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# APPLICATION OF GROUP TECHNOLOGY FOR PRODUCTION TIME ESTIMATION

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**Summary**

The development of industry, transport, communications and technology results in tougher competition, i.e. the process of globalization takes place. Small and medium enterprises (SMEs), which are greatly affected by this process, are expected to accept or to refuse the received offer in a very short period of time. Consequently, it is impossible for a small enterprise to create a technological process in order to calculate production times. The idea of the authors of this paper is to develop a system of part classification by means of group technologies. The classifier is used to classify parts into similar groups. So, if we have a new part, we can find a similar part and adopt its technological process to the new part. In the next step, an application to enable the production time estimation, and consequently the production cost estimation for each family of parts will be developed.

*Key words:* *group technologies, estimation of production times, CAM, code classification*

## 1. Introduction

Technological process planning for metal cutting is one of the most knowledge-intensive activities in manufacturing [1]. In this activity, the product information is mapped onto the available information for various existing manufacturing resources to determine a plan of action to convert raw material into the final product [2]. So we can see that this is a complex process which requires a lot of time and effort.

Nowadays, a lot of customers send a drawing or a 3D model to enterprises and expect to be given production costs and delivery times in response to their enquiry. Due to a very short time at their disposal to provide answers, manufacturers cannot define the whole technological process with defined production times and product price. In most cases, manufacturers give an approximate offer, with an assumed product price and production times based on their experience and on what they can see in the drawing. The authors of this paper aim at developing a system of part classification by means of group technologies. This classificator is used to classify parts into similar groups. So, if we have a new part, we can find a similar part and adopt its technological process to the new part. The authors have also developed an application for the production time estimation. The application is presented here and it is intended only for shafts. The application uses only the example of external turning, and it is orientated towards SMEs, i.e. towards private owners because small and medium enterprises have a large share in the total production in Croatia. The basic features of the single-item production and the small-scale production [3] are:

- a great number of demanding positions in small batches
- short delivery times
- tendency to approximate the prices achieved in mass production.

Today, environmental awareness is growing among people and every day there are more people who think and act "green". All of greening elements [4] can be grouped into the Green Supply Chain Management (GSCM) which by its definition is a concept that encompasses environmental initiatives in all stages of the supply chain as integrating environment thinking into the supply chain management, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to consumers, and end-of-life management of the product after its useful life. So, if we use the application which is presented in this paper instead of CAM, we can reduce energy consumption and we can say that we implement some of the greening elements into our production process.

For example, Antolic [3] uses regression models for the production time per piece estimation. The problem of this model is that it does not take machining parameters into consideration and these parameters have a big impact on the production time per piece. While some authors have optimized the tool path of the machine in order to reduce the production time per piece; the authors of this paper are trying to describe it mathematically so that the time needed for manufacturing can be easily estimated. There are also some researches into the development of a web application for a faster and simple selection of the primary process and a sequence of operations, because these criteria are of major importance for process improvement and cost reduction in production [5].

The activity of the technological process is currently supported by information technology in the form of Computer Aided Process Planning (CAPP) [6]. A considerable amount of research has been carried out to introduce more intelligence into process planning [7]. There are two main approaches of CAPP, a variant and a generative approach. The variant CAPP follows the principle that similar parts require similar plans. Therefore, the process requires a human operator to classify a part, to input part information, to retrieve a similar process plan from a database (which contains previous process plans), and to edit the plan to produce a new variation of the pre-existing process plan. In some variant systems parts are grouped into a number of part families, characterized by similarities in manufacturing methods and thus related to group technology [8].

The generative CAPP utilizes decision logic, formulae, manufacturing rules, geometry based data to determine the processes required to convert raw materials into finished parts. It develops a new plan for each part based on the input on the part's features and attributes. It is more difficult to design and implement a generative CAPP system than a system based on the variant approach, but its advantage is that it does not need help from a human planner [8]. This approach can be usually considered as the hierarchy of [9]:

- setup planning: the determination and sequencing of setups and the selection of machine tools
- operation sequencing: the determination and sequencing of operations and the selection of tools
- operation planning: the determination of machining parameters (cutting speed, feed rate etc.) and trajectories of tools.

Nowadays there are some new approaches in optimizing the technological process planning. Gecevska uses Genetic Algorithms (GAs) as an intelligent process planning. Genetic algorithms are evolutionary search algorithms based on the mechanism of natural selection and natural genetics [10]. There are three fundamental operators involved in the search process of a genetic algorithm: reproduction, crossover and mutation. With these operators the algorithm is given a chance to survive and to produce better strings thereby giving them a chance to have more copies in subsequent generations [10]. Another new approach is the use of an Artificial Neural Network (ANN) which is a biological neural system and its ability to learn through examples. Instead of following a group of well defined rules specified by the user, neural networks learn through intrinsic rules obtained from presented samples [11].

Dae-Hyuk and Suk-Hwan [12] have developed an optimal solution algorithm for process planning for complex machining. The developed algorithm is based on the branch-and-bound approach and heuristics derived from engineering insights. The approach uses a Neutral Process Sequence Graph (NPSG) which is a set of all valid processes for the production of the part. The NPSG contains process information including metal removal volume (turning machining feature), operation (machining operation), tool path pattern (machining strategy), cutting conditions (technology), and cutting tools (cutting tool) [12].

