New Operational Support System for Cutting Process Optimization

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Abstract

Manufacturing cost minimization and productivity maximization are essential for the machining industries sector to survive in the market. The production shop floor is a source of achieving strategic data, providing information to assist cutting processes optimization and better help to use equipment and resources efficiently. In this sense, the objective of this work is to present the development of a New Cutting Process Operational Support System which is following the most modern computational architecture (this system is being known in Portuguese as SIAPU). Before starting the system development, a survey was conducted. For this purpose, a questionnaire was prepared and sent to approximately 3850 companies active in matters related to material cutting process. The number of respondents was 208, or 5.40% of the total queried. This matter should be part of another specific job to analyze the answers. However, it was possible to understand that the industry in general is interested in having such a system like this one being developed in this work. The system development is being based on new optimization cutting process approaches. The expectation is that, at this final development, the system could offer characteristics as practicability, usability, mobility, beyond contain a help system intuitive on-line. Finally, this work has concluded that the use of the system in industry shop floor can contribute as a remarkable tool to minimize costs and maximize productivity, given to the industries, an opportunity to look for larger profits.

Keywords: cutting process; operational support system; optimization.

1 Introduction

Machining process optimization is a very complex task and must be understood, in this work, as a procedure to promote cost minimization and productivity maximization of a given system workpiece, tool, machine and fixtures. To this end, the machining conditions used, must go through an optimization process. It is possible imagine that there is only one set of optimal machining conditions. However, it is quite impossible to achieve this level of refinement, both in research and practice of the process. So, instead of call the results as optimal, it is correct to call them as "optimized".

To improve productivity or minimize costs the industries can purchase and or building equipment and devices over advanced and flexible. However this option represents high investments to companies. According to Baptista (2001), alternatively, you can use, with technical and economical advantages, solutions based on methods and procedures for optimizing the machining conditions. Respecting their limits, such procedures can avoid high costs of investments instead to replace machinery and tools.

In this context, it is considered that, after having exhausted all the possibilities of rational analysis of tool cutting conditions selection based on tools suppliers catalogs, or on the experience of process planners and on the experience of machine tools operators, it is necessary to consider aspects that depend on manufacturing scenario involved (Diniz, Marcondes and Coppini, 2008). This is the main reason why companies have different delivery times for cutting process services, as well as, different manufacturing costs.

Worldwide about 80 to 90% of CNC active machines are working below their limits, according to research published by the tool manufacturer Sandvik® during the 2000 years (Coromant, 2000). This information

demonstrates a field to be exploited and which should receive increased attention by researchers and industries workers belonging in the cutting process sectors.

The optimization of feed rate and depth of cut should occur mainly with the analysis of the geometry involved between tool and workpiece to be cut. So, if the case is heavy roughing, or light roughing, semi-finishing or finishing, or even, smooth finish, it is suggested to select major feed rate possible, for each instance, taking the care of attend the machine tool restrictions and some another eventual manufacturing restriction of the system.

Thus, the best value for the feed rate must be as greater than possible, respecting the machine tool constraints and must be able to generate the final surface roughness desired for the workpiece being produced. Similarly, whenever an operation requiring large amount of material removal, it is recommended select a depth of cut as large as possible, once again, under the constraints of the machine tool.

If feed rate and depth of cut selection follow these concepts, it is allowed to consider that these parameters were optimized. At this moment, it is possible to find several cutting speeds that could be used. Several of these cutting speeds will attend the process, and generate workpieces with design-imposed quality. One of them is the best! SIAPU is being prepared just to determine which cutting speed is the best.

According this context Liu et al. (2010), consider that computer systems based on modern WEB environment are of great value to work in the construction of decision support tools. Currently manufacturing industries are equipped mostly with CNC machine tool. This kind of machine tool can be supported by CAx systems such as: (CAM) Computer Aided Manufacturing, (CAD) Computer Aided Design, (CAPP) Computer Aided Process Planning, among others (Ding and Matthews, 2009).

Among all the references found in this work, only two of them stand out by presenting opportunities to put together scientific and practical aspects related with cutting process, which are: MOS - Machining Optimizer System (Baptista, 2004) and MOS II - Machining Optimizer System II (Grivol, 2007).

