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Preliminary communication

Workpiece Classification Criteria in Automated Process Planning

Maja TRSTENJAK, Predrag ĆOSIĆ, Dražen ANTOLIĆ

Abstract: The classification of products in automated process planning has been researched for more than twenty years now. Automated process planning is a crucial part of computer-aided process planning (CAPP) which enables the user to generate a manufacturing process plan automatically. It is one step towards autonomous process planning required by the fourth industrial (r)evolution. The paper presents process-based software developed for classifying technological properties of a workpiece based on a CAD 3D model. The accessibility of data will be discussed as well as the classifying and working principles of the software that enables both automatic creation of the required manufacturing processes and operation sequencing. The special classification/workpiece coding system will be presented and explained, which is defined by the data from the 3D model that can be reachable or with limited reachability.

Keywords: CAPP; classification of workpieces; Industry 4.0; process planning

1 INTRODUCTION

CAD systems enable the user to create a 3D model while CAM systems enable the user to continue the process and define a part of the process plan. The challenge is how to define the entire process plan automatically, i.e. to include all parameters, machining times and even cost estimations.

To respond to this challenge, data from the CAD model must be extracted and used applying specialized software. As the process planning is mostly very subjective and depends on human knowledge and intuition, there is a wide variety of process plan definitions, depending only on the planner's knowledge. That is why standardized criteria must be established for extracting various data from a 3D model in order to create an appropriate process plan.

The practice in Croatian small and medium-sized enterprises (SMEs) has been an incentive to develop this software. The exact percentage of companies with such needs has not been defined, but from the personal experience of the authors, it can be said that the demand has risen for the last couple of years. The software enables users to generate process plans for variable geometry products minimizing subjectivity and chance for a mistake, and reducing time required for the process plan generation.

1.1 Literature Review

Process planning automation has been a popular research topic ever since CAPP evolved. Full automation has yet not been achieved and is not widely used in companies; furthermore, there are still many approaches to this problem. The first scientific approach is to classify technological properties of products, while the second approach is to fully automate the process planning department and their activities in the company. Decision support systems have also been used in automated processes, supported by machine learning. Tool selection and classification of dielectric fluids used in electrical discharge machining has both upgraded the process planning activities and improved product quality [1]. A special field of automation, sheet metal bending, has also been researched, where a deeper knowledge of the material and its behaviour is required. The process plan is defined in terms of rejection (gauging edge identification, collision detection and tolerance verification) and soft evaluation criteria (ergonomic evaluation and tool set-up evaluation) [2].

The use of feedback data obtained on the factory floor as part of the concept Industry 4.0 is presented as one step ahead of conventional CAPP systems. The activities can be statistically identified via planning algorithms while the level of accuracy and comprehensiveness is increased. The use of data mining, fuzzy logic and decision support enables automated generation of the process plan [3]. But this kind of approach is still to be further developed.

Also, products can be classified into various workpiece groups; then, the workpiece geometry is analysed [4]. Classification coding scheme, based on the product geometry along with the product size can enable quick generation of a manufacturing process plan directly from CAD drawings [5]. The multi-agent approach is also a way of classifying workpieces [6]. The advantages and disadvantages of the manual-visual classification have also been presented; the most effective classification which is also most widely used in CAPP systems is the classification by product coding [7-10], however, the heuristic classification is also possible [11].

2 DEVELOPMENT DATABASES NEEDED FOR PROCESS PLANNING (BTP – Basic Technological Process AND BTD – Basic Technological Database)

The main principle of the automated process plan creation is shown in Fig. 1. The first step is to create a 3D model from which features are extracted according to an algorithm. The algorithm is defined by using previously defined features of the 3D model and the result is stored in the database of quantified 3D model features. This data is then analysed by applying the algorithm for defining the type of the workpiece. This algorithm is created from the database of previously defined workpiece types. The second step is to determine the workpiece type, material, size, complexity and demands. This data is analysed by applying the algorithm for the primary process that is based on previously defined technological processes. This step results in data about the shape of the required raw material and manufacturing processes. In the third step, this data is analysed by applying the algorithm for parameter quantification that was created with the help of the previously defined process plan pattern. This step results in data about product dimensions and manufacturing time. Then, in the fourth step, this data is analysed by applying the algorithm for manufacturing cost quantification that is defined by previously defined cost of work entered manually. The result of this step is data about material, services and cost of work. This workflow (Fig. 1) results in the automatic creation of a process plan.