## 2. Classifier of parts

As there is a large number of different parts in production systems, the aspiration towards a classification system has led to the development of group technologies and later to various approaches to the Automated Feature Recognition (AFR) [13]. The main task of group technology is to find similar parts and group them into the same group. There are three main classifications of the AFR approaches: geometric feature extraction, form identification and pattern recognition.

The group technology has two approaches. The first approach is to group parts according to the production plan so that the machine layout in a plant follows the technological process of the production of a particular group of products. This approach uses the visual method, the production flow analysis and the cluster analysis [14]. The second approach is used for grouping parts according to their geometry and technological features.

This paper deals mainly with an approach-simplified combination of the geometric feature extraction and form feature identification in which all parts will be given a code digit which classifies them into a particular family of parts.

The idea of the authors is to make a database of existing technological processes and then to classify them according to the geometry and technological features of parts. This classification is only done for rotation parts which can be symmetrical or nonsymmetrical. Figure 1 shows the classifier of rotational parts.

| | 1. DIGIT | |
|---|---|---|
| ROTATIONAL PART | 0 | symmetric |
| | 1 | nonsymmetric |

| 2. CODE DIGIT FOR CATEGORY | |
|---|---|
| 0 | discs and rings |
| 1 | cylinders and shells |
| 2 | shafts |
| 3 | shorter rotational parts with eccentric surfaces |
| 4 | shafts with eccentric surfaces |

| 3. DIGIT MATERIAL | |
|---|---|
| 0 | steel |
| 1 | aluminium |
| 2 | copper |
| 3 | castings |

| 4. SURFACE ROUGNESS DIGIT AND TOLERANCE CONVERTED INTO SURFACE ROUGNESS | |
|---|---|
| 0 | Ra $\geq$ 0,2 μm turning |
| 1 | 0,1 μm $\leq$ Ra < 0,2 μm turning and grinding |
| 2 | 0,05 μm $\leq$ Ra < 0,1 μm turning, grinding and honing |
| 3 | 0,025 μm $\leq$ Ra < 0,05 μm turning, grinding, honing and superfinishing |

| 5. L/D DIGIT RATIO | |
|---|---|
| 0 | L/D $\leq$ 3 2 clamping, face machining |
| 1 | L/D > 3 2 clamping, face machining and machining of centre hole |

**Fig 1** Classifier of rotational parts [15]

By using this clasifier every part will be given a code which helps us to find similar parts. After we have found a similar part we can adopt its technological process to the new part. With this approach to classifying we can make our own database of technological processes, so that we can find a similar process for new parts.

## 3. Applications for the estimation of production times

In this paper authors present two applications which are made in Microsoft Office Excel. The first one, the application for the calculation of basic data, is used to calculate some general data which are needed to define the manufacturing process. The second application is used for the calculation of production times for shafts. In the second application, the authors of this paper have come up with the idea to divide the shaft into basic shapes [16] as it is not easy to estimate the time required for the production of a shaft. This part of the classification refers to fine and rough profile machining because the number of passes during turning is not the same; therefore, the division of the shaft into basic shapes makes this process of the production time estimation easier. To estimate the production time, it is necessary to calculate the time required for the production of each basic shape, and the sum of all these times will give the production time per piece. Formulae which are used in the application are the formulae which are used in the classical planning of a manufacturing process and they will be presented below. The accuracy of the application was tested by using the CAMWorks software which was used for the calculation of the production time per piece required for the manufacture of twenty shafts. This production time per piece was then compared with the estimated production time per piece obtained by the Excel application. Figure 2 shows types of basic shapes which were used in the application.

