Systems. This is, we believe, because a great quantity of variables associated in these processes. As Wong et al. (1999) pointed, the selection of cutting data is a complex task and it cannot be easily formulated through deterministic models. According to the mentioned authors, optimized information on appropriate cutting conditions is obtained basically, from the experience of operators and technicians, as well as, based on human intuition. A similar work resented by Almeshai and Oraby (2003) proposed a solution based on AI (Artificial Intelligence) to evaluate selected cutting parameters, comparing them with information of the available resources, production objectives and restrictions. Fang (1995) proposed a system that allows diagnosing of turning operations, using fuzzy logic, starting from a series of coming signals of behavior (cutting forces, vibrations and other parameters of the machining operation). More recently, Hashmi et al. (2000) presented a system of selection of cutting data for drilling operations based on a

Fuzzy approach. The system allows selecting the cutting speed for this operation from data such as material hardness, diameters and feed values.

3. Development

Turning knowledge systematization for automatic identification of operating problems consists on the construction of an information base inserted on an expert system. Expert system development and information processing was implemented using the development environment called Kappa PC 2.3. The system was configured for diagnosing potential of problems from input data describing technological information of certain operation of turning. Essentially that leads to the construction of a knowledge base, which is composed of attributes (variables), values (parameters) and decision rules (machining knowledge), to the definition of a user interface and the development of internal information processing programs. These phases are explained in the next sections.

3.1. Knowledge base construction

This works begun with the gathering of machining information, specially turning information about typical problems or faults that take place during material removal operations and triggered by some erroneous decisions during process planning phases. Concurrently, the possible solutions for each one of the problems or faults considered in this stage were investigated. Main information sources considered here were specialized literature, tool manufacturers´ catalogues and experience from high-skilled technicians and engineers in the machining sector (ASM, 1995; Dieter, 1981; Diniz , 2000; Iscar, 2000; Machado, 1999; Sandvik, 2001; Sandvik, 1994; Seco , 2000; Stemmer, 2001). The result of this phase was a systemized catalogue of problems or faults, their possible causes and potential solutions. That constitutes the elicitation of the knowledge to be systematized. Table 1 presents an extract of the mentioned systematization.

Table 1. Some turning problems, causes and solutions (ASM, 1995; Dieter, 1981; Diniz , 2000; Iscar, 2000; Machado, 1999; Sandvik, 2001; Sandvik, 1994; Seco , 2000; Stemmer, 2001).

PROBLEM	CAUSE	SOLUTION
Vibration	Relief angle too short ($\alpha < 3^o$)	Increase α ($\alpha > 5^o$)
	Nose radius (r_ε) too high	Reduce r_ε
	$4 > (a_p / f) > 20$	$4 \leq (a_p / f) \leq 20$
Excessive roughness	Feed (f) too high	Reduce f
	Cheap scratches the machined surface	Increase the Inclination angle (λ_s)
Insufficient power	Low rake angle (γ)	Increase γ
	Cutting speed (v_c) too high	Reduce v_c
Long chip shape	Rake angle (γ) too high	Reduce γ
	Wrong chip braking geometry	Change the insert geometry
Adhesion (BUE)	Low rake angle (γ)	Increase γ
	Low cutting speed (v_c)	Increase v_c
Chipping edge	High local strength in the edge ($\kappa_r \cong 90^o$)	Reduce κ_r ($\kappa_r < 90^o$)
	Brittle tool material	Toughness tool material

The main objective of this work led to the need of defining a functional model that could be adapted to a variety of practical situations. Considering the high complexity and the great quantity of variables or parameters involved in a given machining process, it was decided to implement a simplified subset of those related to the turning process. So that, the defined model could be enhanced, modified or adapted to other particular situations. The variables considered by the implemented prototype, are those related to the tool holder, represented by its ISO code (clamping mode, geometry, dimensions, style, etc.), inserts, also represented by its ISO code (material, format, type, etc..), process information (operation type, operation application, workpiece material, cutting speed, feed, depth of cut, etc.) and machine tool information (power, rigidity, dimensions of the tool holder seat, etc.). Those variables were considered necessary and sufficient under which a coherent conventional turning process planning is possible. Some examples of variables and their respective values are presented in Tab. 2.