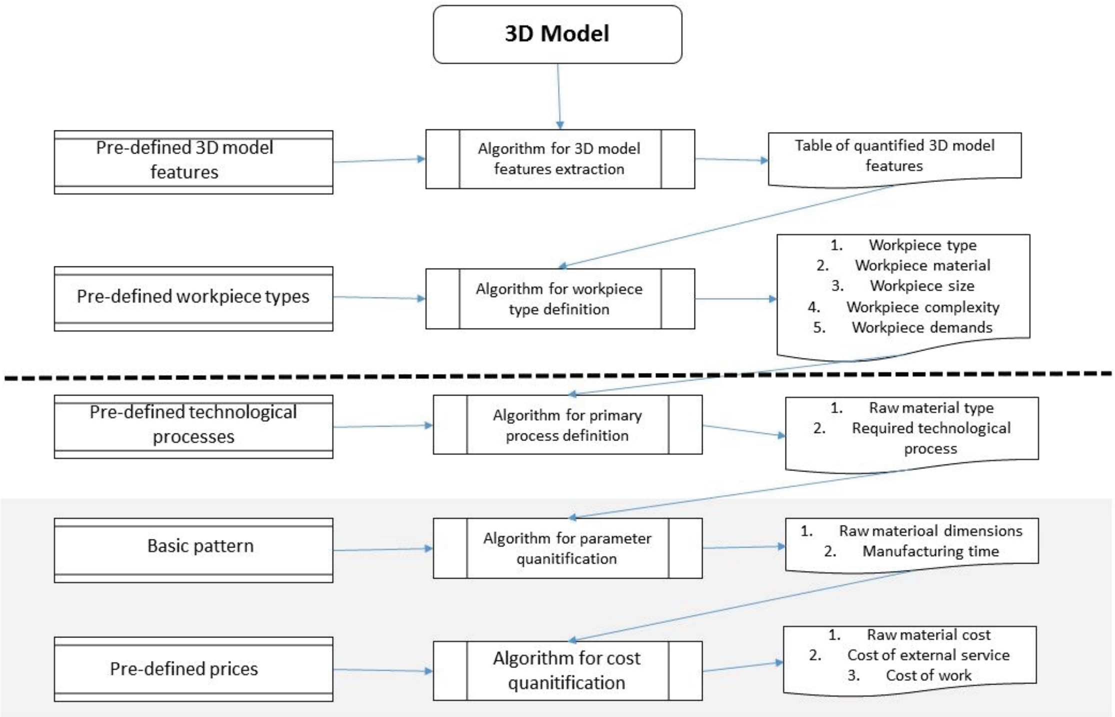


Figure 1 Automated process plan workflow [12]

The classification of technological properties of the product based on the 3D model is best to be done in the STEP format, but this was not the case here because of some specific needs of the company which this software was developed for. The features are extracted from the 3D CAD PTC Creo software which is used by the company, and specialized add-on software called BTP (Basic Technological Process) was created. The BTP software enables the user to define the technological process and the operation sequencing.

To make the 3D model classification possible, the connection between the BTP and the PTC Creo has to be defined: it is defined as the relationship between two file types - .btp and .prt.

.btp (*Basic Technological Process*) is the format of digital writing of technological properties of a 3D model. It is based on the geometric features of the model, primarily on the surfaces, since they undergo some kind of forming operation.

The Basic Technological Database (BTD) process is a set of procedures,i.e. a step between the PTC Creo and the BTP software. Its basic elements and purpose are the following:

Workpiece coding
- based on 3D model features
- unique BTD manufacturing code that contains 14 digits
- every element of the BTD code is defined in advance

Manufacturing process coding
- definition of basic technological process elements
- unique BTD code of the manufacturing process that contains 16 digits
- every element of the BTD code is defined in advance

The connection between the .btp and the .prt file type can be established in two basic ways:

1) by connecting the BTP with the 3D Model
   a) by using a specialized software application
   b) as a 3D model module
2) by importing the file in the .btp file
   a) by using a specialized software application

In this case, the possibility of connecting the .btp with the .prt file was chosen so that the BTP is connected with the 3D modelling software while the model is active in the software. The result of working in the BTP software is a .btp file that contains all the data needed for automatic definition of technological processes and of the order of operations.

2.1 Data Accessibility

Based on their accessibility from the PTC Creo 3D model, data has been grouped into three categories:

Directly accessible data
- The datais directly defined in the .prt format too
  - o mass
  - o moment of inertia

Indirectly accessible data
- Quantification is possible based on two or more data from the .prt format

- number of surfaces
- final number of reference surfaces

\- Quantification is possible by connecting the data from the .prt file with external knowledge databases
  - o material density
  - o accuracy (relation between the surface roughness and dimensional tolerances…)

\- Quantification is possible based upon an additional analysis of the CAD 3D model
  - o model borders
  - o final surface types…

Inaccessible data

\- Non-existing data in the .prt file
  - o strength requirements
  - o surface protection requirements

\- undefined in the .prt file
  - o number of workpiece volumes…

To be able to extract data from the .prt file special algorithms have to be established for each criterion.