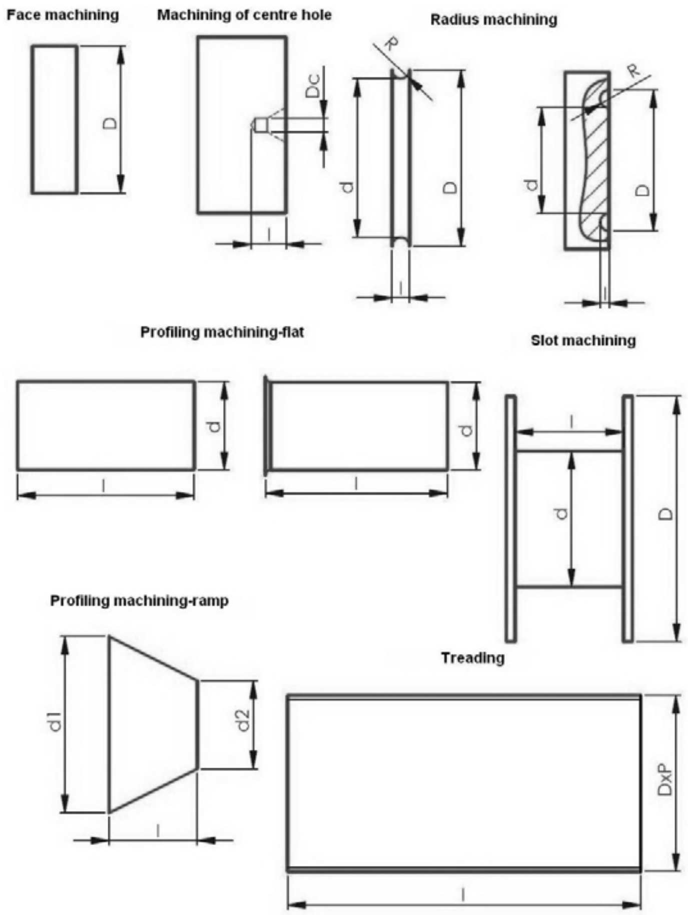


**Fig. 2** Types of basic shapes

### 3.1 Application for the calculation of basic data

The application for the calculation of basic data was developed in Microsoft Office Excel and it has five work sheets and each of them calculate one basic datum (a single item of data). The application calculates the following data with the related formulae:

- Spindle speed,

$$n = \frac{v_c \cdot 1000}{\pi \cdot D} \left[\min^{-1}\right] \tag{1}$$

Where: $v_c$ is the cutting speed calculated in m/min and $D$ is the initial diameter of machining calculated in mm.

- Surface roughness,

$$R_{\max} = \frac{f_{\mathrm{n}}{}^{2} \cdot 125}{R_{\varepsilon}} \; [\mu\mathrm{m}] \tag{2}$$

Where: $f_n$ is the feed rate calculated in mm/rev and $R_\varepsilon$ is the nose radius of the turning grade calculated in mm.

- Required machine power,

$$P = \frac{P_{\mathrm{c}}}{\eta} \; [\mathrm{kW}] \tag{3}$$

Where: $P_c$ is the required cutting power calculated in kW and $\eta$ is the power efficiency.

$$P_{\mathrm{c}} = \frac{v_{\mathrm{c}} \cdot a_{\mathrm{p}} \cdot f_{\mathrm{n}} \cdot k_{\mathrm{c}0,4}}{60 \cdot 10^{3}} \cdot \left[\frac{0,4}{f_{\mathrm{n}} \cdot \sin \kappa_r}\right]^{0,29} \; [\mathrm{kW}] \tag{4}$$

Where: $a_p$ is the cutting depth calculated in mm, $k_{c0,4}$ is the specific cutting force calculated in N/mm$^2$ and $\kappa_\varepsilon$ is the tool entering angle calculated in °.

- Metal removal – V [cm$^3$/min].

$$Q = v_c \cdot a_p \cdot f_n \; [cm^3 / min] \tag{5}$$

This application was made because these data were required for defining machining parameters. Manual calculations of these data require a lot of time and this application was primarily designed to reduce the time needed to calculate the data. In practice, if the user has enough experience with defining machining parameters, he can ignore this application, because applications are fully independent one of the other. In this study, this application was equally used in the calculation of production times by using the Excel application and CAMWorks.

### 3.2 Application for the calculation of production times for shafts

The application for the calculation of the production time per piece for shafts is developed in Microsoft Office Excel. This application consists of the following ten work sheets, i.e. the typical turning processes with respect to the surface:

- machine data
- face machining
- machining of centre hole

- profile machining – straight
- profile machining – tilt
- slot machining
- radius machining
- threading
- support time
- production time per piece $t_1$.

The order of work sheets in the application follows the order of the operations in the technological process. The production time per piece comprises the following times:

- machining time
- rapid time
- support time.

For the calculation of production times, one uses the formulae which are used in the standard process of creating a technological process:

- Spindle speed:

$$n = \frac{v_c \cdot 1000}{\pi \cdot D} \left[\min^{-1}\right] \tag{1}$$

- Technological time:

$$t_\mathrm{t} = \frac{l \cdot i \cdot a_\mathrm{p}}{f_\mathrm{n} \cdot n} \cdot 60 \; [\mathrm{s}] \tag{6}$$

$$t_\mathrm{t} = \frac{l \cdot i \cdot i_\mathrm{s} \cdot a_\mathrm{p}}{f_n \cdot n} \cdot 60 \; [\mathrm{s}] \text{ (only for rough slot machining).} \tag{7}$$

Where: $l$ is the machining length calculated in mm.

- Number of passes:

$$i = \frac{D - d}{a_\mathrm{p} \cdot 2} \; [-] \tag{8}$$

Where: $d$ is the final diameter of machining calculated in mm.

- Number of cutting passes:

$$i_\mathrm{s} = \frac{l}{s} \; [-] \tag{9}$$

Where: $s$ is the amount of overlapping calculated in mm (only for rough slot machining).

- Rapid feed time:

$$t_\mathrm{r} = \frac{l_\mathrm{r}}{v_\mathrm{r} \cdot 1000} \cdot 60 \; [\mathrm{s}] \tag{10}$$

Where: $l_r$ is the length of the rapid feed calculated in mm and $v_r$ is the rapid feed calculated in m/min.

