KAUNAS UNIVERSITY OF TECHNOLOGY

FACULTY OF MECHANICAL ENGINEERING AND DESIGN

Laimonas Meilutis

INVESTIGATION OF COMPUTER AIDED TECHNOLOGICAL PROCESS PLANNING

Master's Degree Final Project

Supervisor
Assoc. prof. dr. Rasa Mankutė

KAUNAS, 2017

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Industrial Engineering and Management (code 621H77003)

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KAUNAS UNIVERSITY OF TECHNOLOGY

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(Title and code of study programme)

"Investigation of computer aided process planning in manufacturing enterprises"

DECLARATION OF ACADEMIC INTEGRITY

____ __________________ 20 _____

Kaunas

I confirm that the final project of mine, **Laimonas Meilutis**, on the subject "Investigation of computer aided technological process planning" is written completely by myself; all the provided data and research results are correct and have been obtained honestly. None of the parts of this thesis have been plagiarized from any printed, Internet-based or otherwise recorded sources. All direct and indirect quotations from external resources are indicated in the list of references. No monetary funds (unless required by law) have been paid to anyone for any contribution to this thesis.

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MASTER STUDIES FINAL PROJECT TASK ASSIGNMENT
Study programme INDUSTRIAL ENGINEERING AND MANAGEMENT

The final project of Master studies to gain the master qualification degree, is research or applied type project, for completion and defence of which 30 credits are assigned. The final project of the student must demonstrate the deepened and enlarged knowledge acquired in the main studies, also gained skills to formulate and solve an actual problem having limited and (or) contradictory information, independently conduct scientific or applied analysis and properly interpret data. By completing and defending the final project Master studies student must demonstrate the creativity, ability to apply fundamental knowledge, understanding of social and commercial environment, Legal Acts and financial possibilities, show the information search skills, ability to carry out the qualified analysis, use numerical methods, applied software, common information technologies and correct language, ability to formulate proper conclusions.

1. Title of the Project

Investigation of computer aided technological process planning

Approved by the Dean Order No.V25-11-8, 21 April 2017

2. Aim of the project

To analyse different types of CAPP systems and to see which type would suit best for Lithuanian metal manufacturing enterprises.

3. Structure of the project

Introduction, 1. Overview of CAPP software, 2. Looking for CAPP software systems, 3. Analysis of process planning with different systems, Conclusions, References, Appendices

4. Requirements and conditions

The overview has to be made using theoretical sources. In order to find the solutions to the tasks evaluations have to be carried out, its results compared and analysed. Results and suggestions have to be based with arguments. The final project has to be prepared according to KTU regulations and requirements.

5. This task assignment is an integral part of the final project

6. Project submission deadline: 20__ ________ __st.

Student _____________________________ _____________________
(*Name, Surname of the Student*) (*Signature, date*)

Supervisor _____________________________ _____________________
(*Position, Name, Surname*) (*Signature, date*)

Laimonas Meilutis. Investigation of computer aided technological process planning. Master's Final Project / supervisor assoc. prof. dr. Rasa Mankutė; Faculty of Mechanical Engineering and Design, Kaunas University of Technology.

Research field and area: Technological Sciences, Production engineering.

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SUMMARY

Manual labour becoming a luxury and industrial automation becoming more and more popular, computer aided process planning (CAPP) has become a must in today's manufacturing companies. In this work CAPP systems and their applications in Lithuanian manufacturing enterprises were analysed. The aim was to analyse main types of computer aided process planning systems and choose the one that fits Lithuanian manufacturing companies. During the analysis, it was noticed that no new of the mentioned system were developed for 20 years. A question arose – why did this happen as the need for this kind of systems has remained and even kept growing. While analysing literature sources and systems it was found that CAPP system being a bridge between CAD and CAM systems, it was merged with the mentioned CAD system. To compare old and new type systems, 2 different systems were analysed: stand-alone variant CAPP system (CAME SAT) and integrated generative process planning system, merged with CAD software (SolidWorks). With the help of three prepared test tasks systems functionality, ease of use, reliability and viability was analysed and compared.

To find out which system best meets todays manufacturing requirements, the results and applications of both systems were analysed and compared. The situation of Lithuanian manufacturing enterprises was also analysed to see their automation level and the need for computer aided process planning systems.

Based on results of the analysis, at the end of the work recommendations were made highlighting the best suited CAPP system type for Lithuanian manufacturing enterprises.

Meilutis, Laimonas. Technologinių procesų kompiuterinio projektavimo tyrimas. Magistro baigiamasis projektas / vadovas doc. dr. Rasa Mankutė; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas.

Mokslo kryptis ir sritis: Technologijos mokslai, Gamybos inžinerija.

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Kaunas, 2017. 57 p.

SANTRAUKA

Rankų darbui tapus prabanga bei plintant gamybos automatizavimui, kompiuterizuotas procesų planavimas (angl. Computer Aided Process Planning, CAPP) tampa šių laikų gamybos kompanijų būtinybe. Darbe buvo analizuotos CAPP sistemos ir jų taikymo Lietuvos gamybos kompanijose ypatumai bei galimybės. Tyrimu siekta išanalizuoti pagrindinius kompiuterizuoto proceso planavimo sistemų tipus ir išrinkti tinkančią Lietuvos gamybos kompanijoms. Atliekant tyrimą pastebėta, jog minėtosios sistemos maždaug prieš 20 metų buvo nustotos kurti. Kilo klausimas – kodėl taip atsitiko, nes poreikis šioms sistemoms išliko ir auga. Analizuojant literatūros šaltinius ir sistemas nustatyta, jog CAPP sistemai esant jungiamajai grandžiai tarp CAD ir CAM sistemų, ji buvo prijungta prie minėtos CAD sistemos programinės įrangos. Siekiant palyginti senojo ir naujojo tipo programas, buvo analizuojamos 2 skirtingu principu veikiančios sistemos: savarankiška variantinė CAPP sistema (CAME SAT) ir integruota generacinė procesų planavimo sistema, sujungta su CAD programine įranga (SolidWorks). Buvo parengtos trys testinės užduotys, kurių pagalba buvo analizuojamas ir lyginamas sistemų funkcionalumas, naudojimo paprastumas, patikimumas ir tinkamumas.

Siekiant atrasti, kuri sistema geriausiai atitinka šių dienų gamybos reikalavimus, buvo analizuojami ir lyginami abiejų sistemų tyrimo rezultatai ir taikymo ypatumai. Darbe taip pat analizuojama ir Lietuvos gamybos kompanijų situacija, siekiant pamatyti automatizavimo lygmenį ir kompiuterizuoto procesų planavimo programinės įrangos poreikį.

Atsižvelgiant į analizės ir tyrimo rezultatus, darbo pabaigoje pateikiamos rekomendacijos, nurodančios geriausiai Lietuvos gamybos kompanijoms tinkantį CAPP sistemos tipą.

CONTENTS

INTRODUCTION

With computers growing involvement in every step of our lives, a new approach to increase efficiency and make manufacturing quality more stable has been developed that would integrate computers into the manufacturing processes.

To stress the importance of integration, the Computer and Automation System Association of the Society of Manufacturing Engineers gives the following definition: “CIM is the integration of the total manufacturing enterprise through the use of integrated systems and data communications coupled with new managerial philosophies that improve organizational and personnel efficiency. (Singh, 1996) [1].

Computer-integrated manufacturing was a new manufacturing approach of using computers to aid in the manufacturing process. There are a number of computer-aided techniques:

- CAD (computer-aided design)
- CAE (computer-aided engineering)
- CAM (computer-aided manufacturing)
- CAPP (computer-aided process planning)
- CAQ (computer-aided quality assurance)
- PPC (production planning and control)
- ERP (enterprise resource planning)

In this work CAPP (computer-aided process planning) system will be analysed. It is now widely used all around the world and most of the factories would be crippled without some form of it.

Process planning is defined as the activity of deciding which manufacturing processes and machines should be used to perform the various operations necessary to produce a component, and the sequence that the processes should follow. Alternatively, process planning is the systematic determination of the detailed methods by which parts can be manufactured from raw material to finished product [2]. Computer aided process planning evolved to replace manual process planning and to automatically select the most suited processes and machines.

There five different stages of process planning:

- Stage I - Manual classification; standardized process plans
- Stage II - Computer maintained process plans
- Stage III - Variant CAPP
- Stage IV - Generative CAPP
- Stage V - Dynamic, generative CAP

Variant and generative CAPP systems are the ones used nowadays, but stand-alone CAPP software is hard to find as it has been integrated into other CIM software.

Lithuania's manufacturing industry is small, but lively and has been growing since the recession of 2009. Companies are upgrading and automating their processes and so CIM approach is one of the milestones in their modernization.

The aim of this work is to analyse different types of CAPP systems and to see which type would suit best for Lithuanian metal manufacturing enterprises.

To achieve successful analysis for the research the aim is divided into tasks:

1. Analyse the different existing CAPP systems.
2. Simulate tasks for stand-alone CAPP system (CAME SAT) and integrated process planning in CAD software (SolidWorks).
3. Analyse and compare the result of both types of systems.
4. Analyse the situation of Lithuanian manufacturing enterprises.
5. Offer recommendations for which CAPP system would be most suited for Lithuanian manufacturing enterprises.

1. OVERVIEW OF CAPP SOFTWARE

1.1. CAPP working principle

Given the engineering design of an item which has to be manufactured, process planning is the act of generating an ordered sequence of the manufacturing operations necessary to produce that part within the available manufacturing facility [3]. Process planning was always done by human workers; it was a serious job that required lots of experience. The manufacturing engineer, who oversaw process planning would have to be experienced in all of the processes, equipment, materials, tools etc. that are involved in that production plant. It was difficult to develop a steady method to measure the success and quality of such work as everything depended on the level of expertise the engineer had and that cannot be quantified.

With ever evolving manufacturing, introduction of new products, products life cycles becoming shorter and shorter, it has become too difficult for engineers to be on top of their game and have enough expertise to create process plans for new products.

One of the earliest CAPP systems was developed under contract to Computer Aided Manufacturing-International, Inc. (CAM-I) in the USA. CAM-I is a not-for-profit organization, formed in the U.S. in the early 1970s by a number of major American manufacturing companies, to provide leadership in the development of computer aids to manufacturing industry [3].

Computer aided process planning (CAPP) is an increasingly important part of the interface between the design and manufacturing engineering processes. A CAPP system provides an important digital link between a CAD model and manufacturing instructions. The CAPP system is developed while the manufacturing method is being determined, and is used and revised throughout the life of the production system. CAPP includes the hardware systems involved in the process, the personnel operating these hardware system, and data stored about current and past production. Some CAPP system automate the manufacturing process by making real-time decisions based on the model of the part, sensors in the assembly hardware, or other sources. Together, the CAPP system's components will determine how to efficiently manufacture the product [4].

PROCESS PLAN ACE Inc.

Part No. S0125-F Material: steel 4340Si
Part Name: Housing
Original: S.D. Smart Date: 1/1/89 Changes: ______ Date: ______
Checked: C.S. Good Date: 2/1/89 Approved: T.C. Chang Date: 2/14/89

No.	Operation Description	Workstation	Setup	Tool	Time (Min)
10	Mill bottom surface1	MILL01	see attach#1 for illustration	Face mill 6 teeth/4" dia	3 setup 5 machining
20	Mill top surface	MILL01	see attach#1	Face mill 6 teeth/4" dia	2 setup 6 machining
30	Drill 4 holes	DRL02	set on surface1	twist drill 1/2" dia 2" long	2 setup 3 machining

Fig. 1.1. Example of a simple process plan

At first, the computer aided process planning systems were nothing more than computerized card index systems. Hardcopy process plans were redrawn to make them digital (Fig. 1.1.). Standardizing process plans still did not solve the main problem – a need for flexible system, because now the plans were standardized and for a new product one would need to update the existing plan. This has become the backbone of a successful CAPP system – a good classification and coding system.

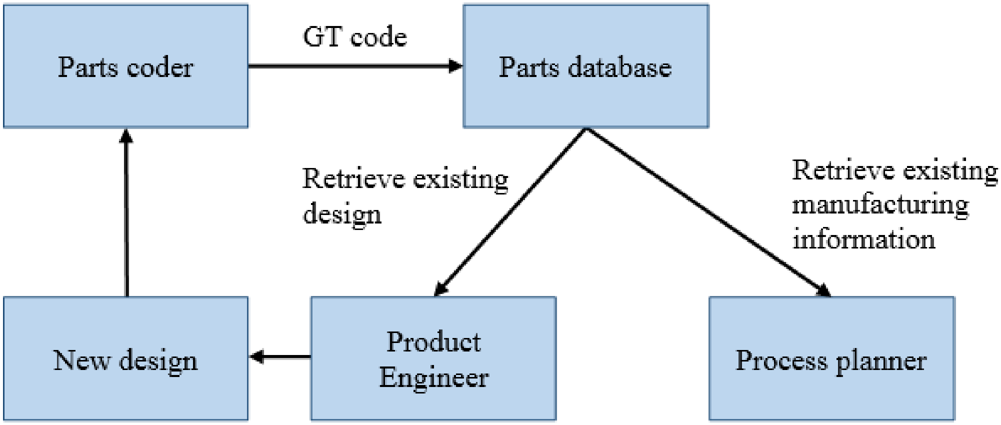


Fig. 1.2. Computer aided process planning using classification systems

CAPP is based on the use of classification and coding system (Fig. 1.2.) to group parts into part families. Each part family has a common, or nearly common, process plan, which is stored in the computer as a standard plan for that family. Each standard plan is a sequential set of instruction that includes general processing requirements, jig and tool data, machine data, and detailed operating instructions (Fig. 1.3.). In the CAPP system, these standard plan details are called work elements and work element parameters [3].

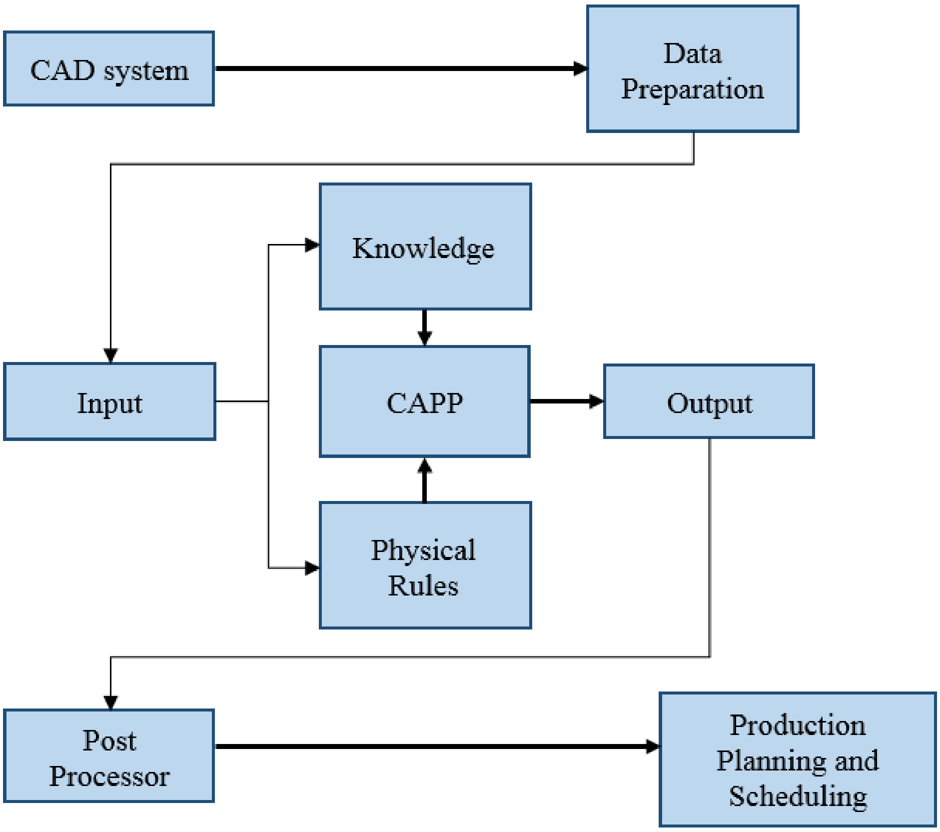


Fig. 1.3. Basic CAPP concept

Computer-aided process planning system is relatively easy to use and does not require any special computer skills from the person who's using it. Probably the most complicated part of the system is its implementation and setting up.