Apart from the definition acquired by the new BTP software, some advice can be given to the designer so that the 3D model is analysed as accurately as possible, excluding the possibility of mistakes. The advice refers to the limitations of the new software application which can be easily avoided when certain rules are followed.

2.1.1 Directly Accessible Data

Directly accessible data is closely connected to the 3D modelling process and can be easily extracted from the 3D modelling software. This is independent data whose values are not defined by the values of other data contained in the 3D model. Their quantitative values are internal parameters of the 3D modelling software that come with the information about their functionality within the 3D model. Most commonly, these are features in the model tree (Fig. 2), but also data given using tools that allow for the comment input in the 3D model (ANNOTATE/ Annotations or ANOTATE/Annotation Features or ANOTATE/Datums) (Fig. 1).

Fig. 2 shows a 3D model with additional annotations (comments) that define roughness of the surface, shape and positioning tolerance as well as their transcription in the model tree. Usually, the data on existence or non-existence of certain objects within the 3D model are accessible and countable. When objects are counted by type, a number of identical features within the model is given. This means that the user has now not only qualitative data about the existence of data, but also quantitative data about the number of single objects available in the 3D model.

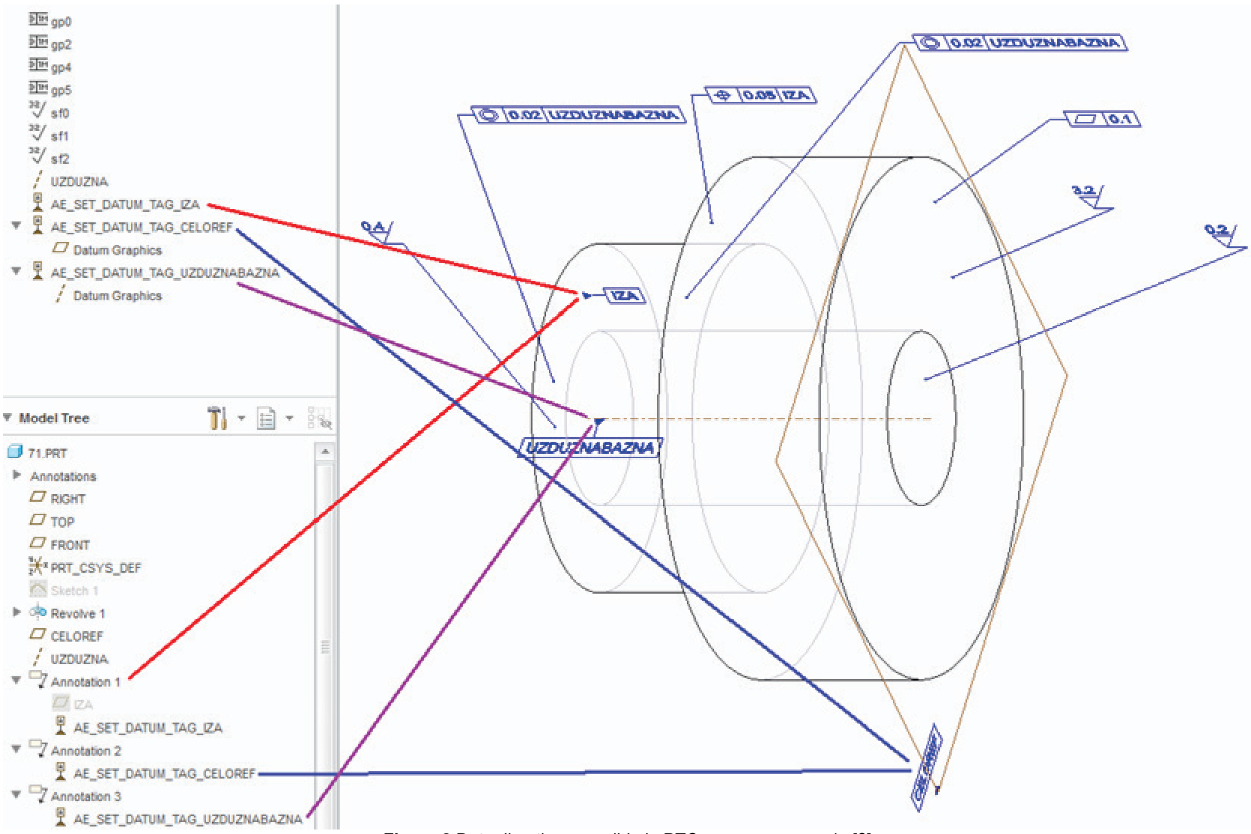


Figure 2 Data directly accessible in PTC creo – an example [2]