- Support time:

$$t_p = \text{time required for work piece clamping} \cdot \text{number of clamping} + \\ + \text{duration of tool change} \cdot \text{number of tool changes } [\text{s}] \qquad (11)$$

Figure 3 presents how the application works.

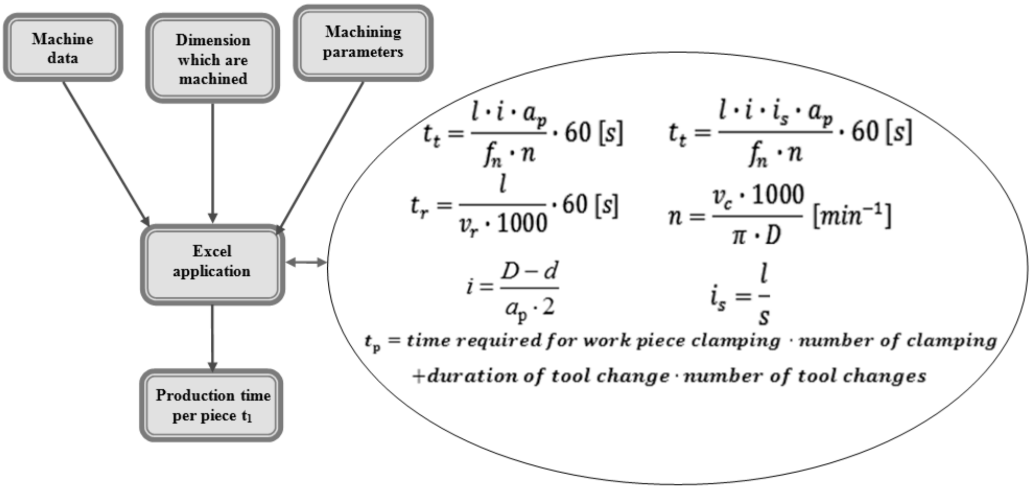


**Fig. 3** Working model of the application

The user needs to input the machining data, the machining dimensions and the machining parameters into the application. Depending on the type of machining operations the user needs to input the following dimensions:

- $D$ [mm]–initial diameter of machining
- $d$ [mm]–final diameter of machining
- $l$ [mm]–machining length
- $R$ [mm]–machining radius
- $D_c$ [mm]–diameter of centre hole machining
- $P_n$ [mm]–tread pitch.

The user also needs to input the following machining parameters:

- $v_c$ [m/min]–cutting speed
- $f_n$ [mm/rev]–feed rate
- $a_p$ [mm]–cutting depth
- $i$ [–] number of passes (only for treading).

When you enter this information, the application automatically puts it into all work sheets. If the diameter in other work sheets changes in the way that spindle speed would be greater than the maximum, the application will automatically change the value to the maximum spindle speed and input it in the work sheet.

After the user inserts the machining dimensions and the machining data, the application will use the above mentioned formulae and will automatically calculate the production time for all operations and add it in the production time per piece work sheet.

The application model has the following limitations:

- The model can be applied to rotational work pieces, i.e. shafts.
- The model is limited only to external turning.

- The operations of milling, grinding, etc., have not been taken into account.
- Profile machining, or more precisely, radius machining is included into the application as part of profile machining – straight. This means that the length of the straight profile machining is increased by the length of the radius. This limitation is introduced to simplify the model, and its impact on the machining time is negligible. Approximately, the error would be less than 0.1 % as it is a small segment of the shaft and its impact on the production time per piece is negligible. For profile – tilt machining such a restriction was not introduced, because the shaft may include a cone, and that simplification would have a great impact on the production time per piece. This constraint is shown in Figure 4.
- Another limitation is the x-axis machining which is not taken into consideration in this application. It can be accounted for by the fact that the sequence of basic shapes in fine and rough profile machining should be defined. The reason for this is that in order to do that, the sequence of basic shapes of rough and fine profile machining should be defined in the application. This would only complicate the work with the application while the impact of errors is not great. This model is only used for manufacturing along the z-axis; exception is face machining that does not take the manufacturing along the z-axis into account but along the x-axis. This limit will have an impact on rough and fine profile machining, and its impact will be greater as cutting speed will be lower, because this increases the technological time and the production time per piece. Also, depending on the design of shafts, and shaft features, some of this limitation will have less impact, because the length of the manufacturing along the x-axis will be much smaller, and some of the shafts will not have manufacturing along the x-axis. In relation to the production time per piece this assumption will not have a major impact on the time estimation which will be shown in the analysis of results. This constraint is shown in Figure 4.