1.2. Types of CAPP systems

According to Kenneth Crow from DRM Associates [5] manufacturers have been pursuing an evolutionary path to improve and computerize process planning in the following five stages:

- stage I - Manual classification; standardized process plans;
- stage II - Computer maintained process plans;
- stage III - Variant CAPP;
- stage IV - Generative CAPP;
- stage V - Dynamic, generative CAPP.

First two stages were covered in the previous chapter, after them the true computer-aided process planning systems appeared when previous attempts of simply classifying plans or storing them digitally, evolved in to a variant computer-aided process planning. However, variant CAPP (Fig. 1.4.) is based on a Group Technology (GT) coding and classification approach to identify a larger number of part attributes or parameters. These attributes allow the system to select a baseline process plan for the part family and accomplish about ninety percent of the planning work. The planner will add the remaining ten percent of the effort modifying or fine-tuning the process plan. The baseline process plans stored in the computer are manually entered using a super planner concept that is, developing standardized plans based on the accumulated experience and knowledge of multiple planners and manufacturing engineers [5].

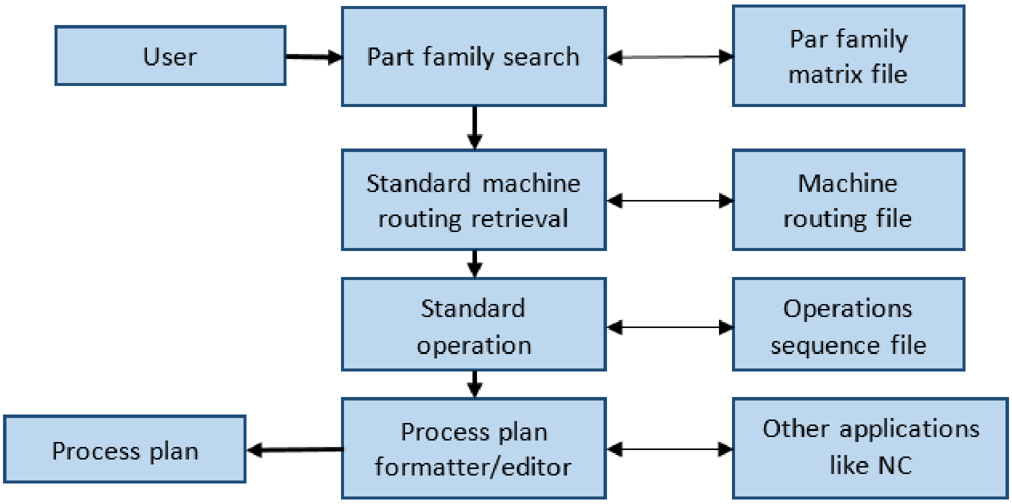


Fig. 1.4. Variant process planning structure

Starting at this stage, the system evolved enough to be more accurate and sustainable (Table 1.1.). Now it has become possible to keep track of the quality and the results gained by planning the process in such way would be more similar in quality as it would less depend on a single manufacturing engineer and his experience in the field. "Although planning activities cover 10%-20% of overall product development time only, the planning quality itself and gained results influence this time significantly." [6]. But as stated above, it still requires an input from an engineer to finish up and fine tune the process plan to bring it to completion. This still reduced the quality and took a long time to do.

Table 1.1. Evaluation of the variant process planning [6]

Advantages	Disadvantages
• Works well with medium and low product mixes • Development time of the system is short • Is usable with other CIM systems • Variant process is very universal and can be used in different industries	• GT codes can get old and lose its purpose in a short time • Compared to generative systems, even with its quick development, the planning itself is slower • Has a bigger chance for errors than the generative system

The next stage of evolution is toward generative CAPP (Stage IV) (Fig. 1.5.). At this stage, process planning decision rules are built into the system. These decision rules will operate based on a part's group technology or features technology coding to produce a process plan that will require minimal manual interaction and modification (e.g., entry of dimensions) [5].

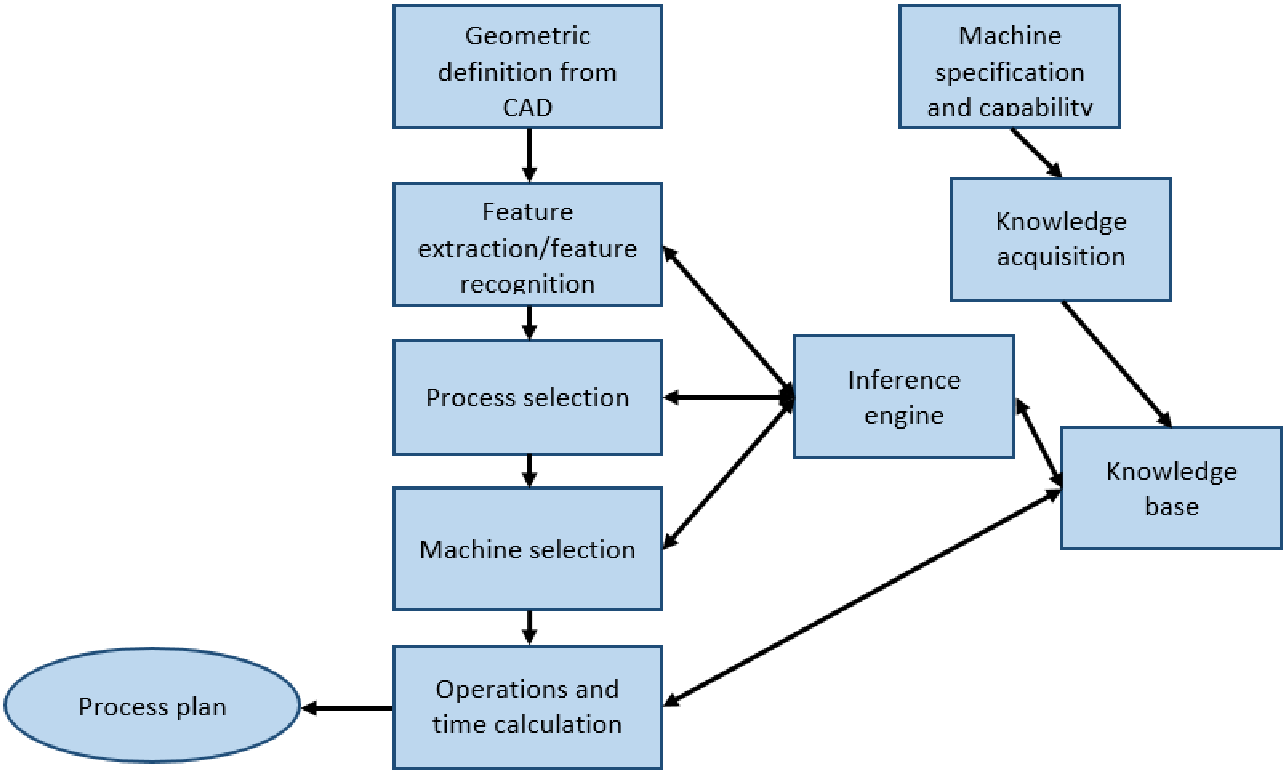


Fig. 1.5. Generative process planning structure

This means that the system works on its own after given the decision rules. It will generate every new process plan from scratch by following the given set of rules and inputs. Inputs can be the CAD designs themselves, user defined features and so on. So far, the truly generative computer-aided system is not possible and thus only test versions are in existence, mostly used for research & development.

1.3. CAD/CAM integration and CAPP features

Computer-aided process planning system is very useful, but in the past it served for kinds of industries and was even used alone, while creating process plans for manual or semi-automated manufacturing. However, with industry evolving and level of automation increasing, due to "Industry 3.0" (Fig. 1.6.).

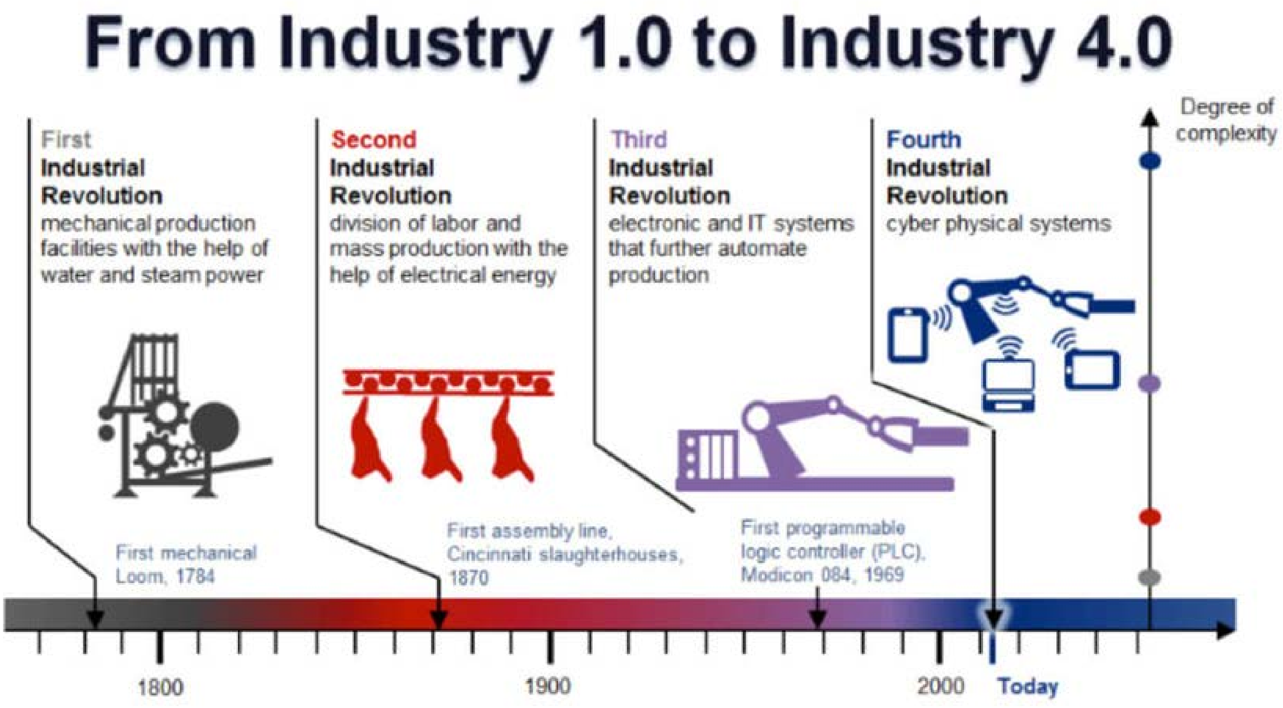


Fig. 1.6. Evolution of industry, Industrial revolutions

In Industry 3.0, automation is key and so an integration of separate systems and software has begun, following is the Industry 4.0 where everything already is integrated and connected via internet of things [7].

Also, unless CAD/CAM systems have a build in function that can act as CAPP, it will prove near impossible to be integrated. CAD software only generates graphically oriented material for visual presentation and analysis, but to use it as instructions, for example for a numerically controlled lathe, the lathe requires commands, things from the right tools, to the parameters like speeds depths etc. This is where CAPP comes in, as it is the sole purpose and function to prepare process plans that include that very information, which is like an extension of the CAD software.

Without some element of CAPP, there would not be such a thing as CAD/CAM integration. Thus, CAD/CAM systems that generate tool paths and NC programs include limited CAPP capabilities or imply a certain approach to processing [5].

CAD systems also provide graphically-oriented data to CAPP systems to use to produce assembly drawings, etc. Further, this graphically-oriented data can then be provided to manufacturing in the form of hardcopy drawings or work instruction displays. This type of system uses work instruction displays at factory workstations to display process plans graphically and guide employees through assembly step by step. The assembly is shown on the screen and as an employee steps through the assembly process with a footswitch, the components to be inserted or assembled are shown on the CRT graphically along with text instructions and warnings for each step [5].

Thus, all pieces of CIM (computer integrated manufacturing) like CAD/CAM and CAPP work best when are integrated together. They complement one another where the other lacks and are able to provide the best level of automation and control for the manufacturing from the design to the very end of assembly and packaging processes.

1.4. Future developments of CAPP

While CAPP systems are moving more and more towards being generative, a pure generative system that can produce a complete process plan from part classification and other design data is a goal of the future. This type of purely generative system will involve the use of artificial intelligence type capabilities to produce process plans as well as be fully integrated in a CIM environment. A further step in this stage is dynamic, generative CAPP which would consider plant and machine capacities, tooling availability, work centre and equipment loads, and equipment status (e.g., maintenance downtime) in developing process plans [5].

Entire process planning would be different from as we know it today in the Industry 4.0 [7]. All the systems and machines, from the tools, lathes, and robots to the software systems will be connected into one network – an internet of things. Sharing information between one another, the entire plan will be fully automated. Then, the amount of information that is fed into the CAPP is constant and always changing, so will change the process plans as well, tracking tool life, production line load and other important aspects of the manufacturing, that before were only calculated using averages and constants, now will be monitored in real time and applied when creating process plans. Meaning that process plans used, will be always update. Allowing things like production line rerouting.

Dynamic, generative CAPP also implies the need for online display of the process plan on a work order oriented basis to ensure that the appropriate process plan was provided to the floor. Tight integration with a manufacturing resource planning system is needed to track shop floor status and load data and assess alternate routings vis-a-vis the schedule [5].

1.5. CAPP necessity

Before the manual process planning and computer-aided process planning were compared based on their pros and cons, to get a better understanding about the benefits of CAPP, a review has been analysed, which stated:

In the approximate time analysis of Manual Process Planning (MPP), 15% time is used for technical decision making, 40% time for data look up and calculations and 45% is required for text and document preparation Almost 85% time is consumed in non-decisional activity. To overcome the disadvantages of MPP, it is needed to develop the expert system for CAPP [8].

The review shows how much time is wasted using manual process planning on processes that could be done automatically, leaving the person to only make important, decision-making activities.

The main difference nowadays between variant and generative CAPP is where it can be applied. Due to variant type only being able to retrieve plans from already existing plans developed for different part families, it is most well suited to be used for mass scale production, where the variety of products is not very large. As for job type production, where the batches are very small and greatly differ in design, variant type computer-aided process planning system is not very useful. For this, a generative type of CAPP is needed, to be able to always adapt or generate new plans that would perfectly fit the ever-changing designs of the parts.

2. LOOKING FOR CAPP SOFTWARE SYSTEMS

The next step after defining the variant and generative types of computer-aided process planning is to look for working CAPP systems. It will be mainly looked at the software that was developed for wide commercial use to be installed in manufacturing plants and available to everyone, but for the sake of a good analysis and a bigger list of different software, software developed for scientific purposes will be analysed as well. The reason for mainly focusing on commercial CAPP software is because it has to pass multiple tests and be fully working, adapted for multiple or at least one industry, as for the software that was developed for scientific purposes it usually has very limited application area and is built by using one specific plant as an example.

2.1. Old CAPP software

At first, using various literatures, research papers and internet searches, a list of CAPP systems both of variant and generative type was gathered (Table 2.1.). It would appear that there are quite a few computer-aided process planning systems out there.

As a next step, all the software in the list were checked for availability, features, developers etc. and a certain reoccurring thing has been noticed. Most of the software from the generated list is no longer available. Most of the names can only be found in the research papers or books, that were published a couple of decades ago.