2.1.2 Indirectly Accessible Data

Unlike the directly accessible data, indirectly accessible data usually are not independent, they depend on other objects of the 3D model. Although the principle to access the processes is similar, there is a difference in the algorithm complexity in the application presented below. In this example, the number of angles can simply be quantified, but the number of angles with the lowest tolerance requires a more complex code. The problem appears because the model can be differently oriented in space, so the distance coordinates do not provide accurate data on the real distances between the main axes of the coordinate system. To solve this problem, the software algorithm to be presented below is based on dot coordinates of the centre of gravity of the model, as the unique dot in space.

2.1.3 Data Based on Additional Standard 3D Software Tools

Tools whose use is not modelling oriented make an essential part of the 3D software. Tools for the 3D model analysis are very interesting, especially for analysing geometric features. The use of these tools does not affect the 3D model, as they simply show the data and can be used in every phase of modelling.

Data that can be used has a big impact on the selection of adequate technology. This data cannot be directly exported to the new software system, so it somehow has to be implemented permanently in the 3D model. The best solution is to create a new feature that is saved in the tree. This allows for a direct extraction of any quantitative data that the model contains.

3 CODING SYSTEMS

The coding systems have been divided into two groups:

- product coding system
- manufacturing process coding system.

The authors have created this system in order to test it and use it in the private manufacturing company that demands various process plan definitions on daily basis. Both systems consist of 14 digits that allow for the automatic creation of a process plan. The number of the digits are being defined by the specialised needs and features that should be extracted in the practical use. Product coding is done automatically, based on the data collected from the 3D model, but also from the previously generated pattern that has enabled the systematic learning of the software by the user. The user simply needs to create or extract data from the 3D model and the coding is done based on special algorithms which analyse the data in the OTP software, a step between the PTC Creo and the BTP software.

3.1 Product Coding

Parameters of the product coding are the following:

Type… K1
SHAPE
  outer…K2
  inner…K3
  radial…K4
  axial…K5
SPACE
  size…K6
  massiveness…K7
  thickness…K8
  complexity…K9
REQUIREMENTS
  material…K10
  heat treatment…K11
  surface protection…K12
  precision…K13
Amount…K14

An example of the classification of the *parameter K1 – Type* is shown in Fig. 4.

It can be seen that the product (3D) model has been divided into nine categories of type. Every category has its number which represents a single digit in the final 14 digit long code. K1, the first digit of the code stands for the standard product available on the market (which is a part the product in question) (1), standard semi-finished product (2), special semi-finished product (3), part as defined in the 3D model (4), non-dismantable assembly (5), dismantable assembly (6), design (7), mechanism (8) and other (9).

Fig. 5 shows the process of defining the second digit of the product type code. This type is also divided into nine groups: laminar (1), rotational (2), hexagonal (3), prismatic (4), combined (5), profile (6), spatial (7), sheet metal (8) and other (9).

The following twelve digits of the product type code are determined according to the same principle – each group of 12 digits is subdivided into nine descriptive categories.

When this process of defining is completed the code consisting of 14 digits is finally generated (Fig. 6).

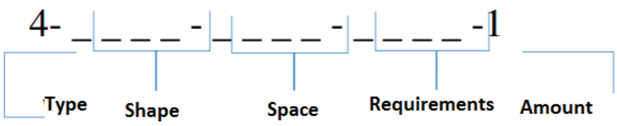


Figure 3 Product code [12]