Based on the literature and computer systems related with cutting process, including the information existing in MOS and MOS II, this work proposes the construction of SIAPU, a new computational tool to support the cutting process, extending their functionality. However, the new system will take profit about much modern computational techniques, new optimization methods, including decision support tools and price formation, aiming to contribute to the improvement of cutting process optimization parameters. At this time the SIAPU development is around 70% concluded.

2 Cutting Process Optimization Review

Over the last years several researches dedicated to find how to optimize cutting process, have been developed ways to reduce costs, increase productivity, maximize profits, gain of agility and flexibility.

The first author's team publication on cutting process optimization published by Pallerosi and Cupini (1975) presents an analysis of trustworthiness in the use of the values "x" and "K" Taylor's life equation coefficients. The basic concepts that guided this study were: do not use data from the tools supplier's catalogs like as optimized values; data must be obtained directly from the cutting process practice coming from the industry shop floor to determine the mentioned coefficients. These concepts were used by the authors of MOS and MOS II.

According to literature, some authors have focused their work on building support systems for cutting process, using resources and computational techniques in different ways, applying scientific and or practical knowledge. Lee et al. (2000) featuring the use of polynomial networks as an option to determine the ratio between cutting parameters and quality of surface roughness, cutting force and tool life evolution in turning process cycles.

Focusing the conditions of minimum cost and maximum production, Meng et al. (2000) determined, based on cutting process theory, a procedure for determine cutting parameters to reach the highest rate of chip removal. Then, using a suggested change in extended of Taylor's life equation and data from tool suppliers' catalogs they found a way to determine optimal cutting speed condition.

Following the same concepts, Muršec et al. (2000) developed a system using data from multiple tool supplier catalogs to determine the optimum cutting parameters conditions.

Shabtay (2002) also proposed an optimization system for extending the concept of maximum gain. Following this subject this author proposed an equation based on "revenue per workpiece, cost per piece and cycle time and tool life as criterion".

Although based on the same conditions, Wang et al. (2002) developed a computational system for the optimization of turning process with a single pass, in which the user informs the maximum and minimum tool life values and the optimize cutting speed is determined by the system considering this tool life interval.

Looking for another approach, Zuperl and Cus (2003) used neural networks for cutting parameters optimization, considering the technological, economic and organizational constraints. The approach was suitable for the quickly determination of cutting parameters during machining when there is enough time for deep analysis.

Baptista (2004) developed the Web-Based expert system named MOS - Optmizer Machining System, aiming to assist in the optimization of turning, milling and drilling, based on Maximum Efficiency Interval (MEI) for several productive scenarios (Figure 1). According to the literature, this system was the first to introduce the cutting process scientific and practice aspects focusing real industrial applications.

Continuing research and application of this system Baptista and Coppini (2007) validated the MOS in the optimization of machining parameters with data from the manufacturing environment, comparing the results with information processed by spreadsheet and data catalog suppliers. The results obtained in the experiments demonstrated that the system correctly identified scenarios, proving to be reliable for application in production environment.

Grivol (2007) developed MOS II based on MOS and introduces new features such as: new approaches to optimizing; division of the system into hierarchies better defined; inclusion of data information for no optimize scenario, among others. These improvements have added benefits that make the system more consistent.

Using the WEB platform Zheng et al. (2008) developed a system where users can select, in a database, machine tools and the appropriate cutting parameters as also evaluate the performance of machining by obtaining the cutting force, power consumption, system vibration and distortion level of the part in accordance with the cutting conditions, such as cutting material, workpiece material, workpiece hardness, heat treatment, depth of cut, etc.

Within the same Web-Based concept, Hanwu and Yueming (2009) developed a virtual operation system for CNC machine tools in order to facilitate users to be trained and to make easy to follow the process by simulation. However, this system has some restrictive features relating to the technology applied, highlighting the dependence of the installation of auxiliary programs and use the browser Internet Explorer® for the operation of the system.