Table 2. Variables and values examples.

VARIABLES	VALUES
Cutting Application	R (Rough); M (Semi-finishing); F (Finishing)
Part Material	Steel; Stainless Steel; Cast Iron
Insert ISO Classification	P; M; K
Stiffness Machine	High; Low
Cutting Edge Angle	45; 50; 60; 63; 72,5; 75; 85; 90; 93; 95; 107,5; 117,5
Feed (mm/rot)	0,10; 0,15; 0,20;......; 1,40; 1,45; 1,50
Operation Type	Longitudinal turning; Facing; Profiling; Grooving

All acquired data was inserted into the knowledge base, so that it is composed by the defined variables, their respective values and linked to decision rules representing the knowledge elicited for the defined domain. The first step consists on the configuration of the variables; they are called SLOTS in the software. In the interior of each slot different values are enabled, so that each variable have a name and a specific address, allowing data search and the inference process through the set of rules. The values are stored in the slots in two forms: the first form consists on the insertion of a list of numbers, characters or words defining a permanent database and allowing its expansion if necessary; the second form is through the composite codes. These composite codes are composed by different number of variables, each one assuming a given value in its respective slot when the user informs the required information (in the case of this work, the user informs the ISO code of the tool holder and the insert). Therefore, the user executes a new processing, the corresponding slots are loaded with the values expressed by the code.

For each one of the variables inserted in the base there is at least one decision rule that relates the inserted values by the user with the knowledge expressed by each rule. That knowledge comes from the information that was gathered and commented at the beginning of this section. There was implemented a number of 76 decision rules, number that, according Waterman (1986), characterizes a demonstration prototype. The program analyzes the information and makes a decision accordingly to the stored knowledge and the values stored in the working memory. The decision is the result of the processing, represented by the orientations and courses of actions recommended to overcome the stated process planning troubles. So, one can represent the machining knowledge through the use of decision rules in the form of: IF condition THEN consequence. In this case the condition is composed by assigned values to the operating variables while the consequence corresponds to troubles or fault linked to the respective recommendations. As an illustrative example look at the decision rule shown in Tab. 3.

Table 3. Knowledge-rule example.

IF	The insert shape is R and the stiffness machine is low	(***condition***)
THEN	There are possibility of vibration in process, with edge chipping and poor surface texture. The problem can be eliminated or minimized using insert shapes V, W or T	(***consequence***)

3.2. User Interface Construction

The graphical user interface was developed for allowing the input information and the correct presentation of the results of the inference process. This task was implemented using the resources of the same development environment used for creating the knowledge base. The input window contains specific fields for the user can inform all the needed variables that could have certain influence in the generation of a given problem or fault during the operation. Two kinds of fields have to be input in this window: the code and isolated variables. In the first case, the user has the possibility of including the code of any tool holder or directly the code of a given insert, since he use the respective ISO standard adopted by the great part of the tool manufacturers. In the second case, the user must to select one on the values available on the rolling bars of each one of the respective variables. Those values are previously defined at the moment of defining the knowledge base, as it was commented in the previous section. Additionally, there is s a set of buttons that performs control tasks (such as EXECUTE and BACK, etc..). Once the system performed the inference process, the window for presenting the results shows a list with the potential troubles or faults that could arise during the operation if executed with the conditions entered by the user. A text box is deployed with the set of rules that was triggered by the specific process that found out the potential of problems or faults. Two control buttons are available in this window. One button allows the user to perform a new analysis, initializing all the defined slots with a zero value. The second button, allows the user to review the entered data for making some modifications if needed according the recommendations made by the system.

3.3. Internal Software Functions Development

Some managing functions were implemented for correct functioning of the software. One of that control function is responsible for triggering the inference processing, what involves fundamental actions such as locating and reading the variables values, loading them into the working memory, sweeping the set of decision rules, allocating and presenting the results in the appropriate format. Other functions clean the working memory, whilst the other four functions control the displaying of the windows according the processing sequence of steps.