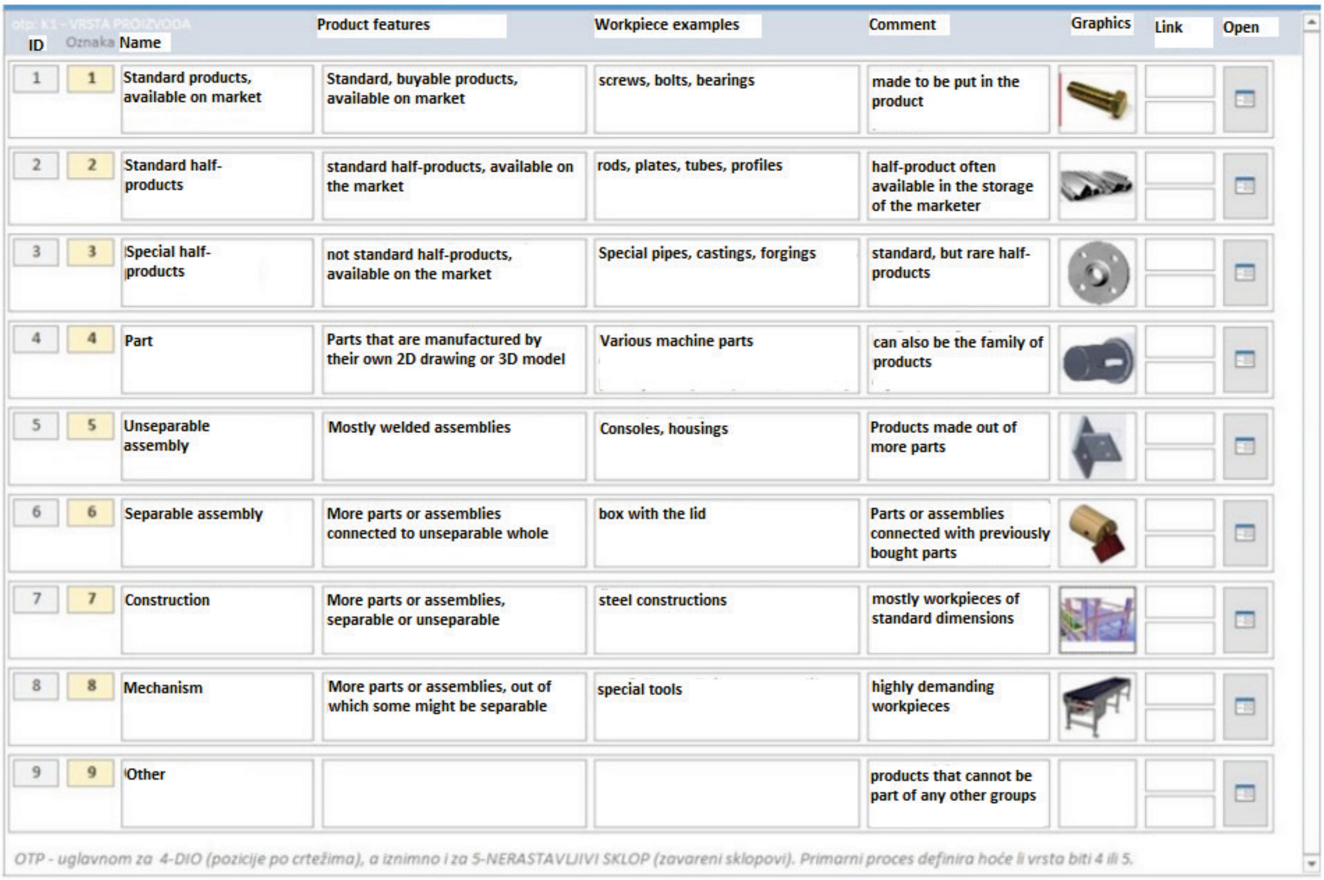
As shown in Fig. 3, the first digit refers to the type, the next three digits refer to the shape, then, the three digits refer to the space features, followed by the three digits that refer to the complexity and the final digit refers to the amount.

3.2 Manufacturing Process Coding

Manufacturing process coding refers to required technologies and it is the final step in the creation of the process plan. The parameters are divided into three basic groups:

1. EXTERNAL SERVICE (PRIMARY PROCESS)
   casting and rolling
   forming, extrusion, bending, drawing
   joining processes
   machining
   heat treatment
   surface engineering
2. MATERIAL
   raw material type
3. WORKING
   sawing
   forging
   turning
   drilling
   milling
   special
   fine (additional)