Summarizing this item is possible to say that the literature review demonstrates that the proposed machining process optimization do not have focused on the possibility of practical applications. Only Baptista (2004), Baptista and Coppini (2007) and Grivol (2007) developed systems based on scientific and practical aspects related to the cutting processes. They used optimization procedure model following Pallerosi and Cupini (1975) to obtain the Taylor's life equation coefficients. The coefficient x was determined applying Eq. (1) and K applying Eq. (2).

$$x = \frac{\log\left(\frac{T_1}{T_2}\right)}{\log\left(\frac{v_{c2}}{v_{c1}}\right)} \tag{1}$$

Where, T_1 is the tool life for v_{c1} and T_2 is the tool life for v_{c2}, considering the same tool life criteria in both cases. T_1 and T_2 must be measured in shop floor during the process evolution. The v_{c1} is the current cutting speed selected from toolmaker catalogs before optimization and v_{c2} = ($\pm$1.20*v_{c1}) is the second cutting speed used to calculate *x* and *K* Taylor's Equation coefficients Eq. (1) and Eq. (2).

$$T = \frac{K}{v_c^x} \tag{2}$$

Where:
T = tool life [min];
v_c = cutting speed [m/min];
K = constant of life Taylor equation;
x = coefficient of life Taylor equation.

3 SIAPU Characteristics

The positive results achieved by MOS and MOS II encouraged the authors to perform SIAPU. This new system will bring improvements such as:

- Use of modern computational techniques; (*)
- Multiple languages; (*)
- Compatibility with the most used internet browsers and mobile devices existing in the market; (*)
- Inclusion of graphics support for decision making;
- Generation of management reports in real time;
- Tool for query historical; (*)
- Dedicated module for identification of idleness, thus allowing maximization of production capacity through the effective use of this idle equipments. Idleness is an relevant impact factor on industrial competitiveness (Rosa, 2011); (*)
- Module to assist in price formation of products and budgets presentation and its negotiation, based on the concept of contribution margin, which model was proposed by Carvalho (2007). The model is intended to provide information detailing the proposed price by the market of service providers in machining, it has some characteristics that differ from traditional models, such as the use of variable costs only for the formation of selling prices; setting the sales price based on variables directly linked to the process, simplification of the formulation of the sale price, using data optimized operation in manufacturing environment; (*)
- advanced interfaces to facilitate and improve practical applications for optimization of cutting processes on shop floor environment industries; (*)
- specific modulus to be applied to teach and to spread the knowledge abut cutting process and also its optimization;
- Automatic cutting speed optimization for the following production scenarios and its respective cutting speeds (Table 1).

(*) *Items already implemented in SIAPU*

Table 1. Cutting speed, scenarios and equations to be determined by SIAPU.

Cutting Speed	Environmental Industry Scenario	Equation for each Cutting Speed determination
*[0.9*v_{c1}, 1.1*v_{c2}]* validity interval	Validity interval for all cutting speeds below. To be used during data collection. It is suggested 10% tolerance.	Cutting speeds must be calculated by SIAPU in this interval validity otherwise could occur errors when applied in practice.
v_{cmxp} Maximum production cutting speed	To be used for bottleneck machines or to ensure the maximum hour production possible. v_{cmxp} can be major than v_{c2}. In this case for bottleneck machines must be used v_{c2}	$v_{cmxp} = \sqrt[x]{\frac{K}{(x-1)\cdot t_{tf}}}$ t_{tf} is tool edge exchange time [min]
v_{cmc} Minimum cost cutting speed	To be used when cutting process must be done under minimum cost per piece possible	$v_{cmc} = \left\{ \frac{K\cdot(S_h+S_m)}{60\cdot(x-1)\cdot\left[K_{tf}+\left(\frac{S_h+S_m}{60}\right)\cdot t_{tf}\right]} \right\}^{\frac{1}{x}}$ S_h = labour salary [$/hour]; S_m = machine salary [$]; K_{tf} = tool edge price [$]
v_{cmcLim} Minimum cost limit cutting speed	To be used in flexible manufacturing systems. In this case, the cutting tool edge exchange time is too fast or zero	$v_{cmcLim} = \left\{ \frac{K\cdot(S_h+S_m)}{60\cdot(x-1)\cdot K_{tf}} \right\}^{\frac{1}{x}}$
v_{cmxca} Maximum Cost Admissible cutting speed	To be used to improve the hour production and keep the costs not much larger than the minimum cost per piece. K_{mxca} is the maximum cost that can be offered to the market and still be competitive	$K_{mxca} = C_1 + \frac{\pi.d.l_f}{60.1000.f.v_{cmxca}}\cdot C_2 + \frac{\pi.d.l_f.v_{cmxca}^{(x-1)}}{1000.f.K}\cdot C_3$ d = tool or workpiece diameter [mm]; f = feed rate [mm/rev]; l_f = feed length [mm]; C_1 = passive costs [$]; C_2 = (labor salary + machine salary) [$/hour]; C_3 = tool edge price and cost to change tool edge [$]
V_{cminca} Minimum cost Admissible cutting speed	To be used in idle machines. t_d is the total fabrication time by piece less than the maximum hourly production time. The respective v_{minca} is limited by the cutting speed v_1 of the validity interval.	$t_d = t_1 + \frac{\pi.d.l_f}{1000.f.v_{c\min ca}} + \left(\frac{\pi.d.l_f.v_{c\min ca}^{x-1}}{1000.f.K} - \frac{1}{Z}\right).t_{ft}$ t_1 = passive times [min].
v_{cmxg} Maximum Gain Cutting Speed	To be used when cutting process must be done under maximum gain G per piece possible. Maximum gain is calculated by d(G)/d(v_{cmxg}) = 0	$G = \frac{\left[PV_u - MP_u - \left(\frac{l_f\cdot\pi\cdot d\cdot v_{cmxg}^{(x-1)}\cdot K_{tf}}{1000\cdot K\cdot f}\right)\right]\cdot t_{disp}}{t_1 + \left(\frac{l_f\cdot\pi\cdot d}{1000\cdot f\cdot v_{cmxg}}\right) + \left(\frac{l_f\cdot\pi\cdot d\cdot v_{cmxg}^{x-1}\cdot t_{tf}}{1000\cdot f\cdot K}\right)}$ PV_u = sell price [$]; MP_u = raw work piece material price [$]; t_d = available time to produce the batch [min];