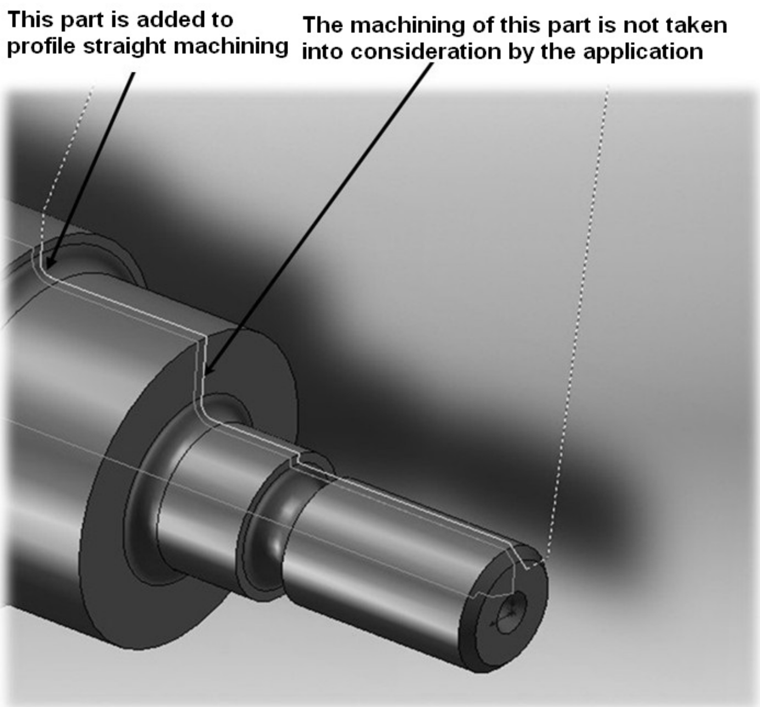


**Fig. 4** Constrains of the application

## 4. Example

To present how the application works, the authors will show the process of the production time estimation for shaft 3. For easier visualization, the authors will show some of the work sheets in which data are entered. The data entered by the user will be shown by a continuous line, while the data given by the application will be shown by a dashed line. Figure 5 shows geometrical features of shaft 3.

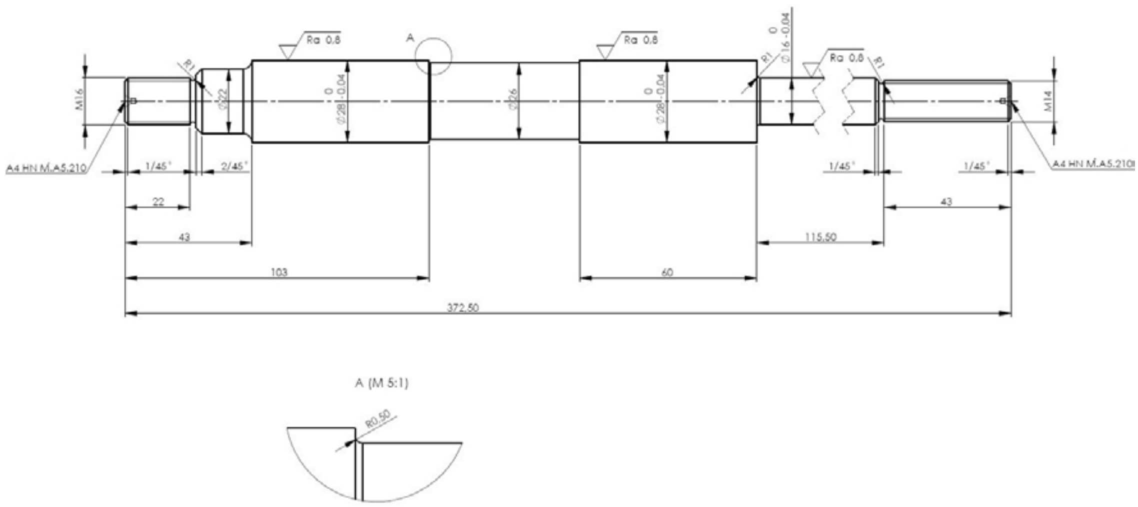


**Fig. 5** Geometrical features of shaft 3

In Figure 5 we can see that the shaft can be divided into 13 basic shapes with the following machining operations:

- face machining (rough 2x, fine 2x)
- machining of the centre hole (2x)
- profile machining – straight (rough 4x, fine 5x)
- profile machining – tilt (rough 4x, fine 4x)
- slot machining (fine 1x)
- radius machining (2x)
- threading (2x).

First, depending on his/her experience, the user can use the application for the calculation of the basic data. If the user already knows the basic data, based on experience he/she can immediately use the application for the production time estimation. But if the user does not know the basic data, then the first logical step would be to check the required power of the machine. This is only done for rough profile machining because there is the greatest cutting force. Figure 6 shows a work sheet for calculating the required power of the machine with entered data.

| Calculating the required power of the machine | |
|---|---|
| Cutting speed-$v_c$ [m/min] | 150 |
| Cutting depth-$a_p$ [mm] | 4,5 |
| Feed rate-$f_n$ [mm/rev] | 0,72 |
| Specific cutting force-$k_{c0.4}$ [N/mm²] | 2050 |
| Tool entry angle -$\kappa_r$ [°] | 95 |
| Power efficiency-η | 0,75 |
| Cutting power-$P_c$ [kW] | 12,54 |
| Required power of the machine-P [kW] | 16,72 |
| Cutting power-$P_c$ [HP] | 17,05 |
| Required power of the machine-P [HP] | 22,73 |

**Fig. 6** Work sheet for calculating the required power of the machine

If the power of the user's machine is greater than the required power we can use this machining parameter for the production time estimation.