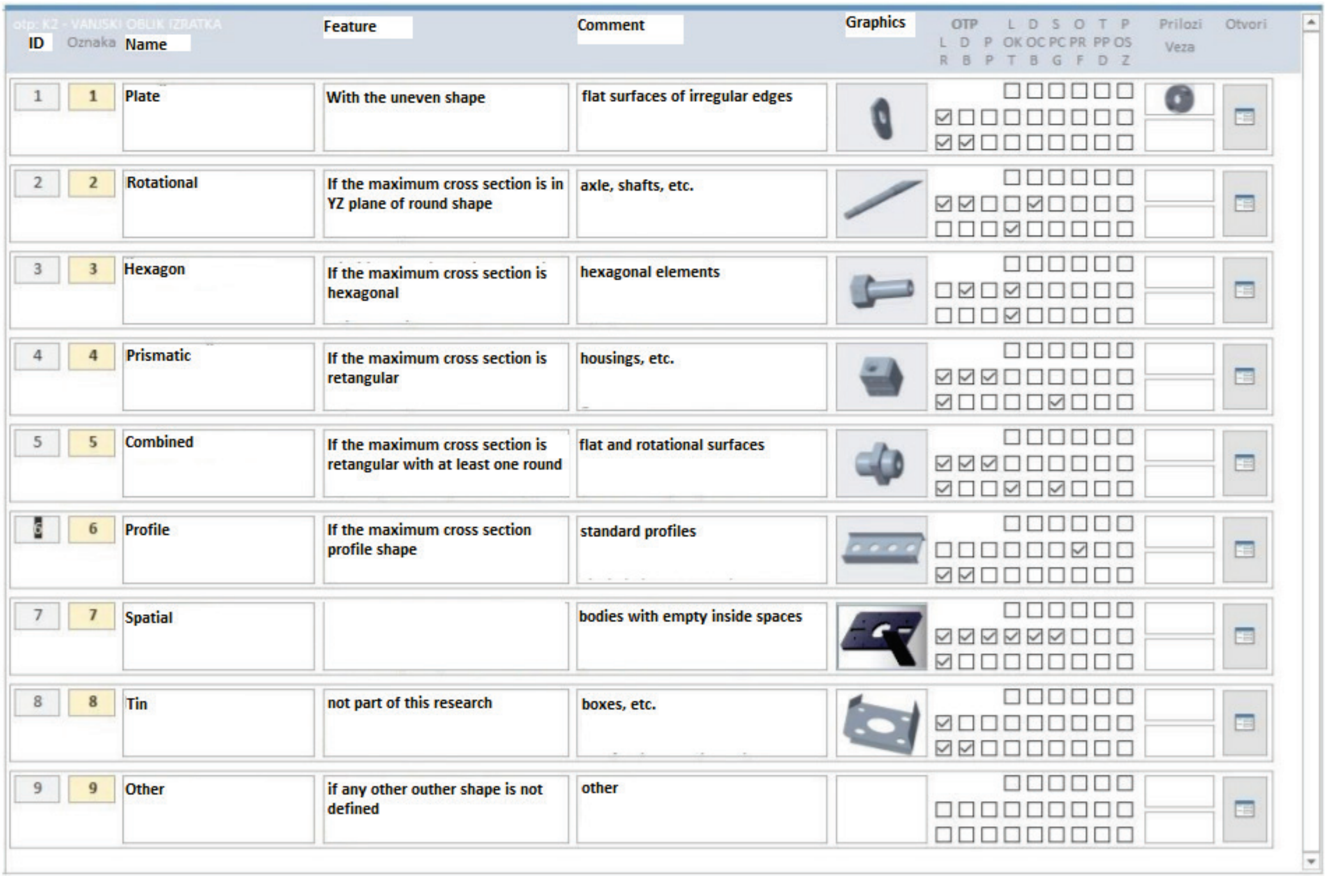
The 14-digit code is developed in the same way as the product type code, based on the mentioned criteria.



ID	Oznaka	Name	Product features	Workpiece examples	Comment	Graphics	Link	Open
1	1	Standard products, available on market	Standard, buyable products, available on market	screws, bolts, bearings	made to be put in the product			
2	2	Standard half-products	standard half-products, available on the market	rods, plates, tubes, profiles	half-product often available in the storage of the marketer			
3	3	Special half-products	not standard half-products, available on the market	Special pipes, castings, forgings	standard, but rare half-products			
4	4	Part	Parts that are manufactured by their own 2D drawing or 3D model	Various machine parts	can also be the family of products			
5	5	Unseparable assembly	Mostly welded assemblies	Consoles, housings	Products made out of more parts			
6	6	Separable assembly	More parts or assemblies connected to unseparable whole	box with the lid	Parts or assemblies connected with previously bought parts			
7	7	Construction	More parts or assemblies, separable or unseparable	steel constructions	mostly workpieces of standard dimensions			
8	8	Mechanism	More parts or assemblies, out of which some might be separable	special tools	highly demanding workpieces			
9	9	Other			products that cannot be part of any other groups			

OTP - uglavnom za 4-DIO (pozicije po crtežima), a iznimno i za 5-NERASTAVLJIVI SKLOP (zavareni sklopovi). Primarni proces definira hoće li vrsta biti 4 ili 5.