Table 2.1. List of CAPP systems [9, 10, 11, 12]

Ben-Arieh & Wu '99	AUTOPLAN	camos.CAPP
PARIS	CAM-I	Jagdale & Wang
Gayretli & Abdalla '99	GENPLAN	PIPP-ICAPP
Chemg et al '98	MIPLAN	SMBAPP
FBICS	AUTAP	Younis & Wahab
CyberCut	CIMS/PRO	APPS
Joo et al '01	GARI	Fuh Et al
Zhang et al '00	PROPLAN	Radwan
CFACA	SIPS	GCAPPES
Chu et al '00	APPAS	Wong and Wong
Yang et al '01	CMPP	IIPPS
ASUFTB '95	EXCAP	OMEGA
Kim et. Al. '97	XPLAN	GAPP
Joo '00	ESPIRIT	Zhao & Masood
Cho & Joo	NX	FRAPP
Pemg & Chang '97	CATIA Solutions	Dong et al
Joo & Choo '97	Wong & Wong '95	

Even though there is plenty of literature about computer-aided process planning, rarely any will talk about specific, existing or widely used examples of CAPP systems.

When the term "computer-aided" has become very popular, systems for all parts of manufacturing process and further were thought of. All of it fall under the computer integrated manufacturing or CIM term. CAPP was one part of it. Like all of the other systems, it was an old-fashioned task that has been automated by the help of computers, hence the computer-aided words before the function name. The biggest boom for CAPP development was in the 1980s and 1990s. The software developed at that time was available until around 2000s. Most of it were created for research purposes or for special purpose factories as a test or some sort of program and was not meant to be universal or adaptable.

Later, a new wave of computer-aided system has started to appear. Software like SolidWorks, CATIA, and ANSYS were not one stand-alone computer-aided system, that has a singular purpose, but instead a blend of all CIM systems that were once stand-alone. For example, SolidWorks can be used as CAD software, to draw parts, but also carry out analysis, like testing the tensile strength of the construction or make assemblies, electrical connections and so on. Similar thing happened to the CAPP system, it has become a part of a bigger block of systems.

2.2. New CAPP software

Even though most of the stand-alone CAPP software is not available anymore, there are some companies that still develop such CAPP systems. Following are couple of examples of such systems that are from the more recent times. One of the systems analysed will be CAME SAT, a system developed by Kaunas university of technology.

2.2.1. MetCAPP

MetCAPP is a knowledge-based process planning and cost estimating system targeted at providing **[13]**:

- improved productivity by reducing process time and variability;
- reduced inventories;
- consistent and higher product quality levels.

According to the description on the MetCAPP developers Cimskil page, their software falls into the space between design and manufacturing floor, linking both things together. It does so by using CAD generated solid models to generate process plans. Software recognises the drawings from most of the popular CAD systems like Pro/Engineer, CATIA, SolidWorks and Unigraphics. The software then picks out the best [13]:

- machines;
- tools;
- sequence of steps;
- timing;
- routing/cost combinations;
- provision for alternate and concurrent operations.

This is achieved by continuously generating and evaluating plans until the plan that will use the least resources is generated.

Because the software is knowledge-based it uses a database of information to generate its plans. The developers Cimskil state in their website that:

"MetCAPP rules and supporting data provide the ability to generate an optimal process plan in a very short time. These rules are based on over 100 years of manufacturing experience and capture the best machining practices." [13]

Also, there is an option to use other data instead of the one, gathered by Cimskil or even use both, so that they could support one another in providing the best possible solution of the problem.

Everything is used through the Technology Module Manager (Fig. 2.1.)

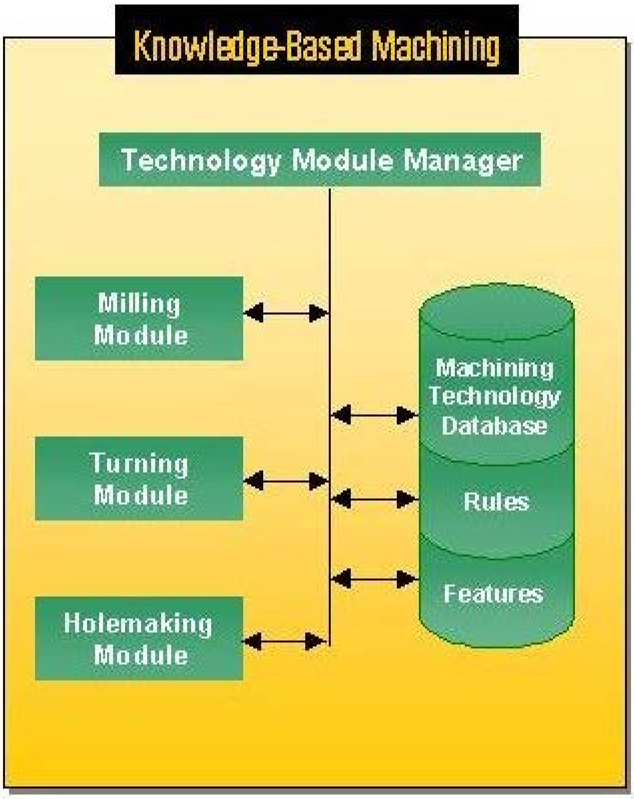


Fig. 2.1. MetCAPP software composition [13]

Following are the MetCAPP features as stated by the developer Cimskil [13]:

- Automated Feature Recognition - generates the flow of data from solid models directly into MetCAPP. This module allows users to import 3D solid CAD models into MetCAPP and then automatically analyses the part to extract manufacturing features for sequencing and process plan generation.
- Process documentation. MetCAPP's report writer - allows users to merge text and graphics, including CAD drawings, photographs, electronic documents and bar codes into a single document. This can be printed, sent to the floor electronically or through API to other parts of the IT system (e.g. NC tape generation, MRP or order entry).
- Graphics. MetCAPP's redline capability allows the user to add layers of annotations to a file without changing the original drawing/graphic. MetCAPP supports over 40 different graphic file types for viewing, printing and redline/mark up (Fig. 2.2.).

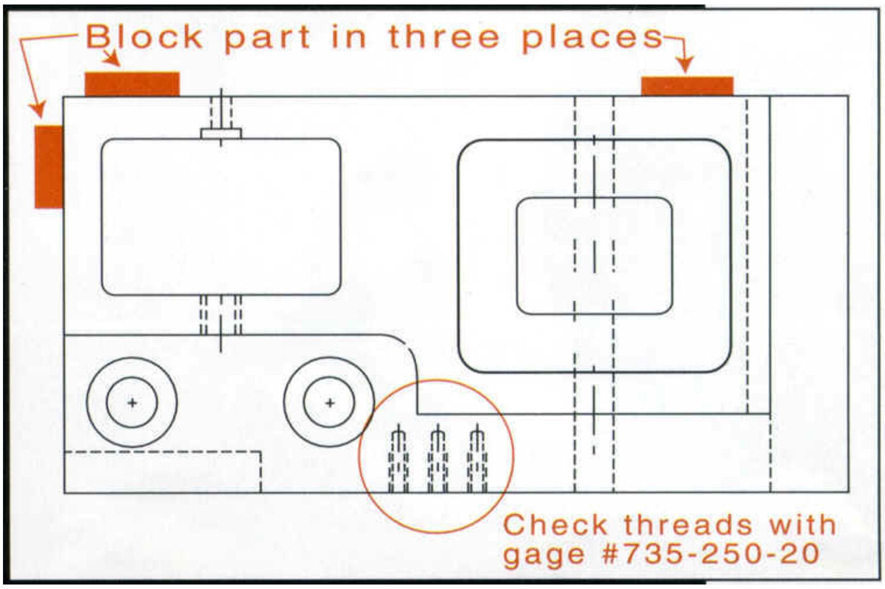


Fig. 2.2. Example of MetCAPP redline capability [13]

- The MetCAPP Technology Modules. These contain rules and data to support a wide range of features. These automatically select a process sequence, tools for each step and speeds/feeds for each machining pass. The Technology Modules evaluate the capabilities of the machine and utilize as much machine horsepower as is available at the selected speed range.
- Templates and formulas - provide MetCAPP users the flexibility to define tasks and work procedures specific to their operations. Recall and replication of these on demand further enhances planner productivity.
- Cost Estimating - Costed routings with accurate tooling, fixture, and materials provide the estimator with strong quotation support.
- Group Technology - MetCAPP provides the ability to interrogate a standard database of process plans and identify parts and assemblies by their characteristics. This enables identification of similar parts for more rapid plan generation as well as strong support for configuring products in order entry.

Also, the developer states the “Documented MetCAPP Benefits” [13]:

- 50% increase in process planner productivity;
- 40% increase in existing equipment capacity;
- 25% reduction in setup costs;
- 12% reduction in tooling requirements;
- 10% reduction in scrap and rework;
- 10% reduction in shop floor labor;
- 6% reduction in work-in-process;
- 4% reduction in material usage.

There is no source as to how they got these numbers, but the numbers look reasonably achievable, as the most efficiency is seen to come from increased planner productivity, where a person will not have to do the process planning manually and by equipment capacity as everything will be sorted and routed automatically enabling the machines to be always working preventing hold up and bottle necks.

A price of Cimskil software ranges from \$37,000 to \$60,000 [14]. Although, the last entry in the website is way back in 2003.

2.2.2. ESPRIT KnowledgeBase

DP Technology has developed software that they call "ESPRIT KnowledgeBase". As they say on their website:

ESPRIT's KnowledgeBase™ provides a push-button approach for any programmer or operator to determine the best method to machine a given part or feature by automatically selecting the most appropriate machining cycles, cutting tools, and machining parameters [15].

Even though the term "computer-aided process planning" is not used anywhere in the description of the product, the description is very much alike. Developer describes the software capabilities to store process-specific information into databases that can later be used. The software uses multi-user SQL database.

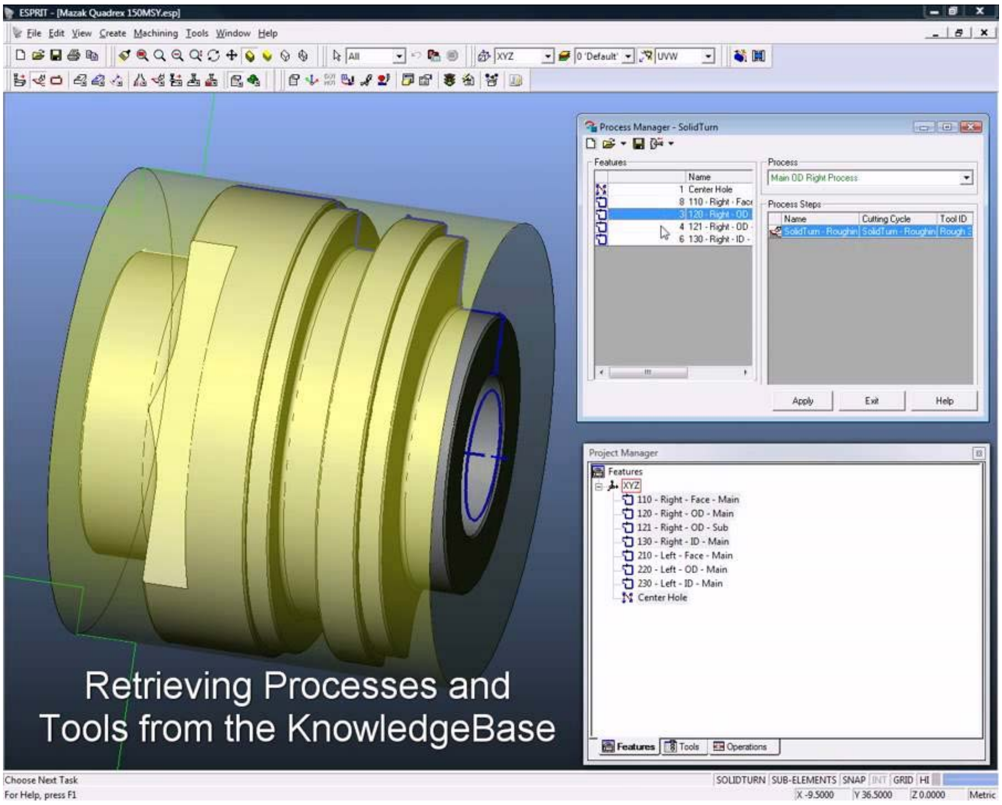


Fig. 2.3. Example of ESPRIT KnowledgeBase **[**Screenshot from youtube.com**]**

It seems that the software is adaptive and moving towards the direction of the generative type. As the processes stored in the database are automatically retrieved and updated include improved methods, always improving on the processes.

Another feature that all similar type of software shares is feature recognition (Fig. 2.4.), automated feature recognition divides analysed part into features like holes, slots etc. Each feature has set characteristics like height and area. The software then categorizes the features and connects them to the database used by the shop to get the standards, terminology and each features characteristic.

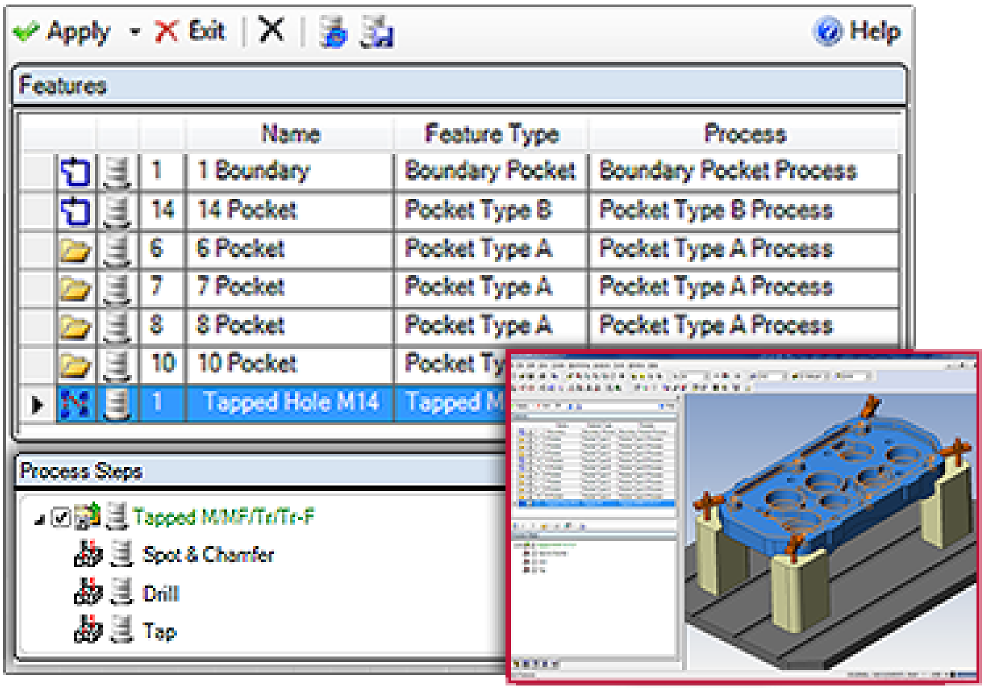


Fig. 2.4. Example of feature recognition in KnowledgeBase [15]

KnowledgeBase automatically picks out the best suited process to machine the described feature, picking all of the needed machining parameters like machining cycles as well as speeds and feeds of the tools. Developer also offers an existing database "CUTDATA", containing over 100,000 speed and feed recommendations.

The prices for ESPIRIT solutions range from $5,500 to $19,900 and the company has installed over 28,800 seats of their software [14].

2.2.3. Costimator

Another example of what CAPP software has become is Costimator. It has been developed as a cost estimating software. The main principle of Costimator is its databases that the company has been updating since 1982 [16]. It is filled with industry validated cost models and time standards. The system contains manufacturing database libraries for:

- Material Speeds & Feeds;
- Process Cost Models;
- Feature-Based Cost Models;
- Parametric Cost Models;
- Worldwide Shop Rates;
- Raw Material Data;
- Assembly Time Standards;
- Handling Time Standards.