All cutting speeds presented in (Table 1) are graphically shown in (Figure 1). The interval between v_{cmc} and v_{cmxp} is the Maximum Efficiency Interval (MEI). It may be that V_{cmxp} come to be larger than the cutting speed v_{c2} plus 10% above its tolerance value. This will occur whenever the tool edge exchange time t_{tf} be very small or zero. In this case, the upper end of (MEI) would be 1.1*v_{c2}.

The internal structure and navigation system, showed in (Figure 2), has been made prioritizing and facilitating the user's access. The modeling was developed to allow receiving new functions through new modules insertion, without the need to rewrite or adapted new sources codes.

It will be developed a module provided with Artificial Intelligence (AI). The target will be to evaluate the behavior of optimizations performed, learning how it took place and thus, use the value already optimize to start a new optimization procedure, always an adequate level of similarity occurs between the last and current case.

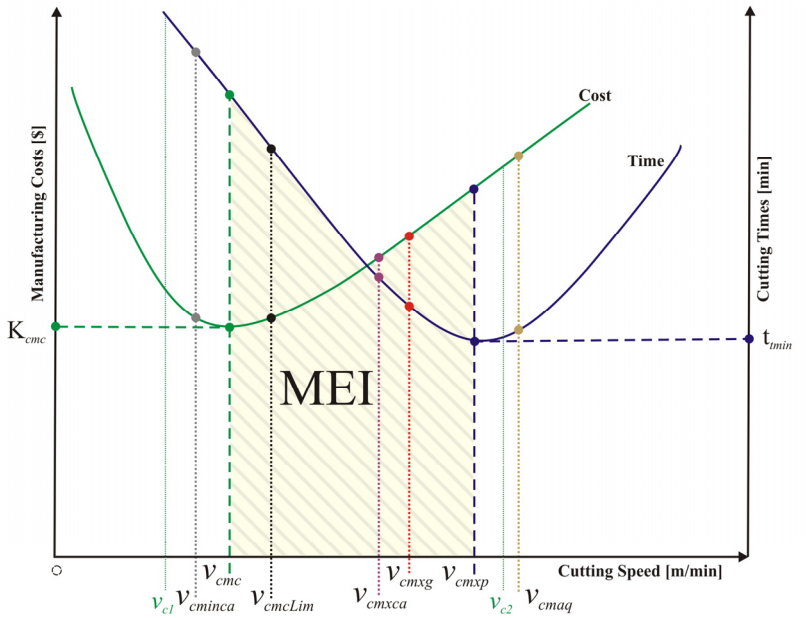

Figure 1: Maximum Efficiency Interval (MEI). Source: Adapted from Diniz et al. (2008) p. 142.