Figure 4 K1 - Product coding–the first digit definition – workpiece type [12]



ID	Oznaka	Name	Feature	Comment	Graphics	OTP	Prilozi Veza	Otvori
1	1	Plate	With the uneven shape	flat surfaces of irregular edges				
2	2	Rotational	If the maximum cross section is in YZ plane of round shape	axle, shafts, etc.				
3	3	Hexagon	If the maximum cross section is hexagonal	hexagonal elements				
4	4	Prismatic	If the maximum cross section is retangular	housings, etc.				
5	5	Combined	If the maximum cross section is retangular with at least one round	flat and rotational surfaces				
6	6	Profile	If the maximum cross section profile shape	standard profiles				
7	7	Spatial		bodies with empty inside spaces				
8	8	Tin	not part of this research	boxes, etc.				
9	9	Other	if any other outher shape is not defined	other				

Figure 5 K2 – Product coding – the second digit definition – external shape [12]

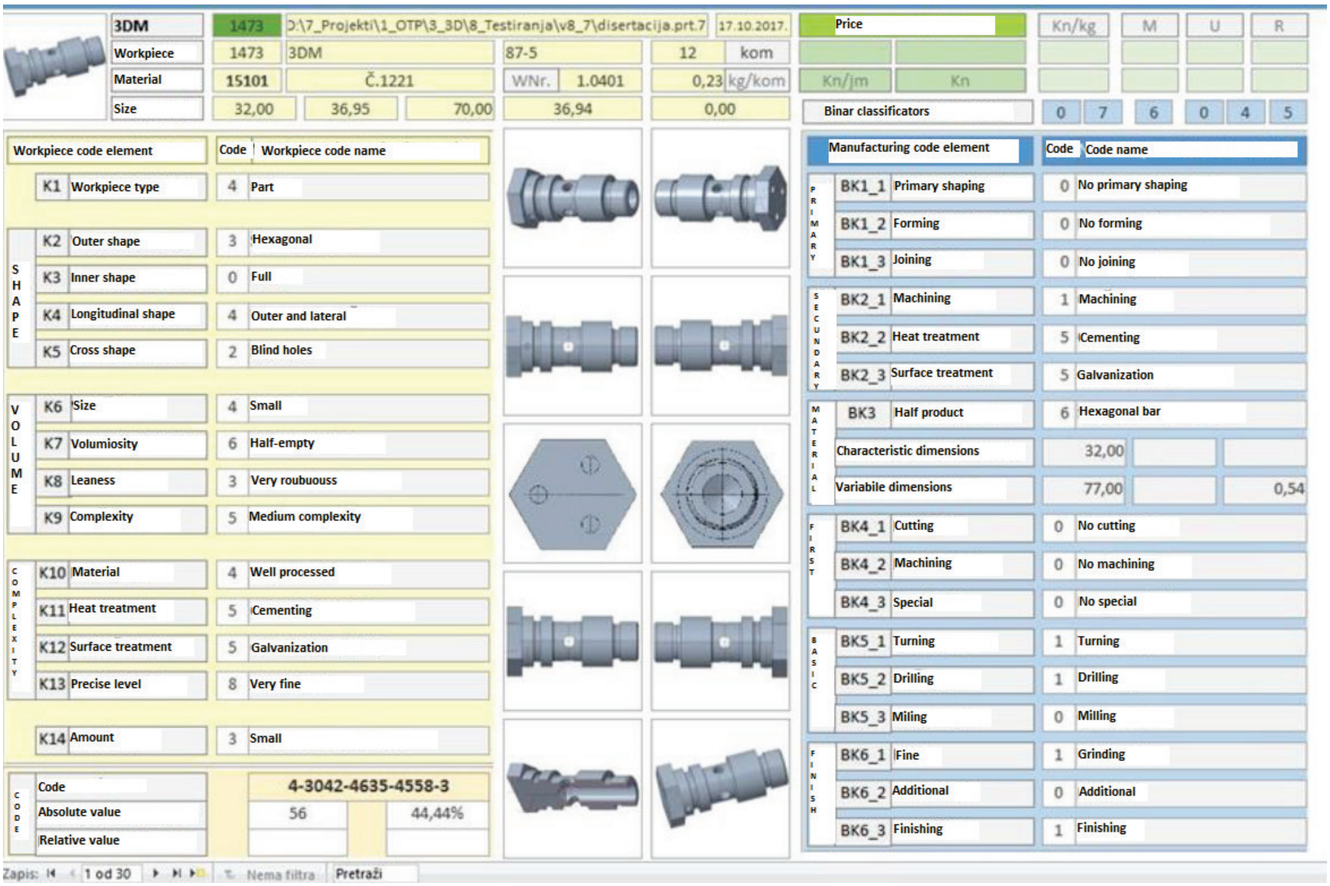


Figure 6 Final process plan [12]

3.3 Process Plan

The final process plan (Fig. 6) consists of the following information:

- *WORKPIECE*
  - *WORKPIECE DATA*
    - material quality
    - amount
    - BTD code
- *SERVICES*
  - *PRIMARY PROCESS DATA*
    - manufacturing process type
    - technological processes
- MATERIAL
  - RAW MATERIAL DATA
    - semi-finished products
- WORKING
  - IN MOST CASES: MACHINING
    - procedures
    - operation sequences
    - workplaces

Due to the automatic definition of the process plan the user can now automatically define manufacturing time and delivery time as well as estimate the cost.