4. Model validation

For demonstrating the functioning of the developed solution under the point of view of the user and for validating the technical feasibility of the model, we describe here a sample session using, in fact, one situation containing some process planning mistakes, commonly made in industry. This particular case is a finishing operation, in a single pass in a workpiece of stainless steel as is shown in Fig 1.

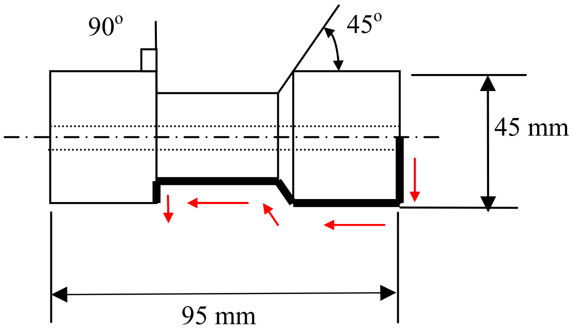

Figure 1. A sample workpiece

Additionally, operation's information is introduced in the data input window as can be seen in Fig. 2. It is assumed that the information entered by the user here is sufficiently representative of a process plan. All the data informed by the user can be considered as essential part of a any process plan, where the selected cutting tool, tool holder, cutting conditions and the selection of appropriate machine tool constitute the minimum information that is to be present on an actual process plan.

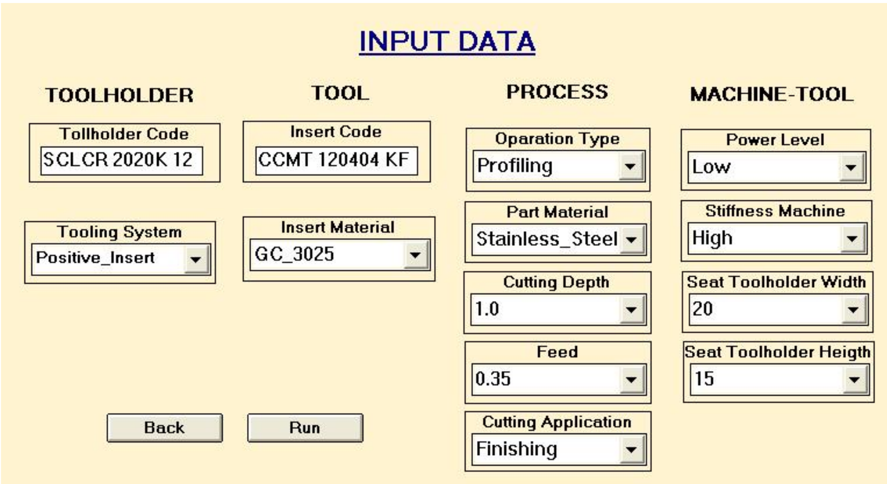

Figure 2. Input window

According the entered data, the system found out a set of six possible problems or faults and suggests possible solutions or recommendations for each one of them, as can be seen in the output window in Fig. 3.