Costimator contains pre-built process, feature-based and parametric cost models that can be modified or created new by the user meaning that it works on a variant or retrieval principle, where the models are still edited manually by the person.

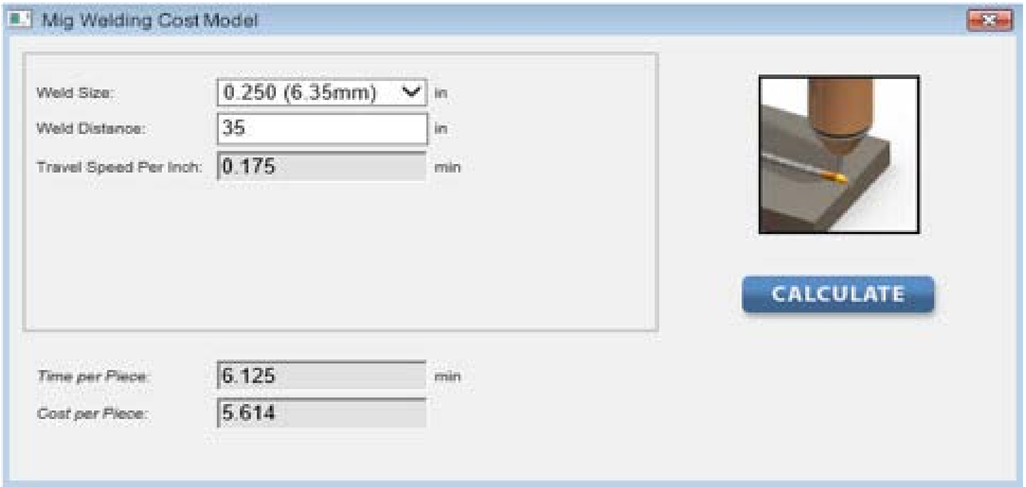


Fig. 2.5. Choosing the cost model in Costimator [16]

With 3DFX, Costimator has the ability to automatically read, extract and import part data from 3D CAD solid models in to the Costimator (Fig. 2.6.). It automatically recognises CAD features like holes and slots.

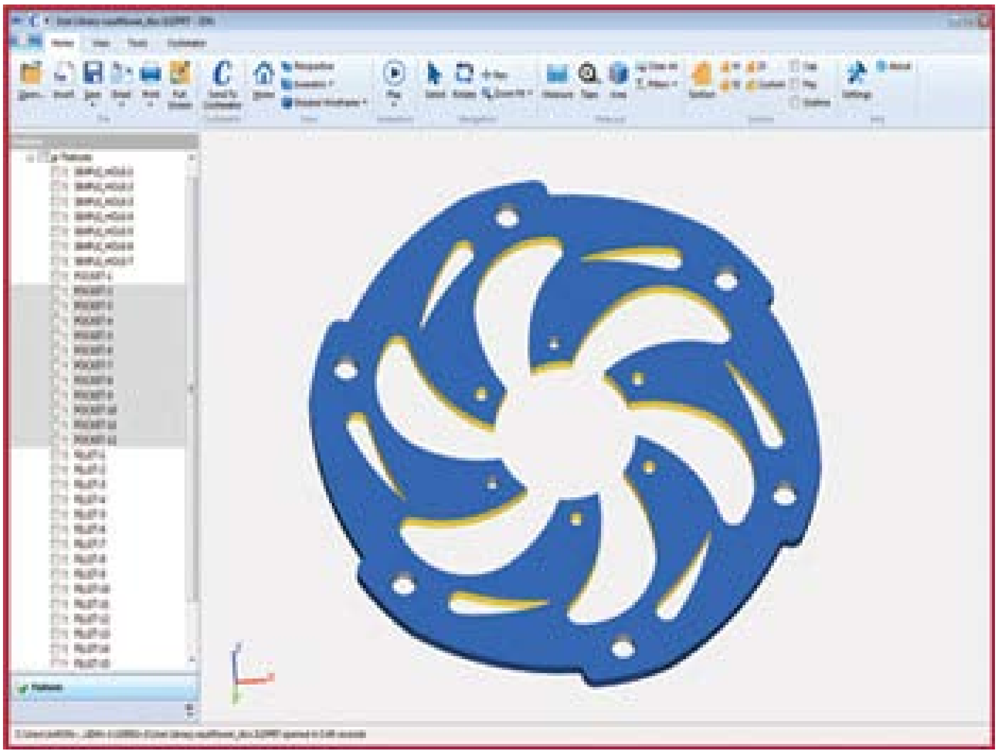


Fig. 2.6. Feature recognition by 3DFX [17]

Costimator software can generate the process plans among many other types of report (Fig. 2.7.).

Part - [Pillow Block via Detail-Pillow Block Housing]

Detail	Note	Time (minutes per piece)
Part Information		12.3599
Quantity [Default=5000]		
Material		
10 - CNC Machining Center		1.6520
Facemill - Positive Insert		0.6327
Load & UnLoad <50 lb Part		0.7500
Cnc Machine Handling, Rapid Trav incl acc/decc		0.2000
20 - CNC Lathe @ MORI SEIKI - SL6		4.0355
Bore		0.9830
Bore		1.5074
Groove		0.4126
Chamfer		0.0501
Cnc Handling, Rapid Traverse		0.1000
Load & UnLoad <25 lb Part On/Off Machine		0.6667
30 - Drill Press		0.9214
40 - Burr		0.2648
50 - Mark & Identify		1.2596
60 - Inspection		0.0106
70 - Wash		0.0967
80 - Paint		3.2705
90 - Inspection		0.0190
100 - Pack & Ship		0.8298

Fig. 2.7. Example of process plan from Costimator [18]

Costimator, even though presented as cost estimating tool, looks like one of the computer-aided process planning systems out there. It shares many features with other similar software, but shows process planning and generation of reports as one of its main functions.

Price of the software starts from $4,000 of which the company has sold over 1,600 as of 2015 [14, 19].

2.2.4. CAPP-4-SMEs

CAPP-4-SMEs was a project back in 2012 that run until 2015 funded EU to create an innovative knowledge-based computer aided process planning system to enhance the competitiveness of European companies, particularly SMEs, in sustainable manufacturing environment [20].

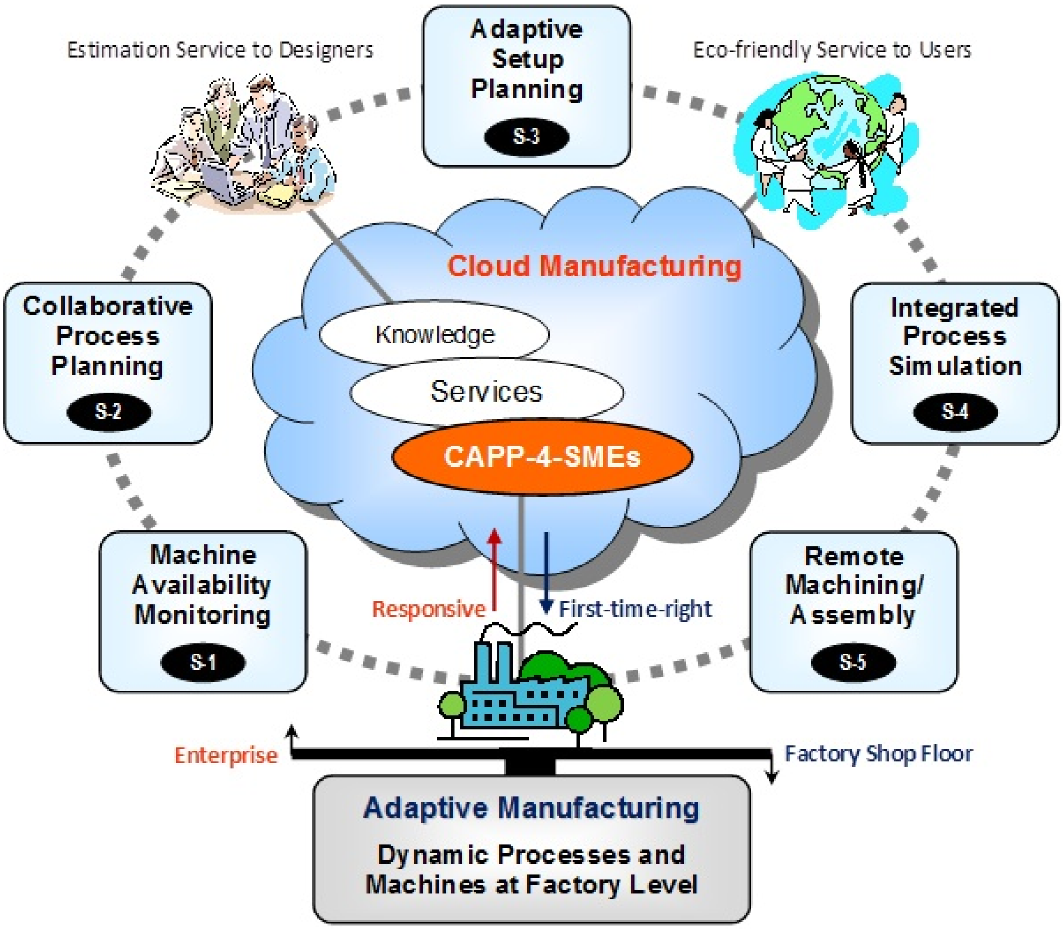


Fig. 2.8. Logical relationship of different services united on one cloud [20]

The project has created, what is called Cloud-based Distributed Process Planning (Cloud-DPP) (Fig. 2.8.) and online planning system that collects real-time information on the availability of machines, available cutters and tools, as well as guidance on design.

The consortium comprised of 11 partners [21]:

- 4 universities;
- 1 multi-national manufacturing company;
- 6 SMEs.

The members were from 5 European countries: Sweden, UK, Greece, Germany and Spain. *"Targeting to showcase 40% reduction in resource consumption, 30% improvement in process robustness and accuracy, and 30% increase in productivity by reduced cycle times under more reliable and efficient manufacturing conditions…"* [22]

The total budget of the project was close to 5 million EUR and EU contributed almost 3,5 million EUR. This shows that the computer-aided process planning system subject is still relevant if European Union is willing to invest so much money into it. What is more, the way CAPP was looked at has changed; the newest trends were applied to it, to make it more flexible and accessible to everyone. Before it was very rigid and mainly developed for one company or the software was very basic and not specifically oriented, like the examples that were analysed before. But using cloud technology, small companies can be connected and share information and expand their knowledge, as well as plan and monitor everything real time, without investing big amounts of money that were required before.

The project was tested out in the companies that were members of the consortium. The developed system is seen to be using “pay as you go” when it is released.

2.2.5. CAME SAT

Integrated Computer Aided Manufacturing Engineering system “SAT” is developed in Kaunas University of Technology, department of Manufacturing Technologies for automated technology route design and manufacturing expenditures calculation of mechanical components’ (work pieces, assembly units, parts) [23].

It is a system that integrates together systems:

- Computer aided process planning (CAPP);
- Material resource planning (MRP);
- Manufacturing resource planning (MRP II).

Its working principle is similar to others analysed before apart from CAPP-4-SMEs as it is running on the cloud-based platform. The principles are that all necessary information like material, operations, work pieces etc. are stored in databases (Fig. 2.9.).

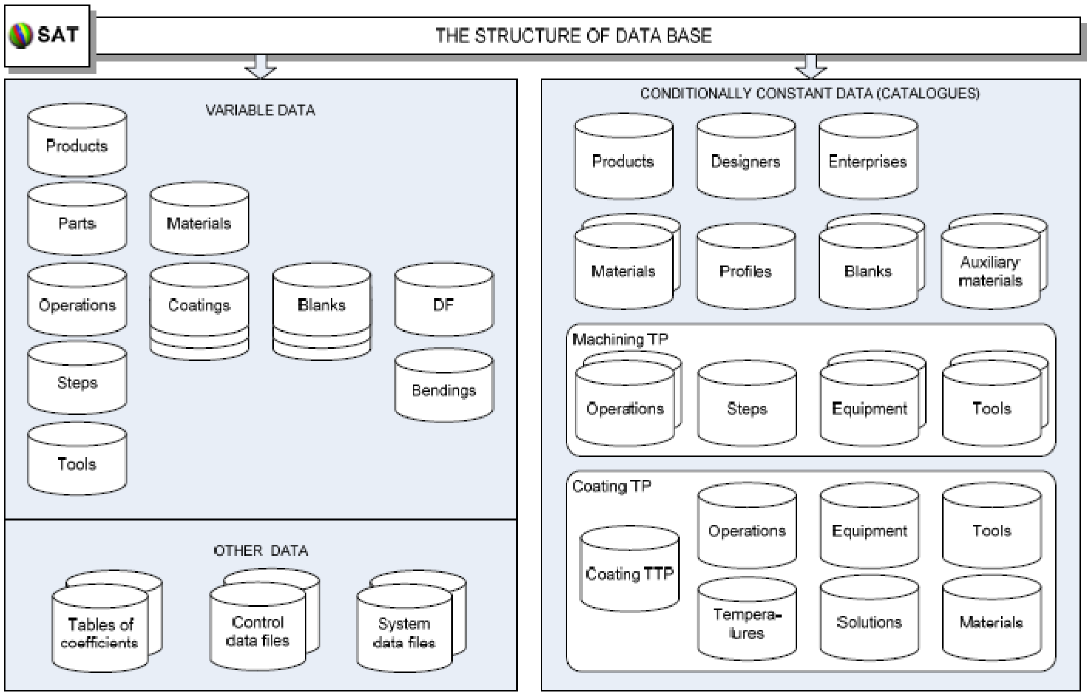


Fig. 2.9. CAME system "SAT" database structure [23]

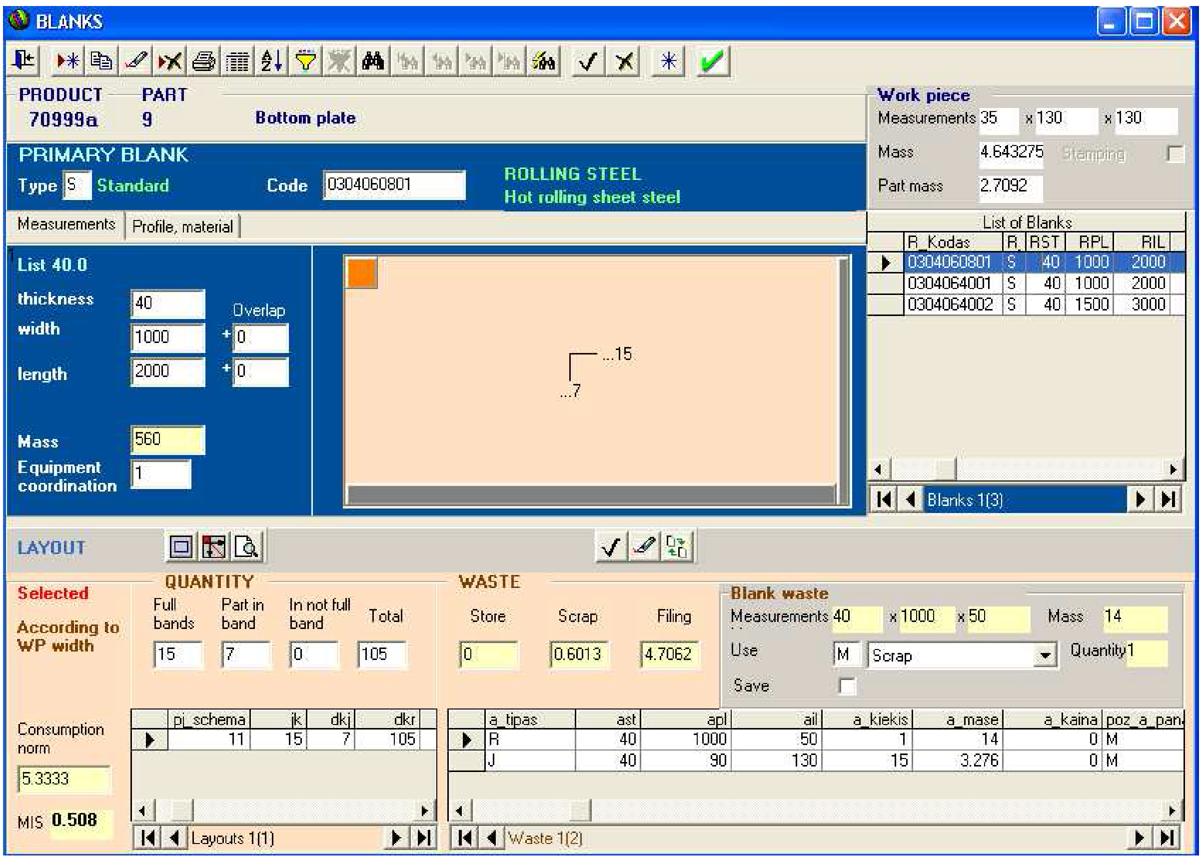


Fig. 2.10. Dialog window for designing the work piece layout in primary blank [23]

Although, when compared to other CAPP systems analysed, CAME SAT still requires an experienced engineer who has knowledge and experience in process planning as he still has to fill in all of the necessary data inputs like measurements of the work piece and all of the locations of specific slots and holes (Fig. 2.10.). Whereas other examples of CAPP software already have a feature recognition and all of this is done automatically by the software simply by using a 3D drawing.