4 CONCLUSION

Automated process planning including the classification of technological properties of products is still a popular research topic. This paper has presented one solution to the automated process planning by extracting geometric features from a PTC Creo 3D model and by developing product and manufacturing process coding by which the process plan that includes the information about the technology, time and cost estimation can be defined.

The classification has been done for both the product and manufacturing process features and it has shown that by using specially developed algorithms in the new BTP software, such as the add-on PTC Creo, a process plan can be generated accurately and automatically.

Future work will consider upgrade to the STEP 3D model format as well as the use of the software within the Industry 4.0 concept. The digitalization requires establishing a connection between the software and other parts of the company and using this kind of data to optimize the processes and improve product quality.

5 REFERENCES

[1] Filipič, B. & Junkar, M. (2000). Using machine learning to support decision making in machining processes. *Computers in Industry*, 43, 31-41. https://doi.org/10.1016/S0166-3615(00)00056-7

[2] Duflou, J. R., Vancza, J., & Aerens, R. (2005). Computer aided process planning for sheet metal bending: A state of art. *Computers in Industry*, 56, 747-771. https://doi.org/10.1016/j.compind.2005.04.001

[3] Schuh, G. et al. (2017). Knowledge discovery approach for automated process planning. *Procedia CIRP 63*, 539-544. https://doi.org/10.1016/j.procir.2017.03.092

[4] Jagirdar, R., Jain, V. K., & Batra, J. L. (2001). Characterization and identification of forming features for 3-D sheet metal components. *International Journal of Machine Tools and Manufacture*, 41, 1295-1322.

https://doi.org/10.1016/S0890-6955(01)00006-2
[5] Jiang, B. et al. (1999). An automatic process planning system for the quick generation of manufacturing process plans directly from CAD drawings. *Journal of Materials Processing Technology*, 87, 97-106. https://doi.org/10.1016/S0924-0136(98)00337-9
[6] Andreadis, G. et al. (2014). Classification and Review of Multi-Agents Systems in the Manufacturing Section. *Procedia Engineering*, 69, 282-290. https://doi.org/10.1016/j.proeng.2014.02.233
[7] Kuric, I. & Kuba, J. (2007). New Methods of Product Classification for Computer Aided Process Planning Systems. *Engineering Review, 27*(1), 13-17.
[8] Rojek, I. (2010). The Coding System for Automatic Injection Mold Integrated CAD/CAPP. Control and Cybernetics, 39 (1), 55-68
[9] Wang, L., Kailing, L., & Liang, C. (2010). Automatic process planning of mold components with integration of feature recognition and group technology. *Advanced Materials Research, 97*(101), 3413-3417. https://doi.org/10.4028/www.scientific.net/AMR.97-101.3413
[10] Sugar, P., Sugarova, J., & Kolnik, M. (2011). A New Sheet metal parts classification and coding system. *Annals & Proceedings of DAAM International 2011, 22*(1), 341-342
[11] Klauck, C., Legleitner, R., & Bernardi, A. (1992). *Heuristic classification for automated CAPP*. Deutsches Forschungzentrum für Künstlishe Intelligenz GmbH, Research Report.
[12] Antolić, D. (2017). Algorithm for Technological Classification based on CAD 3D Model of the Workpiece, *doctoral thesis* (Croatian language). University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, Zagreb.

Contact information:

Maja TRSTENJAK, mag. ing. mech.
(Corresponding author)
University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture,
Ivana Lučića 5, 10000 Zagreb, Croatia
E-mail: maja.trstenjak@fsb.hr

Predrag ĆOSIĆ, PhD, Full Professor
University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture,
Ivana Lučića 5, 10000 Zagreb, Croatia
E-mail: predrag.cosic@fsb.hr

Dražen ANTOLIĆ, PhD
Antolić Dražen, Proizvodno poduzetništvo
Ilirski trg 5, 10000 Zagreb, Croatia
E-mail: drazen@adpp.hr