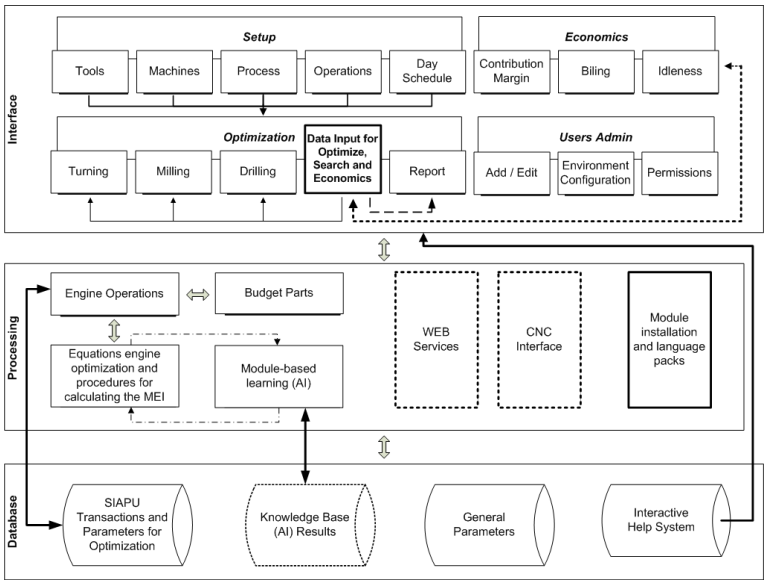

Figure 2. Diagram of the internal structure of SIAPU.

4 Technological Base

The WEB platform is the market tendency, as demonstrate in the work of Liu et al. (2010) and Li (2011). This platform offers an environment that can be easily accessed using a Web browser on computers and mobile devices, requiring only an internet connection or local network where the proposed system is found installed. This platform has many characteristics such as flexibility, speed deployment and maintenance, as well as, provides cost savings on infrastructure for Information Technology (IT).

SIAPU was built under the paradigm of object oriented programming (OOP), a term that describes the software organization as terms of collections and independent objects with behaviors strongly coupled according to Murthy et al. (2011).

This paradigm differs from the traditional approach of structured programming development. This structured programming is based on routines and data structures of weak coupling, making it difficult to maintain and add new features quickly.

The code fragment (simulated), presented in (Figure 3), shows the preparation of an operation to be used for optimizing a process of turning written in PHP 5.3 (OOP) to script language programming.

```
...
        $op = new SIAPU_Optimize();

        $op->setProcess('P1');
        $op->setOperationType('TURNING');
        $op->setOperationCode('OP1');
        $op->setMachine('M1');
        $op->setTool('F1');
        $op->setVcIni(110);
        $op->setFeedRate(0.25);
        $op->setMachiningDepth(1);
        $op->setTaylorX(4.156376);
        $op->setTaylorY(50396117944.56);
        $op->Execute('OP1');
...
        $op->getResult('OP1');
...
```

Figure 3. Code fragment example of a turning operation.

It was used PHP 5.3 scripting language to develop SIAPU. This language has advantages for being free software and simple syntax, high speed processing, reliable security and stability, and is compatible with the paradigm of object orientation (OO) according to Mercer et al. (2004). For storage data was utilized the database MYSQL 5.1, a database management system (DBMS) plus SQL - Structured Query Language, that main characteristics are stability, reliability, portability and high performance (Batista, 2009).

4.1 Methodology Development and Software Quality

In order to develop proposed software keeping quality it was used the international standard ISO/IEC 12207, which according to Dias et al. (2010) provides a high level structure for life cycle software processes. It was also used the eXtreme Programming (XP) methodology (Abrahamsson et al., 2002). Its main features are project control prioritization in aspects of cost, time, quality and scope of the project, using a life cycle divided into six phases: Exploration, Planning, Iterations to Release, Production, Maintenance and Death (Figure 4). This methodology proposes a set of best practices such as standards codes, test-driven development, refactoring, continuous integration and acceptance testing.