CAME SAT system or parts of it were used in some companies in Lithuania. Now the system is used as a learning tool for students. Due to having an access to the system, it will be used as an example of CAPP when conducting further tests.

2.3. CAPP integrated into other systems

The other place to look for computer aided process planning software is in the other computer aided software. Due to software becoming interactive and accessible to everyone, the software packages keep on growing and increasing in functionality. At first software like AutoCAD or SolidWorks was only meant to create solid 3D drawings, but now, companies that have developed that software are buying companies, developing other types of computer aided software. In some cases, companies even offer their software as an add-in to the software like SolidWorks. In particular, system like CAPP have been integrated into the software as some functions or offered by a third-party company as an add-in function. This is available due to feature recognition which is built in to the software:

The Automatic Feature Recognition system extracts geometric and topological data of the part from STEP AP203 Ed2 to recognize manufacturing features [24].

2.3.1. SolidWorks

One of the best examples of such software is SolidWorks, published by Dassault Systems, it is a solid modelling computer aided design and computer aided engineering software (Fig. 2.11.). It is one of the most popular solid modelling software today. Many companies and universities use it due to its ease of use and a very big range of possible add-ins and functions like simulations, electrical functions, visualizations and many other.

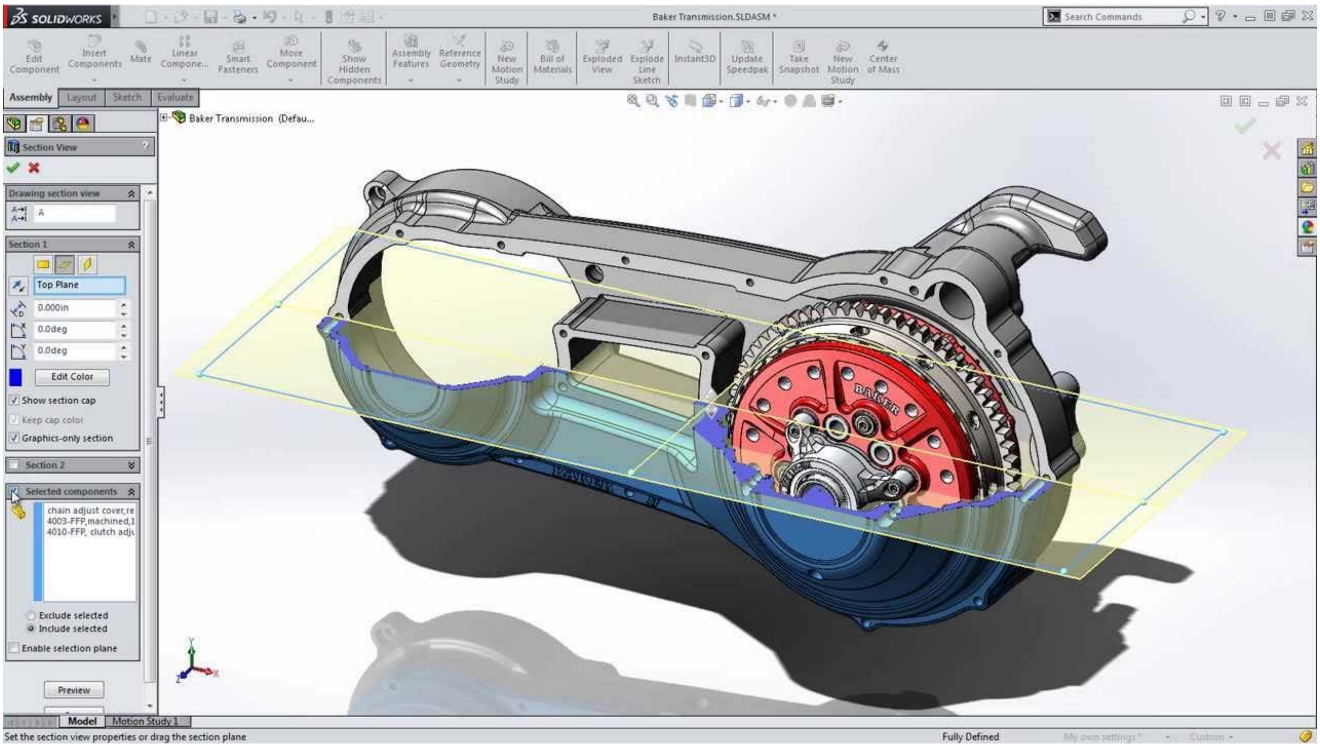


Fig. 2.11. Example of SOLIDOWKRS 3D modelling function [25]

The function of interest is called "Costings" (Fig. 2.12.) it takes a 3D CAD model, that the user can create himself or import into the software and analyses it. The user then chooses all the necessary input data like the type of material, roughness, thickness of the work piece, the kind of blank to be used, etc. Then SolidWorks takes all that data and using information stored in databases (Fig. 2.13. and 2.14.) prepares a report of a process plan that includes data like [26]:

- raw material types and costs;
- manufacturing processes, machines, tooling, and associated costs;
- direct labour rates for specific machines and processes;
- company specific manufacturing process information, including feeds, speeds, and setup costs;
- any custom operations, such as deburring, painting, anodizing, data entry, shipping, etc.

All of this is given within seconds with only a small input from the user. This software can be used not only by specialized engineers that have experience in process planning raising the question whether the professional stand-alone CAPP is even necessary.

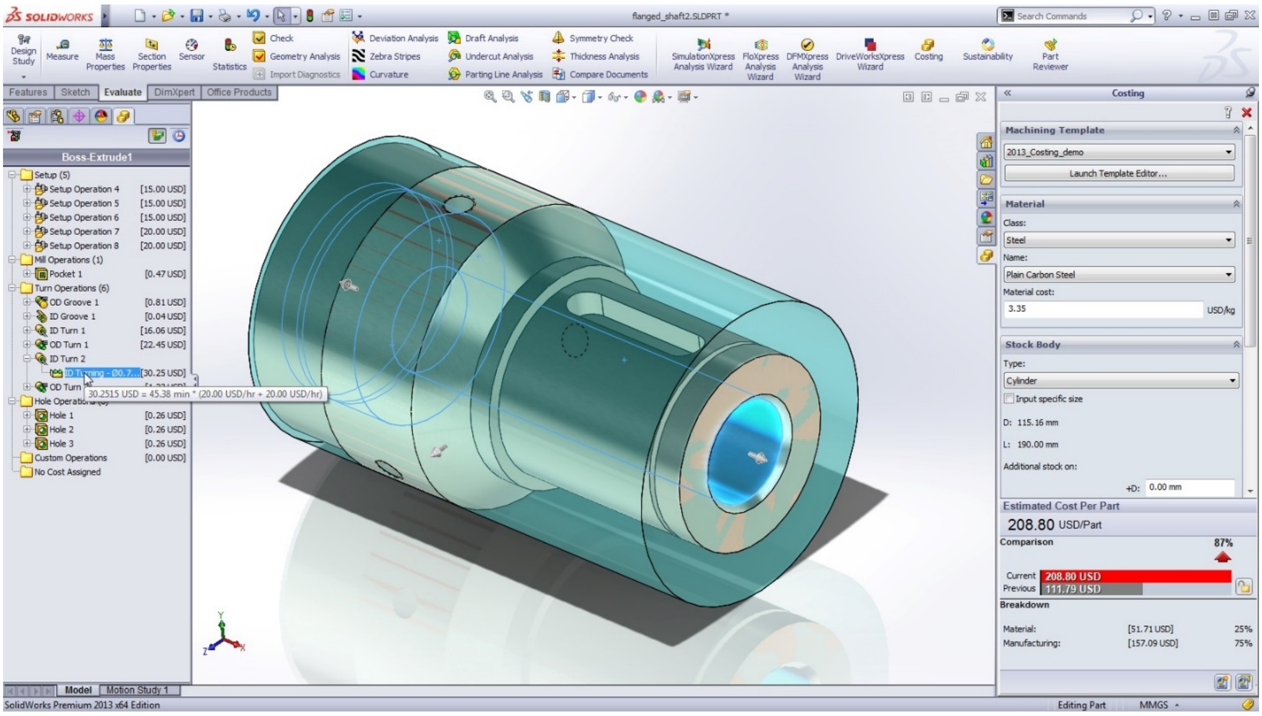


Fig. 2.12. Example of a SolidWorks Costing interface [27]

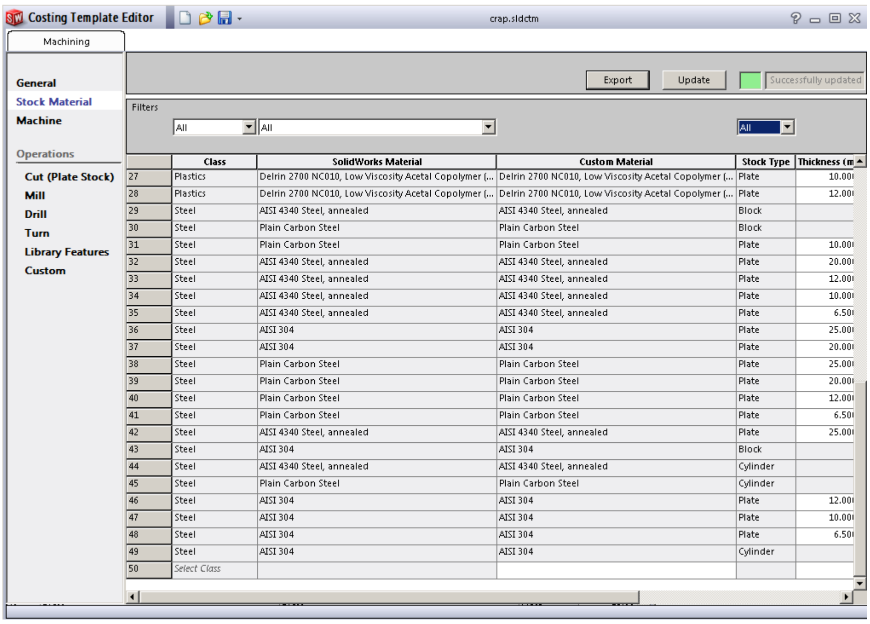


Fig. 2.13. Example of stock material lists

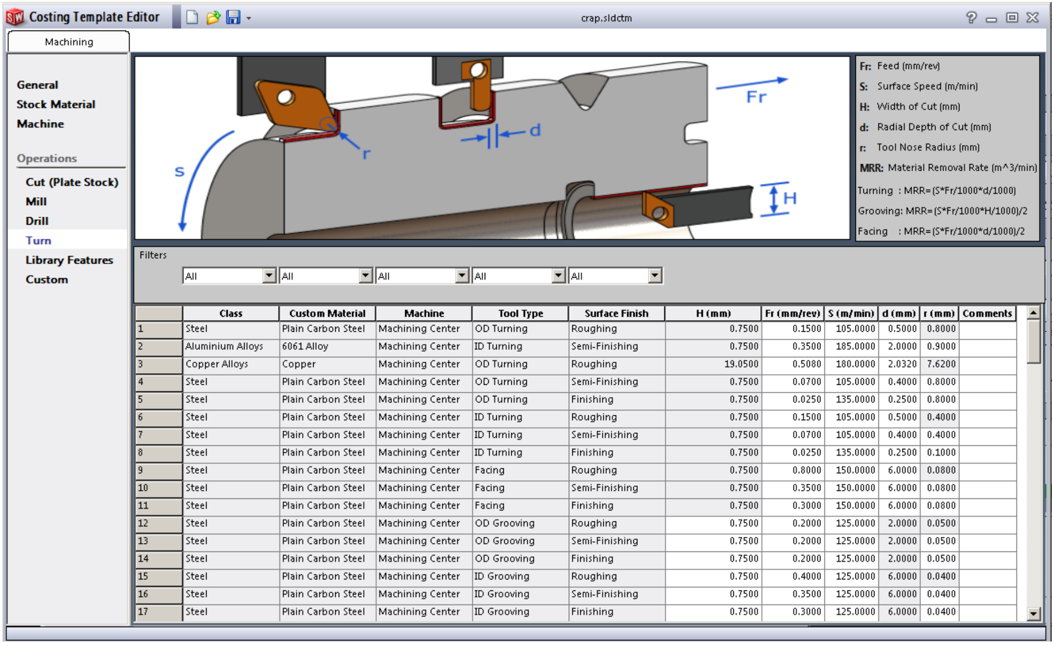


Fig. 2.14. Example of the tools for turning database

2.4. Results overview

Up until now, different software both of CAPP and systems that have parts of CAPP has been analysed. It is an obvious and logical move to merge all stand-alone systems into one, interactive and well connected system that would enable the user to have all of the benefits of all the different computer integrated manufacturing parts in one place. The price of the system is significantly lower as well; the old CAPP systems would start from tens of thousands of dollars and go up to even hundreds of thousands when the new CAD systems can be purchased for few thousand dollars, depending on the license (Table 2.2.). But in most cases, some of the functionality is lost when the systems are merged. In this case, some of the functions could be lost, when it was merged with systems that have created SolidWorks. Although, this type of software is more accessible to everyone and removes the need for specialised personnel with background in process planning.

Table 2.2. Summary of analysed software

Software name	Type	Price (thousand $)	Availability
Metcapp	CAPP	37-60	Available
ESPRIT KnowledgeBase	CAPP	5,5-9,9	Available
Costimator	CAPP	From 4,4	Available
CAPP-4-SMEs	CAPP	n.a.	(to be released)
CAME SAT	CAME	n.a.	Only in university
SolidWorks	CAD/CAM	From 4 to-8+ 1,3 per year (EUR)	Available

3. ANALYSIS OF PROCESS PLANNING WITH DIFFERENT SYSTEMS

To find out how well SolidWorks software is able to do the work of computer aided process planning system, both have to be given the same task so that the results from both software systems would be comparable. Then the results can be compared and analysed to find out pros and cons of both CAD software and CAPP. Criteria like ease of use, precision, user interactiveness or time it takes to prepare the plan.

For this analysis, 3 models were chosen:

1. cylindrical shaft (Fig. 3.1.);
2. bearing part (Fig. 3.2.);
3. solid part (Fig. 3.3.).

The different models were chosen due to their different structures and complexities. Also, because their manufacturing processes differ as one is made mainly using milling operations, while the others are made using turning operations. That will give a change to analyse a wider range of processes to see how well both systems handle the tasks and where their shortcomings are.