After that the user uses the application for the calculation of production times and enters the information about the machine shown in Figure 7.

| Machine information | |
|---|---|
| Maximum spindle speed [min$^{-1}$] | 3500 |
| Maximum speed driven tools [min$^{-1}$] | 2000 |
| Rapid feed-$v_r$ [m/min] | 12 |
| Tool distance change from the front of the shaft-$Z_{sh}$ [mm] | 254 |
| Tool distance change from the front of the shaft-$X_{sh}$ [mm] | 35 |
| Workpiece clamping time [s] | 60 |
| Tool change time [s] | 0,6 |

**Fig. 7** Machine information entered into work sheet

The next step is to enter data into other work sheets. Of course, the user needs to input the required data in those work sheets which are intended for the calculation of the basic shapes which are presented in his work piece. Figure 8 shows data entered by the user and data given by the application for rough and fine face machining of shaft 3.

| Face machining-rough | | | | | | |
|---|---|---|---|---|---|---|
| | I. Operation | II. Operation | III. Operation | IV. Operation | V. Operation | VI. Operation |
| The initial diameter of the machining-D [mm] | 30 | 30 | | | | |
| Cutting speed-$v_c$ [m/min] | 150 | 150 | | | | |
| Feed rate-$f_n$ [mm/rev] | 0,72 | 0,72 | | | | |
| Rapid feed-$v_r$ [m/rev] | 12 | 12 | 0 | 0 | 0 | 0 |
| Spindle speed-n [min$^{-1}$] | 1592 | 1592 | 0 | 0 | 0 | 0 |
| Technological time for single operation-$t_t$ [s] | 0,89 | 0,89 | 0,00 | 0,00 | 0,00 | 0,00 |
| Feed rate time for single operation-$t_r$ [s] | 2,33 | 2,33 | 0,00 | 0,00 | 0,00 | 0,00 |
| Total machining time-t [s] | 6,45 | | | | | |

| Face machining-fine | | | | | | |
|---|---|---|---|---|---|---|
| | I. Operation | II. Operation | III. Operation | IV. Operation | V. Operation | VI. Operation |
| The initial diameter of the machining-D [mm] | 30 | 30 | | | | |
| Cutting speed-$v_c$ [m/min] | 200 | 200 | | | | |
| Feed rate-$f_n$ [mm/rev] | 0,25 | 0,25 | | | | |
| Rapid feed-$v_r$ [m/min] | 12 | 12 | 0 | 0 | 0 | 0 |
| Spindle speed-n [min$^{-1}$] | 2122 | 2122 | 0 | 0 | 0 | 0 |
| Technological time for single operation-$t_t$ [s] | 1,81 | 1,81 | 0,00 | 0,00 | 0,00 | 0,00 |
| Feed rate time for single operation-$t_r$ [s] | 2,33 | 2,33 | 0,00 | 0,00 | 0,00 | 0,00 |
| Total machining time-t [s] | 8,29 | | | | | |

**Fig. 8** Face machining work sheet

Figure 9 shows the data entered by the user and the data given by the application for rough and fine profile straight machining of shaft 3.

| Profile machining-rough | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | I. Operation | II. Operation | III. Operation | IV. Operation | V. Operation | VI. Operation | VII. Operation | VIII. Operation | IX. Operation | X. Operation | XI. Operation |
| The initial diameter of the machining-D [mm | 30 | 30 | 30 | 30 | | | | | | | |
| Final diameter of machining-d [mm] | 16 | 18 | 24 | 18 | | | | | | | |
| Machining length-l [mm] | 44 | 112,5 | 17 | 23 | | | | | | | |
| Cutting speed-$v_c$ [m/min] | 150 | 150 | 150 | 150 | | | | | | | |
| Feed rate-$f_n$ [mm/rev] | 0,72 | 0,72 | 0,72 | 0,72 | | | | | | | |
| Cutting depth-$a_p$ [mm] | 4,5 | 4,5 | 4,5 | 4,5 | | | | | | | |
| Number of passes-i | 2 | 2 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Rapid feed time-$v_r$ [m/min] | 12 | 12 | 12 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Spindle speed-n [min$^{-1}$] | 2076 | 1989 | 1768 | 1989 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Technological time for single operation-$t_t$ [s] | 3,53 | 9,42 | 0,80 | 1,93 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| Feed rate time for single operation-$t_r$ [s] | 1,44 | 2,13 | 1,09 | 1,23 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| Total machining time-t [s] | | | | | | | | | | | 21,58 |

| Profile machining-fine | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | I. Operation | II. Operation | III. Operation | IV. Operation | V. Operation | VI. Operation | VII. Operation | VIII. Operation | IX. Operation | X. Operation | XI. Operation |
| Final diameter of machining-D [mm] | 14 | 16 | 26 | 22 | 16 | | | | | | |
| Machining length-l [mm] | 44 | 112,5 | 171 | 17 | 23 | | | | | | |
| Shaft lenght-$L_{sh}$ [mm] | | | | | | | | | | | 372,5 |
| Cutting speed-$v_c$ [m/min] | 200 | 200 | 200 | 200 | 200 | | | | | | |
| Feed rate-$f_n$ [mm/rev] | 0,18 | 0,18 | 0,18 | 0,25 | 0,25 | | | | | | |
| Rapid feed time-$v_r$ [m/min] | 12 | 12 | 12 | 12 | 12 | 0 | 0 | 0 | 0 | 0 | 0 |
| Spindle speed-n [min$^{-1}$] | 3500 | 3500 | 2449 | 2894 | 3500 | 0 | 0 | 0 | 0 | 0 | 0 |
| Technological time for single operation-$t_t$ [s] | 4,19 | 10,71 | 23,28 | 1,41 | 1,58 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| Feed rate time for single operation-$t_r$ [s] | | | | | | | | | | | 2,61 |
| Total machining time-t [s] | | | | | | | | | | | 43,78 |