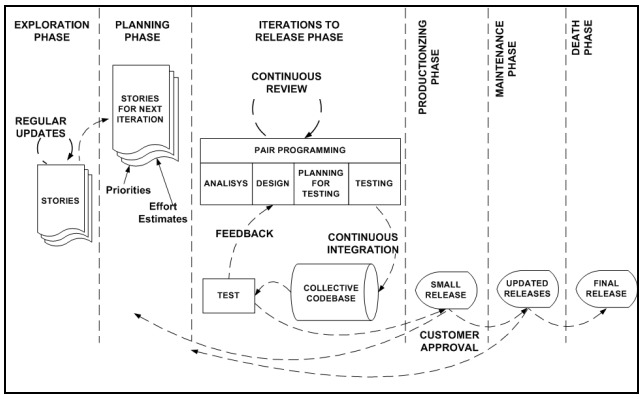

Figure 4: Life cycle XP processes. Source: Adapted from Abrahamsson et al. (2002) p. 21.

The SIAPU main interface (Figure 5) follows standards for usability, as shown in (Figure 6), described by ISO 9241 - Ergonomics of Human System Interaction parts: 100 - Introduction to standards related to software ergonomics, 151 - Guidance on World Wide Web interfaces, 171 - guidelines on accessibility software. It was also followed the recommendations of W3C (World Wide Web Consortium) - International Standards Organization for the World Wide Web for system development. In addition, it was

applied an interactive help system in order to assist users to use SIAPU properly and take the system maximum efficiency.

Figure 5: SIAPU Control Panel.

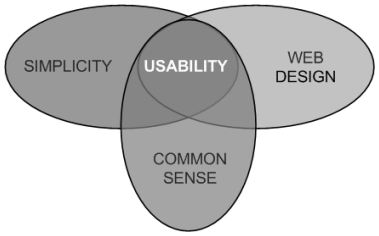

Figure 6: Diagram of Usability Human-computer interaction.

5 System Validation and Tests

The mathematical models showed in (Table 1) and the optimization model procedure used in the SIAPU was validated by simulations based on data from the turning, milling and drilling industries shop floor and or in laboratories by adopting the same production shop floor routine (Pallerosi and Cupini, 1975); (Coppini and Baptista, 2006); (Baptista and Coppini, 2007), (Santos, 2011) and (Da Rosa et al., 2009). The obtained results in the experiments will be matched to each other by means of a spreadsheet in order to establish the validation of routine calculations and the correct identification of productive scenario.

The entire SIAPU validation will follow the proposed method described in Rocha and Baranauskas (2003), probably before the ICIEOM 2012 conference.

6 Final Considerations

SIAPU is being developed to presents modern architecture, faster data access and a friendly and more intuitive interface, following the standards concepts of WEB 2.0. It was used PHP 5.3 which is excellent tool

for programming and is compatible with object orientation paradigm (OOP). The data storage is done in MySQL 5.1 database that has portability, stability and high performance. SIAPU was developed in WEB platform and was validated by W3C. The system presents usability and compliance with all main browsers existing in the market. It can be also accessed by mobile devices, which is a feature that provides flexibility especially on shop floor. Their interfaces were built under user-friendly and flexible conditions and it allows the inclusion of extra features according with each user interest. It also has a multi-language option available.

SIAPU, as described in this work, is an Operating Support System specifically developed to be used in practical applications to optimize cutting process parameters with the target of minimize costs or maximize production. Two main characteristics can be pointed out: it was used a deterministic mathematical model to find Taylor's tool life equation coefficients and the data to be used for this propose, must be collected in industries shop floor in real time with workpieces production. Tool life data taken from tool manufacturer's catalogs can be used, however, are not recommended by the system authors for not having adherence with the scenarios' users.

Besides being possible to perform the cutting processes optimization, SIAPU also allows to:

- identify bottlenecks and idleness machines in manufacturing cells;
- cutting process service suppliers can use the system to prepare price formation based on contribution margin concepts and organize budgets to be presented and discussed with their costumers;
- be used for education and teaching classes about cutting process;
- be used for dissemination of knowledge in the area of cutting process and related matters.

Acknowledgements

The authors express their thanks to University Nove de Julho - UNINOVE and CNPq - National Research Council for the support received to develop this work.

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