Plain carbon steel material was chosen for all three parts so that masses got from both systems would be possible to match.

Drawings of all three parts can be found in the Appendices 1.

Cylindrical shaft

A shaft (Fig. 3.1.) is a rotating machine element, usually circular in cross section, which is used to transmit power from one part to another, or from a machine which produces power to a machine which absorbs power [28]. For this part, turning processes will be used; only the two slots will be milled. Also, the part will not be finished in one take due to clamping, so half of the part will be machined in one step and then, after the clamping of the part is changed, the other half will be machined.

Shaft is a very common part in the mechanical industry as it is needed practically everywhere, depending on the application; there are different requirements for the surface quality of the finished product. In this analysis attention, will not be paid to the surface quality, just the basic operations of material removal.

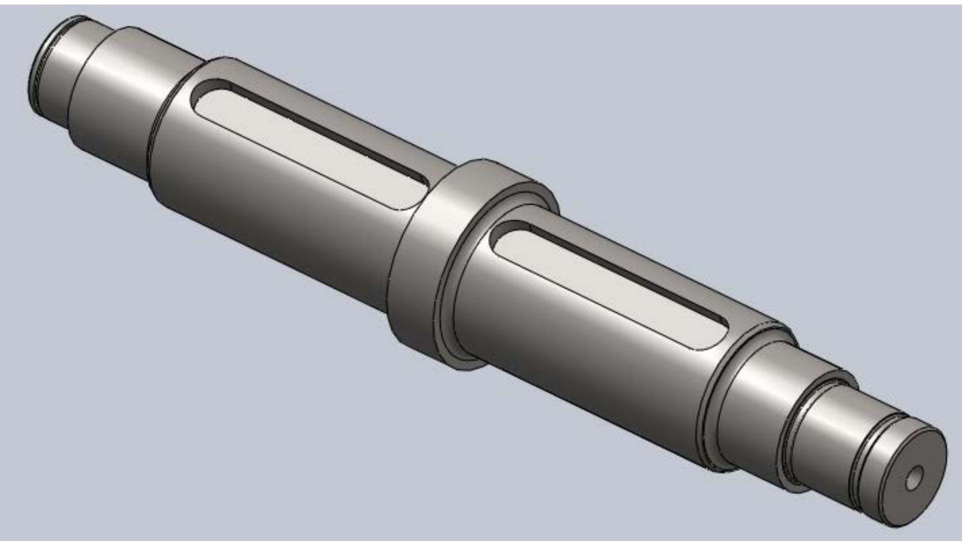


Fig. 3.1. 3D model of the cylindrical shaft

Bearing part

Bearings are widely used to constrain relative motion to only the desired motion and reducing the friction between moving parts. For this analysis, a bearing ring (Fig. 3.2.) will be used, a part that works as a body of the bearing in which the bearing insert is placed that reduces the friction.

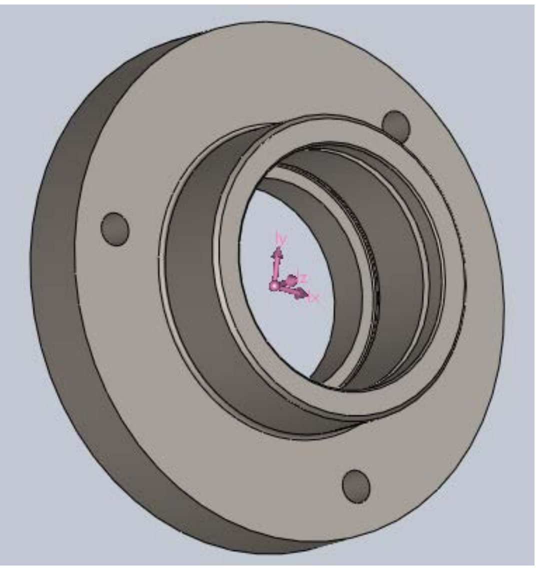


Fig 3.2. 3D model of the bearing part

Solid part

The third part is a simple square part (Fig. 3.3.) that originally was designed to work as a shaft cover. It was chosen because not like the other two parts, to manufacture it, milling will be used, meaning completely different operations from the other two parts. Blank will also be different as it will be made from a plate and not a rod.

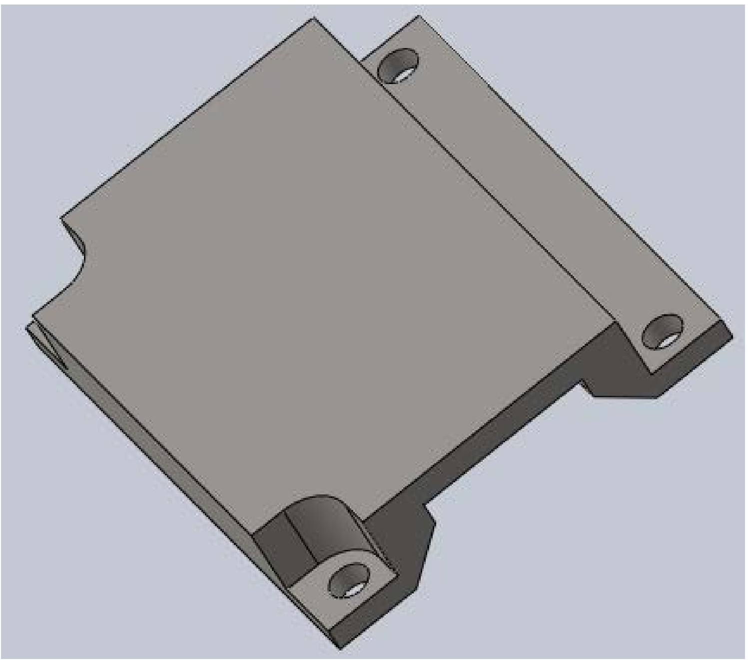


Fig. 3.3. 3D model of the solid part

3.1. Planning using SolidWorks

In this paragraph the SolidWorks Costing function will be used to generate process plans for the parts chosen earlier. All the steps needed to generate the process plan using SolidWorks will be presented using bearing part model as an example.

After having a 3D model the only thing remaining to do to get a process plan using SolidWorks is to apply a material.

Using SolidWorks built in function “Mass Properties” mass of the model can be evaluated (Fig. 3.4.). Bearing part models mass is 1114.42 g (1,1 kg).

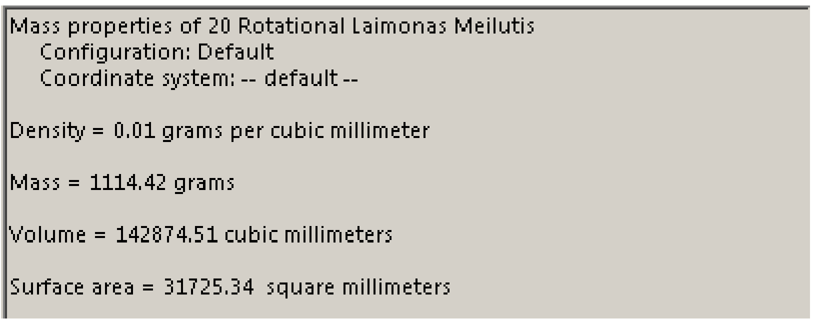


Fig. 3.4. Mass Properties evaluation of the bearing part

SolidWorks automatically reads the 3D model so one only needs to specify the basic information (Fig. 3.5.) like the material, type of blank material used and the measurements and allowances of the blank to be used. Using this information SolidWorks picks out the most suitable tools and processes to make the designed part from the blank that has been described. The database can be updated by the company or connected to the external databases that include countless number of factory information to simulate the manufacturing floor.

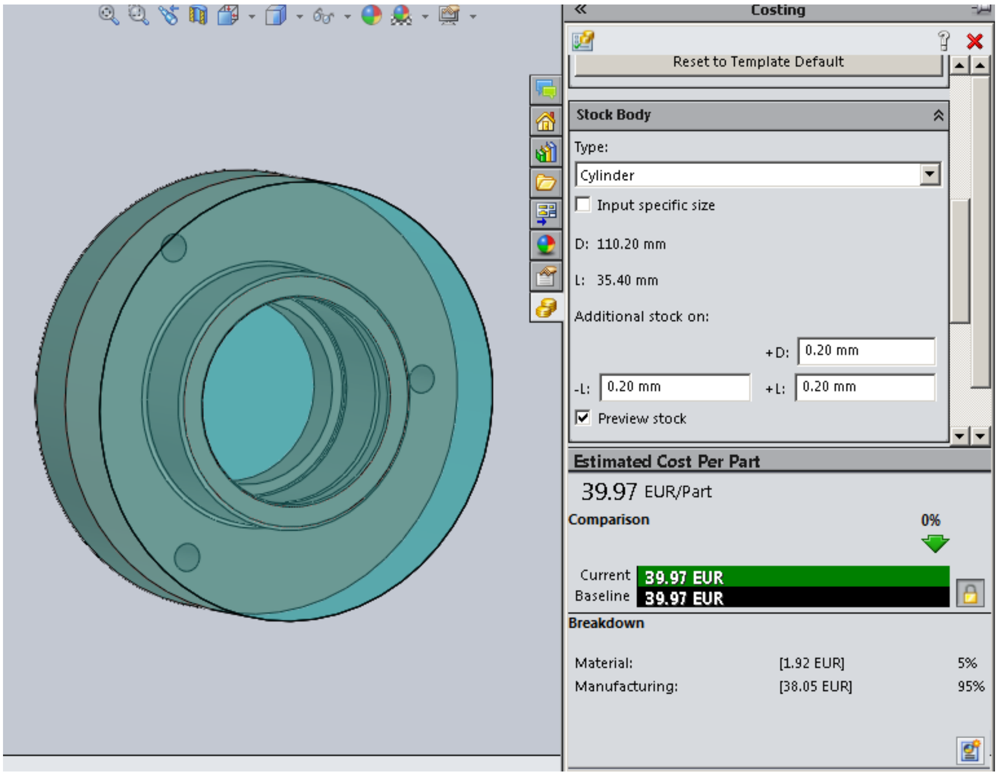


Fig. 3.5. Selection window for Costing function

When all the necessary information has been provided a preliminary list of operations (Fig. 3.6.) is generated. This can be adjusted according to the requirements of the user: machines, tools, operations or setup operations can be added or adjusted. The list is interactive and highlights which section of the part the process is going to be used for including times and costs.

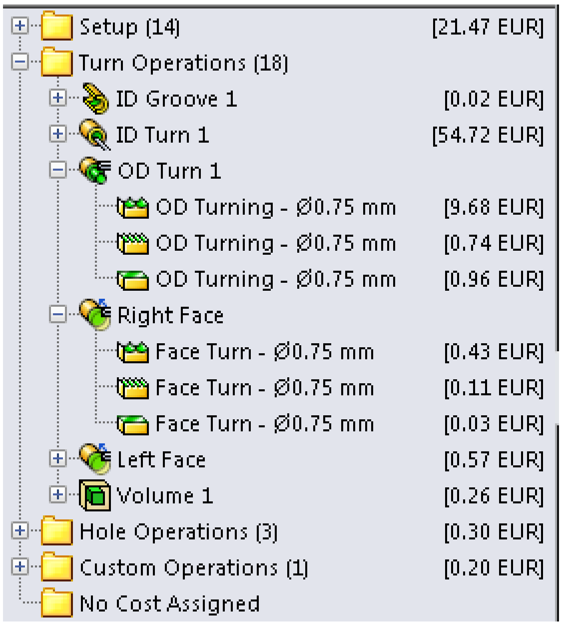


Fig. 3.6. List of operations

After all the parameters are suiting, the process plan report can be generated. It included all the detailed information for process plan: process step, duration, cost, tool used and surface finish. The only thing to note is that in the process plan report, SolidWorks shows weight of the blank and not the weight of the finished product, so the value from function “Mass Properties” will be used in this analysis.

The full process plan for bearing and other parts generated by SolidWorks Costing function can be found in the Appendices 2.

3.2. Planning using CAME SAT

Next, using the KTU computer-aided process planning software CAME SAT the process plans will be prepared for the same parts. As an example, for the steps for preparing the plan, the bearing part will be used.

As CAME SAT software is not generative and does not contain a function for reading 3D drawings all the information will have to be inserted manually.

First, the part must be defined, this is done my dividing up the part into separate sections and their dimensions defined to get the total mass of the part (Fig. 3.7.). For that, TDF (typical design features) method is used. The separate sections of the part are called design features (DF), each DF is described by choosing its class (prismatic or rotational form), quantity and dimensions. When all separate design features are described, the total mass of the part is calculated. The total mass of the bearing part is 1119.7 g.

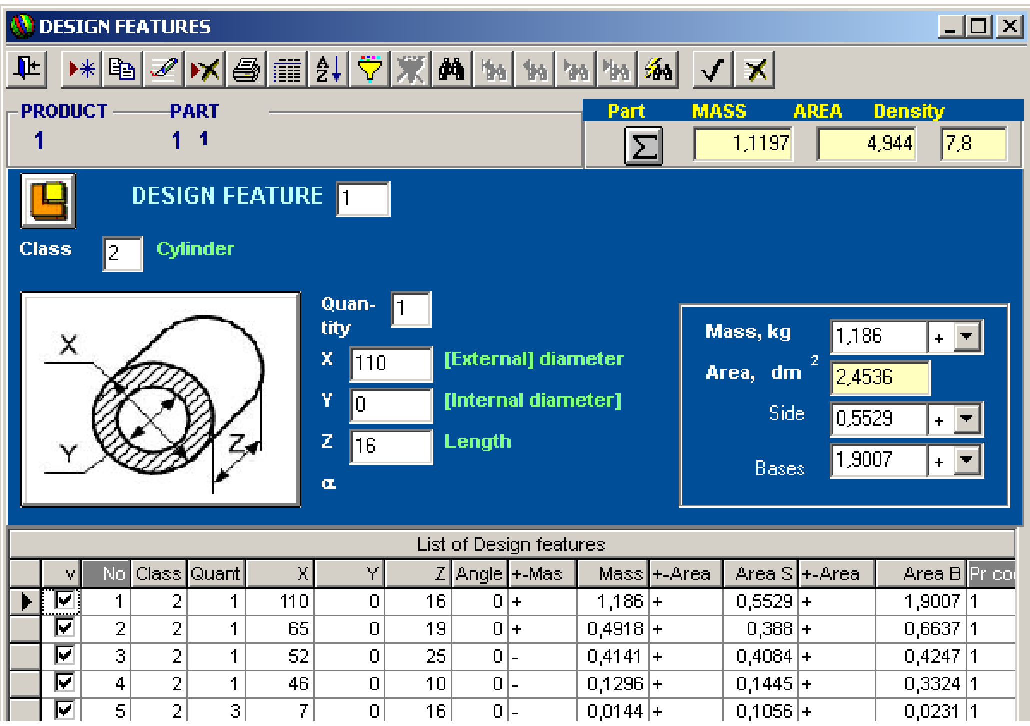


Fig. 3.7. TDF example for bearing

After part dimensions and mass have been defined, work piece dimensions are generated with additional information like material coefficient, showing how far away from the part mass, the mass of the work piece is (Fig. 3.8.).