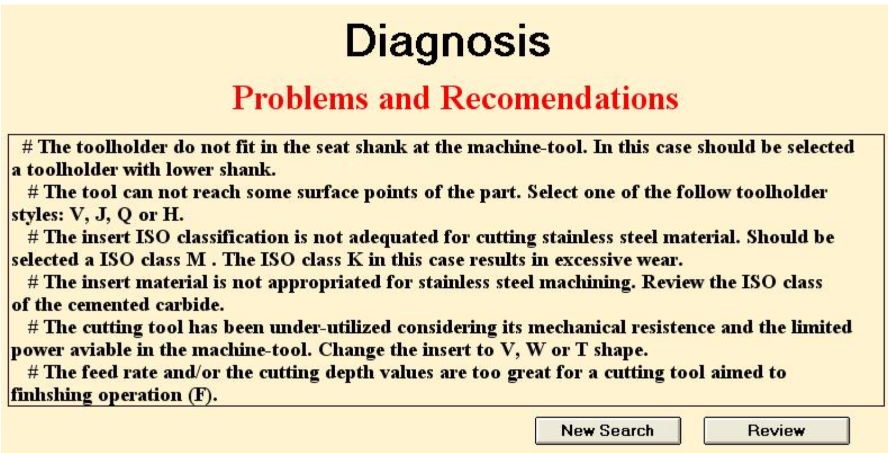

Figure 3. Output window with the first diagnostic made by the system

Using the diagnostic made by the system and the analysis of the possible causes of each fault, shown in Fig. 3, one can observe the following planning misleading decisions or faults in the operation:

- Inadequate Tool holder selection. Because the workpiece presents a single face to be machined, beside a 90º undercut, and the finishing pass is unique (without tool changes), the workpiece part could not be machined using the selected tool holder (“V” type and κ_r = 72º30´). Fir this operation a J type tool holder is needed in combination with a V type insert.
- Material Insert is inappropriate. As it can be observed from Fig. 3, the insert material is oriented to the machining of cast iron (K ISO class), while the process plan is being prepared for machining a stainless steel workpiece.
- The selected insert does not need to be that thick and its shape of the C type is not the better choice to a very light operation. Therefore, the insert is super dimensioned and presents more resistance than the needed for this type of operations, which may cause an unnecessary operational costs increasing.
- The high of the tool holder is higher that the maximum high of the seat in the machine tool, so that the tool holder does not fit.
- The feed is excessive. Once the tool is selected for the operations under analysis, two main issues make unfeasible the selected feed value of 0,35 mm/rev. First, the insert shape is incompatible with that feed value, and second, considering the nose radius of the tool, the projected superficial roughness is impossible to be obtained with combination of feed higher than 0,3 mm/rev.

The diagnostic allows the user or process planner to do the corrections needed. For illustrative objectives, the corrections relatives to the tool holder and to the insert were made, keeping the conditions relatives to the tool feed unaltered as can be seen in Fig. 4. In Fig. 5 the system performs a new diagnostic process and generates a new set of recommendations to be considered by the process planner.