**Fig. 9** Profile straight machining work sheet

After all basic shapes are entered into the application, the user also needs to input the number of clamping and the number of tool changes, so that the application could calculate the support time. Figure 10 shows the data input into the work sheet for calculating the support time.

| Support time | |
|---|---|
| Work piece clamping time [s] | 60 |
| Number of clamping | 4 |
| Tool change duration [s] | 0,6 |
| Number of tool change | 11 |
| Support time-$t_P$ [s] | 246,6 |

**Fig. 10** Work sheet for calculating support time

Figure 11 shows the last work sheet in the application, the output work sheet. In this work sheet the user gets the table of the production time per piece depending on the type of machining.

| Production time per piece | |
|---|---|
| Face machining-rough-$t_t$ | 6,45 |
| Face machining-fine-$t_t$ | 8,29 |
| Machining of centre hole-$t_t$ | 9,14 |
| Profile machining-rough-$t_t$ | 21,96 |
| Profile machining-fine-$t_t$ | 47,56 |
| Slot machining-rough-$t_t$ | 0,00 |
| Slot machining-fine-$t_t$ | 24,23 |
| Radius machining-$t_t$ | 6,66 |
| Treading-$t_t$ | 20,11 |
| Technological time-$t_t$ | 144,39 |
| Support time-$t_p$ | 246,60 |
| Production time per piece-$t_1$ | 390,99 |
| Production time per piece-$t_1$ [min] | 6,52 |

**Fig. 11** Output work sheet: production time per piece

## 5. Results

The authors calculated production time for 20 shafts and Figures 12 and 13 show the average differences between the production times per piece obtained by the Excel application and those obtained by the CAMWorks software.