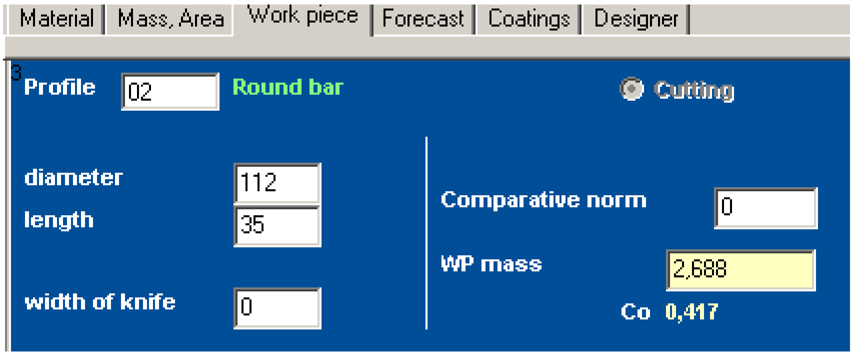


Fig. 3.8. Work piece data of the bearing

Next step is to define and pick out the blank material that will be used to make the bearing part. This is done by choosing from existing blanks that are in the database that company should keep updated with the latest stock information. The software automatically picks out one most suiting blank, per the dimensions that were inserted before and considering such things like the amount of waste. The software shows a basic view of how the work piece would look like in a blank (brown part on the left side) and what part of the material will go to waste (dark grey part on the right side) (Fig. 3.9.). Here it can be seen that the work piece only takes up a very small portion of the blank as there can be made 85 bearing parts out of one primary blank that has been chosen. The software shows other information as well like blank waste dimensions, consumption norms; it gives some additional options to choose from as to what to do with waste material and so forth. There are quite a lot of additional options, but they are not necessary for this analysis as the focus is the process plan of the part itself.

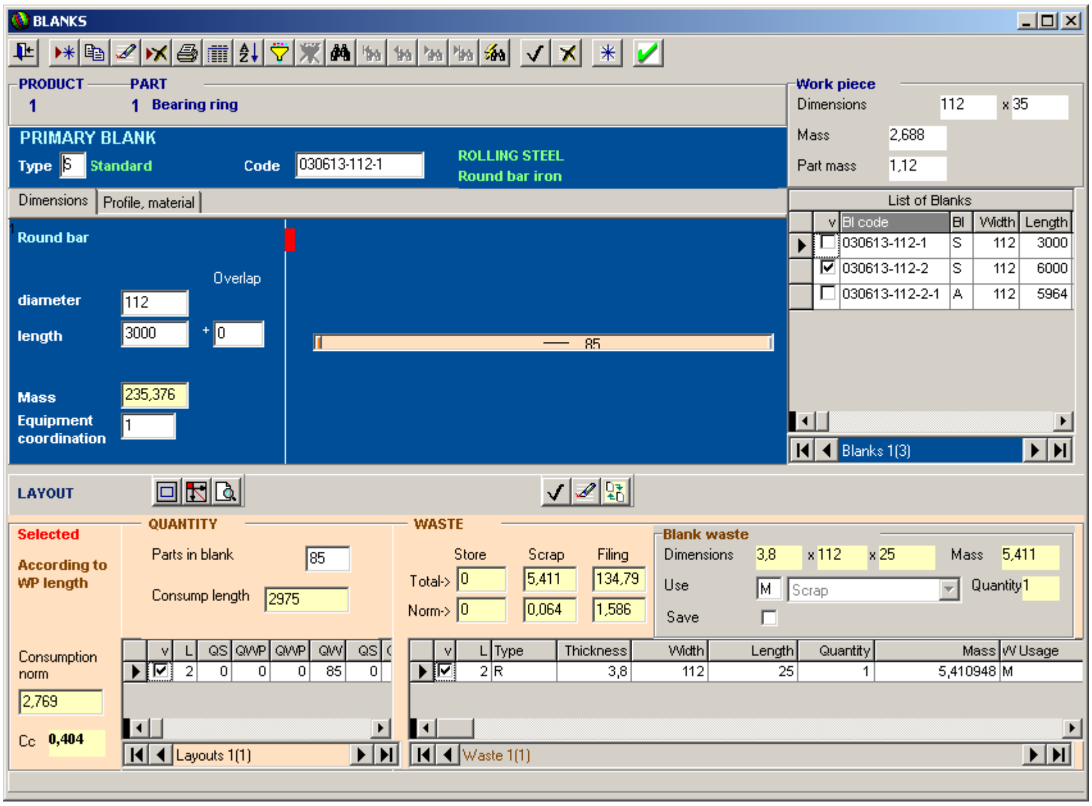


Fig. 3.9. Calculation of main material consumption

After the preparation steps are completed, the main steps that are the focus of this analysis can be started. Not unlike in the SolidWorks case, here the user picks out all the operations by himself.

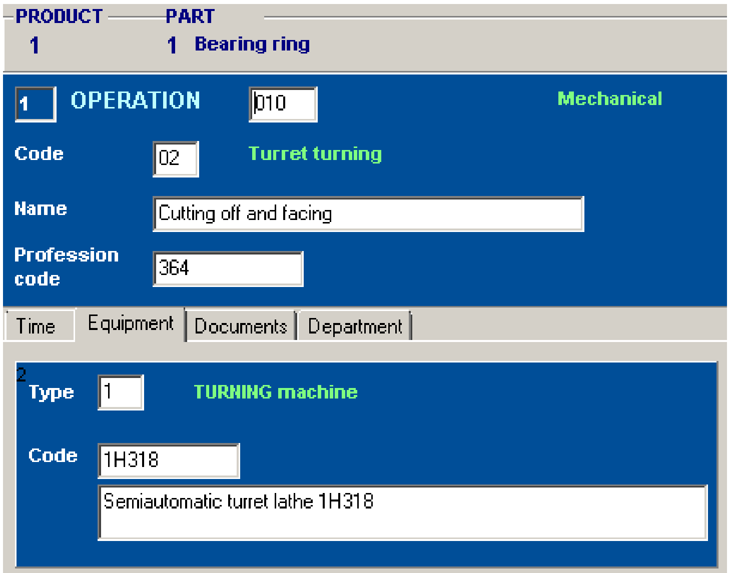


Fig. 3.10. Machine selection for the step

To start this part, one should have a list of processes for the part already put together. As this is a variant type of software, all the process steps are default templates and do not necessarily apply to the part that is being prepared now. The work begins by describing each step (Fig. 3.10.) with information like what type of process step it will be what machinery will be used there. Then inside that step, operations are selected, here default templates can be used that have a standard description of the operation with variable parameters already prepared for the user (Fig. 3.11.), one only needs to insert the relevant machining parameters that apply to the part. Next thing to do is to choose the machining tools (Fig. 3.12.), every machine has tools that are attached to it and can be chosen as default, but for any specific non-standard operation, the tools and in some cases the operation itself are created from scratch. This may cause problems mainly for non-standard and low-volume parts as all the processes and steps would need to be created from scratch. How quick the selection of operations and machine tools goes also depends on how well the databases are maintained. If the database the company uses has a high number of previous operations and all the machines and machine tools available in the factory, the process will be more precise and quicker. In this case as the version of software used was only for educational purposes, the database did include many examples of operations and machines. Because of this the process plan generated will only feature the main operations and the tools will be standard ones used on the machines that were provided in the database.

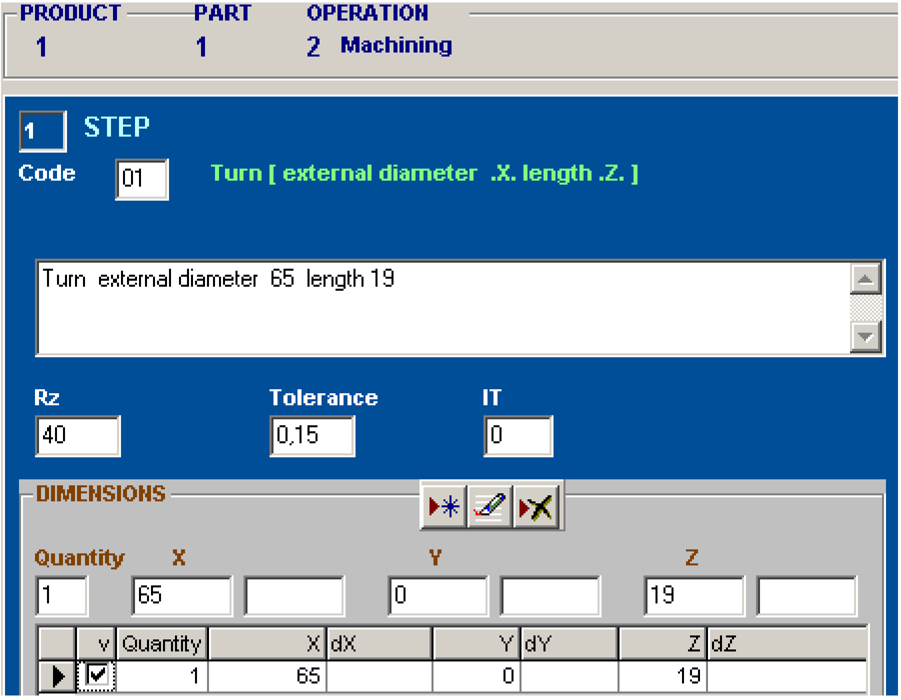
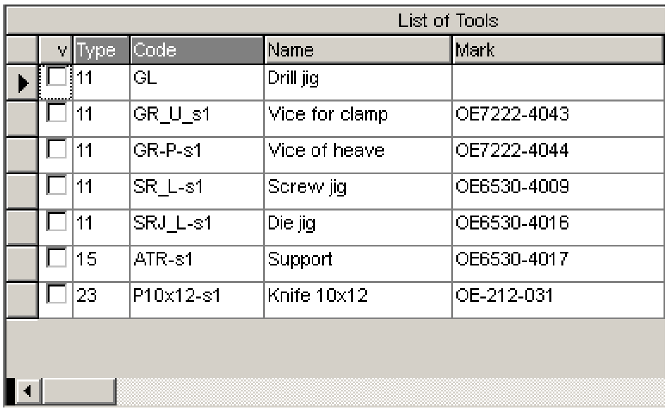


Fig. 3.11. Default operation description



List of Tools

v	Type	Code	Name	Mark
☐	11	GL	Drill jig	
☐	11	GR_U_s1	Vice for clamp	OE7222-4043
☐	11	GR-P-s1	Vice of heave	OE7222-4044
☐	11	SR_L-s1	Screw jig	OE6530-4009
☐	11	SRJ_L-s1	Die jig	OE6530-4016
☐	15	ATR-s1	Support	OE6530-4017
☐	23	P10x12-s1	Knife 10x12	OE-212-031

Fig. 3.12. Machine tool selection

When the process step is fully defined, a machining time can be calculated (Fig. 3.13.). This is done automatically evaluating all parameters that have been chosen. A standard function is used so the times will differ from the ones that were generated using SolidWorks as there the calculation involves analysing the part itself and in CAME SAT functional relationships between total machining time and the volume of removed metals for all manufacturing engineering operations are considered [29].

$$T \rightarrow f(S, D, QD, QDF, M, R)$$

S- Class level of product

M – Type of material

QD – Quantitative parameters of parts

QDF – Qualitative parameters of design features

R – Manufacturing traditions

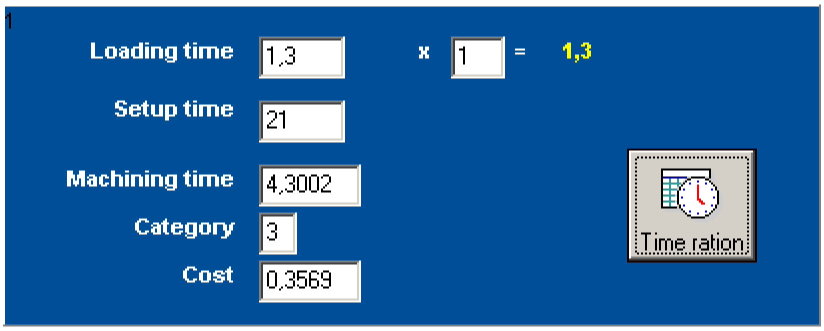


Fig. 3.13. Machining time calculation

The full CAME SAT process plan report of all three parts can be found in the Appendices 3 at the end of this work.

3.3. Results and impressions of process planning

Now when the analysis using both SolidWorks and CAME SAT were carried out, the results and impressions can be summarized. First thing to mention is that both systems are quite different, SolidWorks is a more advanced and automated generative system while CAME SAT is of the old variant system type. This means that everything in SolidWorks is generated for the user while in CAME SAT the user still has to choose everything by himself from already prepared templates. This in turn makes both systems and their application areas quite different.

3.3.1. Mass comparisons

At the beginning for both analysis the mass of the part was checked (Table 3.1.), looking at them now they are almost a match, the mass that was received from CAME SAT is a bit bigger but that might be, because the part was simplified there and did not include all chamfers and other small slots as describing them as not all of them are in database of the DF (design features).

Table 3.1. Calculated mass comparisons

Part	Mass, g		Difference, g
	SolidWorks	CAME SAT	
Cylindrical shaft	7601.5	7590.1	11.4
Bearing part	1114.4	1119.7	5.3
Solid part	264.6	263.4	1.2

In SolidWorks, only one button was needed to be pushed in order to get the information, while in CAME SAT user has to insert the entire parts dimensions, divided up into some blocks. If surface area of the part is needed, even more work needs to be invested. Of course, for SolidWorks to be so efficient it needs a 3D drawing of the part, but nowadays most of the parts and products are designed using 3D modelling software. It makes the task at hand easier while in CAME SAT the process is complicated. Unless, the customer is not able to provide company with a CAD drawing to read from, then, TDF method can be applied to make the process planning easier.

3.3.2. Time

All of this add to the time of the entire process planning, while SolidWorks takes all the parameters and input it needs from the 3D drawing, using feature recognition. CAME SAT uses inputs from the user or chosen from the database. Comparing time at this point is quite difficult as SolidWorks does it instantaneously; user can spend at most a couple of minutes for picking out the material, blank and additional operations. On the other hand, for CAME SAT it highly depends on the complexity of the part and the quality of the database being used. Some parts can be described in 10 minutes; others can take even hours. An analysis in another work has been done to see how the times differ depending on the complexity of the part (Fig. 3.14.) This prolongs the time until the product hits production, increasing the design to production time which costs money and in today's quickly changing market can mean lost market share.

Process planning time, min.

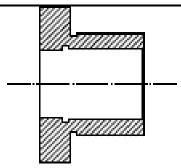
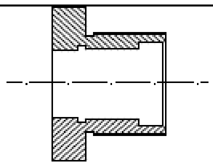
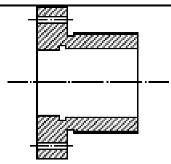
Parts / Planning type			
Manual individual planning of the unique technology processes	37	40	42
Computer-aided individual planning of the unique technology processes	26	28	29
Computer-aided repeated use of the unique technology processes	5	7	7

Fig. 3.14. Example of process planning times with CAME SAT [30]

Because defining parts and preparing process plans using CAME SAT can take so long and the user has to have extensive knowledge about process planning and manufacturing in order to prepare an accurate process plan the process becomes sluggish.

3.3.3. Accuracy

As there is more input needed from the user, the margin of human error increases, while in SolidWorks it is at a medium level as there can be some software glitches or error in the drawing itself.

For example, while preparing the process plan for the cylindrical shaft, using SolidWorks, the software was unable to read half of the part and apply process step to it (Fig. 3.15.). This could be due to many different reasons, error in the drawing, software bug or glitch as the software used was not of the latest version or some other factor.