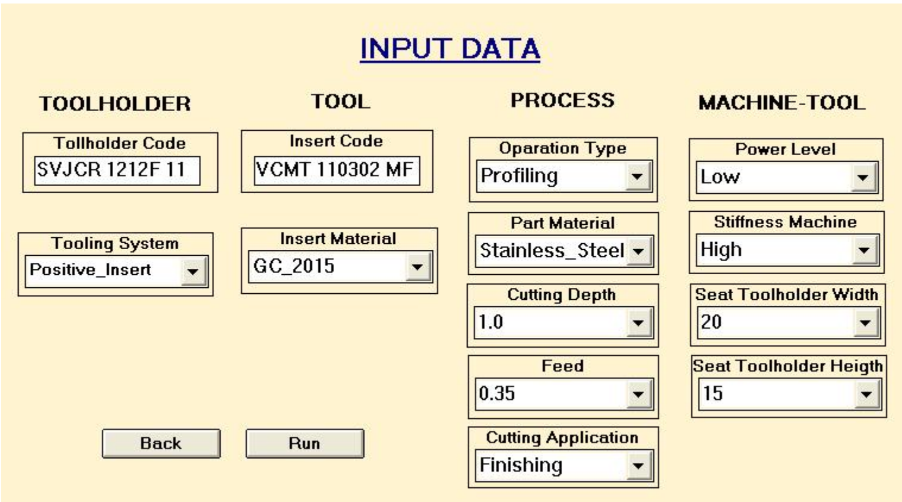

Figure 4. Second input window showing the partially corrected data

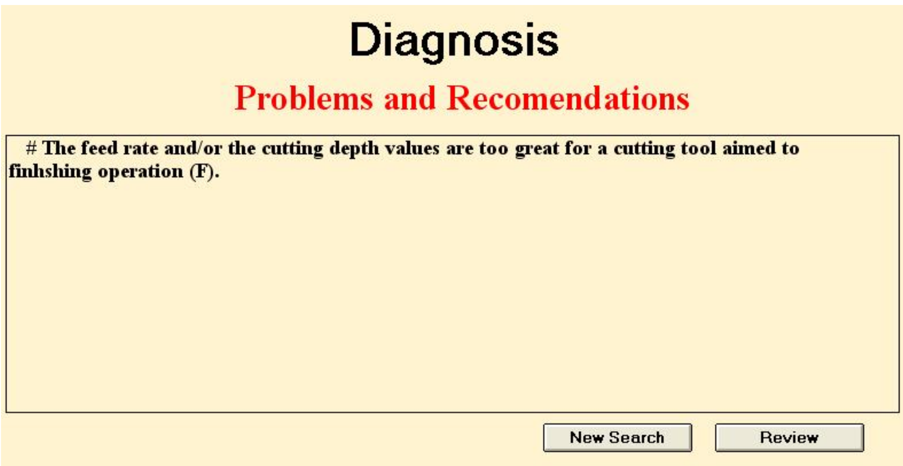

Figure 5. Output window with the diagnostic of the operations with the corrections (partial) made

Once all the inconveniences were eliminated the system performs a new diagnostic or evaluation and informs the user that the suggested process plan is correct, as can be observed in Fig. 6.

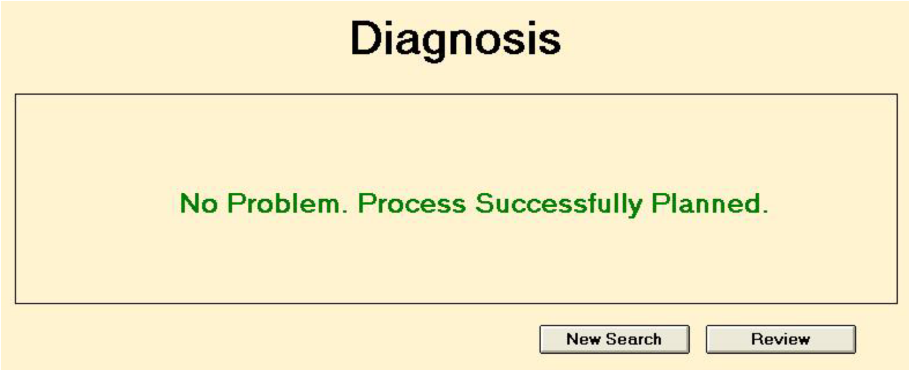

Figure 6. Output window showing the final approbation of the process condition

5. Conclusions

Automatic detection of machining faults, within a defined domain, is characterized by the implementation of a Expert System (ES). The ES is based on a structured database for diagnosing turning problems or faults and orientating the user for overcoming them is a easy and fast manner. Two main contributions can be drawn from the proposed system: it can be considered as a powerful tool for process planner and provides a useful help in diagnosis and overcoming operational faults detected from the cutting conditions selected or defined by the user.

As it was commented before, machining processes are very susceptible to planning mistakes; the great number of variables involved and the empiric character of the operations cause this susceptibility. Within the industrial environment this situation is aggravated by the great number of available cutting tools and when the technological knowledge is restricted or is not up to date or when there are no skilled technicians in the organization. All these situations are commonly detected in companies especially in the low-sized ones. It is especially in these situations where the proposed system aims at making its main contribution. The proposed model can also be considered as a great contribution in the educational environment. In fact, interactive relationship between the system and machining process students turns the system a powerful and evolving self-teaching media. Future works point to the amplification of the stored knowledge and its configuration for specific domains such as certain material machining, a set or family of workpieces, etc.. Next stages in the development of the presented model are: (1) test the proposed model in an actual industrial environment, (2) amplifying the knowledge base and incorporating more decision rules for enhancing the system intelligence; (3) Extending the use of the systems in other types of machining processes such as milling or drilling.

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