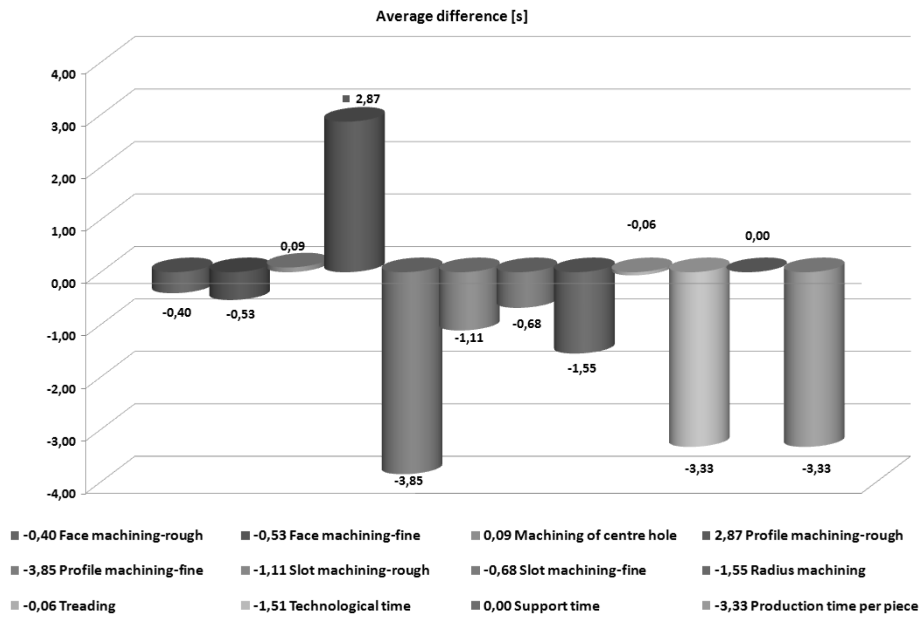


**Fig. 12** Average differences in production times per piece in seconds

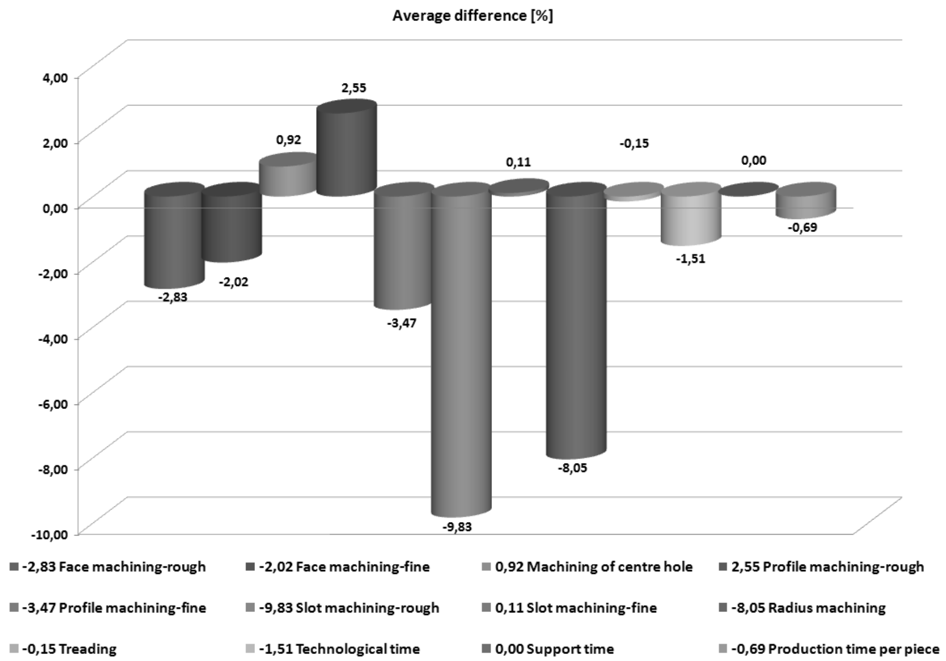


**Fig. 13** Average differences in production times per piece in percentage

In Figure 13 we can see that the highest average difference is in rough slot machining and in radius machining. For rough slot machining, the difference is 9.83 %, while for radius machining the deference is 8.05 %. Although this percentage seems high, both of these operations are short in duration, and the average time difference for rough slot machining is 1.11 seconds, while for radius machining the difference is 1.55 seconds. These differences occur because it is difficult to mathematically express, i.e. to describe this operation. The reason for this is that it is difficult to describe the tool path in these operations. None of these differences has a major impact on the overall difference in the production time per piece.

The biggest impact on the production time per piece has profile machining. For rough profile machining, the difference is 2.87 seconds, while for fine profile machining the difference is 3.85 seconds. These differences occur because of the model limitations described above. This includes the neglect of machining along the x-axis. Since both of these operations are of long duration, their average difference in percentages is not so big. For rough profile machining the difference is 2.55 %, while for fine profile machining the difference is 3.47 %. Face machining, machining of the centre hole and threading are operations which are easy to be expressed mathematically, so in their case the average difference in the production time per piece is practically negligible.

The average time difference for the technological time is 3.33 seconds, or 1.51 %, which is a very small deviation. If we take support time in consideration where the difference is 0.69 %, or 3.33 seconds, we can say that the application is very good at estimating shaft production time.

## 6. Conclusion

This application provides good quality estimation of production times; therefore, it could find its application in the teaching process where students could use it for estimating production times of their work pieces. This application is not fully automatic and the user, i.e. the student, is expected to interact with this application while using it. In addition, the application can be used in industry, in single-item and small-scale production, for estimating the production time per piece of shafts. This paper and its application for the production time estimation is a preliminary research in the field of production time estimation and further steps in research will be to automate and generalize the application.

The application cannot be fully automated if one wanted to do it. The part that could be automated is the recognition of basic shapes, i.e. machining operations. In order to achieve this, a system that would automatically recognize these shapes [13], i.e. operations, should be developed on the basis of 2D and 3D models. The part that cannot be automated is the data input, i.e. the input of parameters related to machining and to the machine into the application because these parameters depend on the type of the machine applied, the shaft material, tools, etc.

Improvements to the application could include the before specified limitations. This means that profile machining should be modified in the way that the model includes the machining along the x-axis. As for the simplification of the model with respect to the before mentioned limits of radius machining which is listed under straight profile machining, it could be divided into separate work sheet, one for radius machining and other for straight profile machining. But that would only complicate the work with the application and would not result in some big improvements in terms of the estimation of production time.

As far as the generalization of the model is concerned, i.e. the introduction of operations of milling, boring, grinding, etc., into the application, generalization can be achieved by adding work sheets referring to these operations. Using this application, one can achieve considerable savings when estimating the production times per piece.

The average difference for 20 shafts between the production times per piece obtained by the Excel application and those obtained by the CAMWorks software is 0.69 %. The results of Antolic's [3] regression model for the production time estimation per piece are between 5 % and 30 % of the calculated (actual) production time per piece depending on the regression model used and the sample size. From this we can see that this application gives better results because this application takes machining parameters into consideration, while Antolic's regression model doesn't, and Antolic's model is generalized for all machining operations (turning, milling, boring).

The estimation of production times per piece by using this application takes 15 minutes regardless of what is used as the basis: a 2D drawing or a 3D model. Savings in time are four times greater with respect to CAMWorks when a 3D model is involved and 5 times greater when a 2D drawing is involved. If CATIA, less user-friendly and more complicated than CAMWorks, is used as CAM software, savings in time are 6 times greater for the 3D model and 7 times greater for the 2D drawing. Therefore, the time required for the estimation of production times is reduced; as a result, the price is also reduced. So, this application can reduce time needed to make an offer, which increases the competitiveness of SMEs.

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