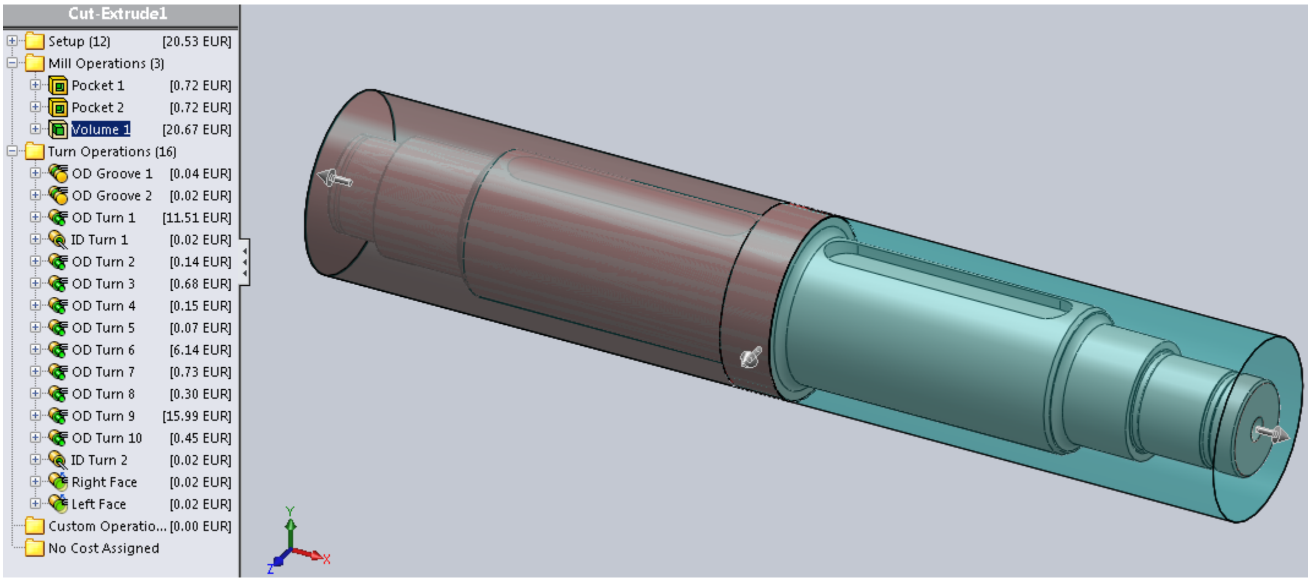


Fig. 3.15. Error in SolidWorks process planning

Although the speed at which SolidWorks prepares the process plan is very impressive, some of the precision or accuracy suffers from it. The processes that were generated were default and not necessarily fit the parts manufacturing process. Of course, this is non-existent in CAME SAT as the entire process is prepared by an experienced engineer. In this case the accuracy of the process plan depends solely on the experience of the engineer. Also, there are ways to increase the quality of the reports SolidWorks generates, it also gets all the information from a database, which can be expanded using subscriptions and buying additional add-ons with extensive databases filled with machine tools and processes and their characteristics.

3.3.4. Maintenance

This comes to the last point of evaluation – maintenance. Using add-ons for SolidWorks removes all maintenance altogether as everything is done automatically and the cloud databases used are updated automatically, user only has to push a button from time to time to get the latest version of the software, while CAME SAT has to be maintained manually, the databases are handled manually and this on itself makes for a huge task which cannot be done by the engineer himself, meaning that probably a third party company or a specialised person in the company has to take care of it.

Table 3.2. Summary of evaluation of both systems

	SolidWorks	CAME SAT
Mass (Bearing ring)	1114.42 g	1119.70 g
Process	easy	complicated
Time to prepare the plan	quick	Long (depends on the complexity of the part)
Need for experience	low	high
Margin of error	medium	high
Precision	medium	high
Maintenance	low	High

3.4. CAD and CAPP application areas

According to catistore.com price of SolidWorks license ranges from 3.7 to 7.4 thousand Euros. It has three different packages:

1. Basic package that includes all main features like 3D/2D modelling and drawing and other advanced features. The package costs around 3.7 thousand Euros.
2. Professional package adds a big component library and rendering. The package costs around 5 thousand Euros.
3. Premium package adds motion simulation, tolerance and structural analysis. The package costs around 7.4 thousand Euros.

SolidWorks offers an annual subscription that costs 1.2 thousand Euros. The subscription includes upgrades and technical support. This is license for one computer, a company usually requires more than one license, for that there are corporate licenses or floating licenses which connect to the internet for verification. In this way, the price of a single license decreases.

The add in “Costing” used in the analysis only comes with Premium and Professional packages. So in order for the company to be able to plan their processes using SolidWorks, minimum prices will be 5 thousand Euros and in order to have a constant technical support and updated databases, the price rises close to 6.4 thousand Euros [31].

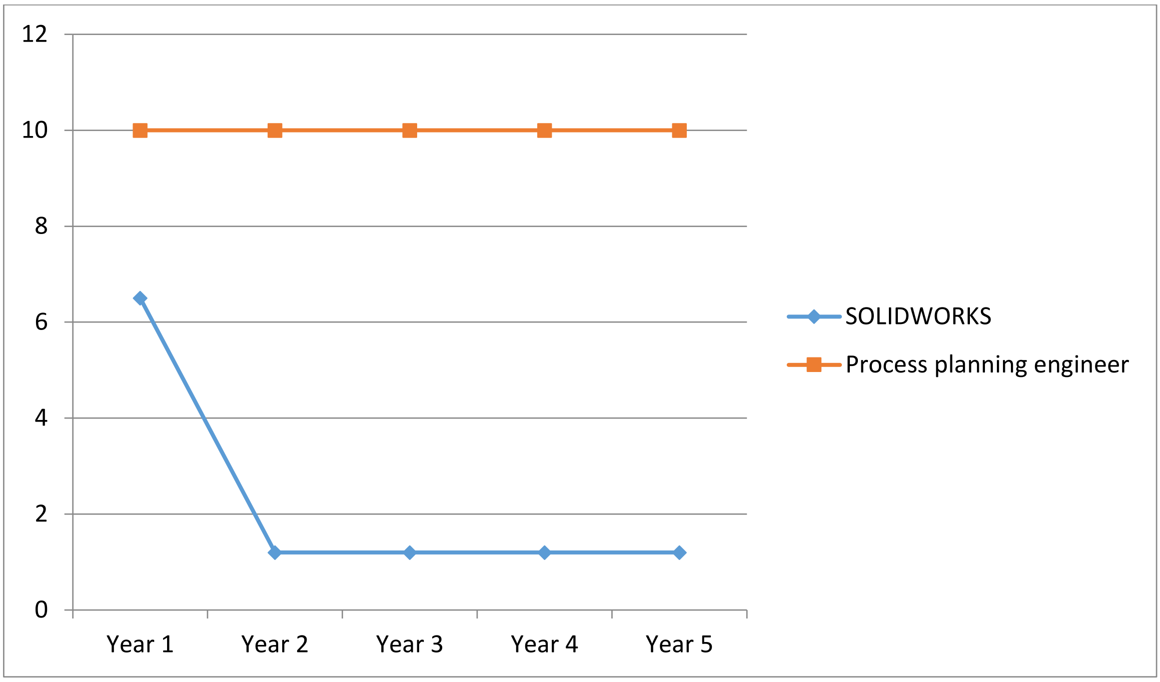


Fig. 3.16. Annual expenditures for process planning

According to "Sodra" average monthly salary in Lithuania in 2016 was around 800 Euros [32]. If for example, a person responsible for creating process plans manually or with a variant system would earn around that amount. Every year it would cost around 10 thousand Euros at least (Fig. 3.16.), not including the price of a variant computer aided process planning software and other expenditures. With a more automated generative system the position could be removed and added to other engineer's responsibilities as it would not take a full work day.

So after the initial purchase the company would only need to pay the annual subscription fee of around 1.2 thousand Euros for one user. This, theoretically, would save around 8.8 thousand Euros every year [33].

Additional thing to notice would be trainings if the engineer, who will be taking over the process planning, has no experience in working with SolidWorks. As an example, UAB "IN RE" – specializing in software training courses, offers basic SolidWorks trainings starting from 300 Euros [34].

Application areas, CAD software like SolidWorks can be used in virtually any today's manufacturing or design company. Usually all companies have at least one license. In Lithuania, according to an official SolidWorks software retailer in Lithuania "IN RE" over 250 companies have more than 500 licenses [35]. So, it makes an average of at least 2 licenses per company not taking into account the size of the company. And this is only one licensed retailer, there are more retailers and many companies buy the software straight from the creators or in case of international companies – from other countries.

For small companies that not necessarily can afford or need the software constantly, SolidWorks offers monthly licenses.

Stand-alone CAPP systems like CAME SAT or its newer counterparts can be used in companies that do not find any need to own CAD software and have a very stable product portfolio with little to no variation and addition of new products. New stand-alone CAPP systems can also be paired up with CAD software or read 3D part drawings. Such software could be used in small companies who do not have a need for their own design departments or even one CAD software license as all of their orders come from other companies with already made 3D part designs. This way they could save money on an expensive license and also gain from more accurate, specialised CAPP software.

Big companies can find use for stand-alone CAPP software as well, if a company is big enough to have its own design department especially if they have more than one production site, having a big number of CAD software licenses is pointless and costly. All drawings are prepared in one centralised design department and the manufacturing floor gets already prepared drawings for which they only need specialised CAPP software with 3D model recognition to generate a process plan. This way, they save money on licenses, training, and maintenance of the software and get a better accuracy as well. Although, some specialised CAPP systems tend to get expensive as they still need to be adjusted to every company, so that kind of system usually is more suited to a very big manufacturing company, like for example, Boeing, one of the biggest plane manufacturers in the world.

Table 3.3. Application areas of different planning software

	CAD software	Variant CAPP software (CAME SAP)	Generative CAPP software
Company size	Any company size	Small	Small or very big
Application area	From design office to production facility	Production facility	Production facility
Conditions	Company has to use 3D drawings for manufacturing	Stable product portfolio with little new products introduction	Source of 3D drawings (external or internal)

3.5. CAPP software in Lithuanian manufacturing companies

The analysis was carried out for products manufactured from metal, so the analysis applies mainly to the companies that specialize in metal machining and manufacturing metal products. According to Lithuanian statistics bureau and “Versli Lietuva” - a non-profit agency, there were 192 companies in Lithuania in 2016 [36] that specialize in machine building – one of the industries where process planning for products made out of metal is highly used as the machines are made out of many metal parts like bearings, shafts, covers, bolts, adapters and many others. In Fig 3.17., it can be seen that metal products make up around 7% out of all manufacturing industries. That is not very much, but the entire industry is very fragmented and only a couple of industry segments are clearly bigger than others. For such a small market like Lithuania there are still quite a few of companies and in the recent years, the metal manufacturing has been picking up face after it suffered greatly during the recession of 2009 and now there are around 700 companies specializing in metal manufacturing [37], with medium enterprises (50-249 employees) dominating.

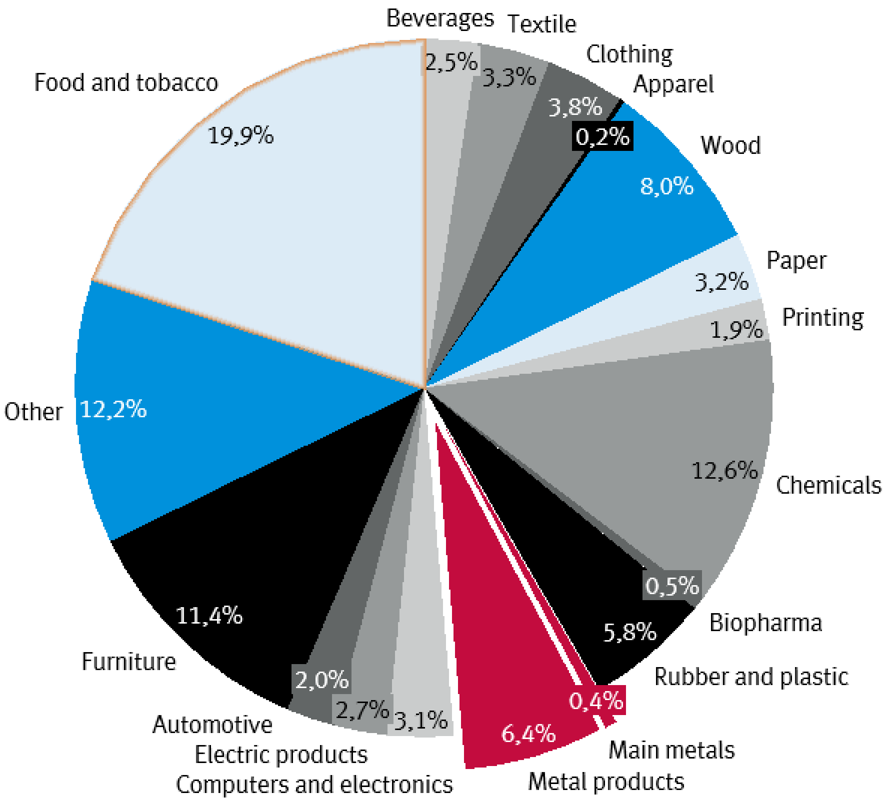


Fig. 3.17. Manufacturing industry segment market shares [38]

Most of those companies work closely with foreign customers. Usually it is a very big company outsourcing and getting standard parts from a cheaper market, like Lithuania. Good example would be car manufacturers, like Rolls Royce or German manufacturing firms that import metal parts made in Lithuania. This means that if Lithuanian companies want to be attractive and also be able to successfully finish the orders and ensure the top quality of the products, they have to improve their manufacturing facilities and processes. This of course means new CNC machines, fully automated processes, highly skilled specialists. But another important part is the software and one part of that software is CAD software. Companies, especially the ones, working with foreign customers, need to have CAD software to be able to design or fix the parts also to read the parts and generate drawings.

It can be seen in the pie chart (Fig. 3.18.) that manufacturing industry is among the industries investing the most into software.

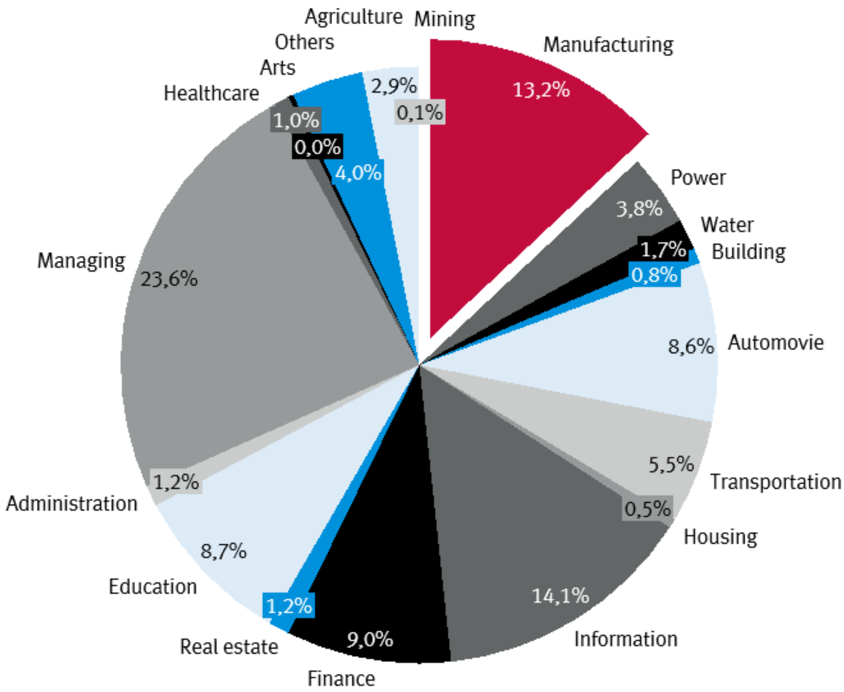


Fig. 3.18. Investment in software by industries [38]

This is an important indicator that Lithuanian companies are turning hi-tech. This makes sense as the companies are usually of medium size, so the prices of implementing new software or manufacturing processes are lower. Also, because they are small and unknown in the world it helps them to get on the map and offer the highest quality with state of the art manufacturing facilities. Low labour prices attract countries like Germany, where work is expensive and because Lithuania is in a good geographical location, it becomes more attractive than the Asian countries. It can be seen in the graph (Fig. 3.19.) that there were peaks going for two years in manufacturing industry for the amount of investment in software. Apart from those two peaks, the state has remaining stable, but not decreasing, for the last three years.

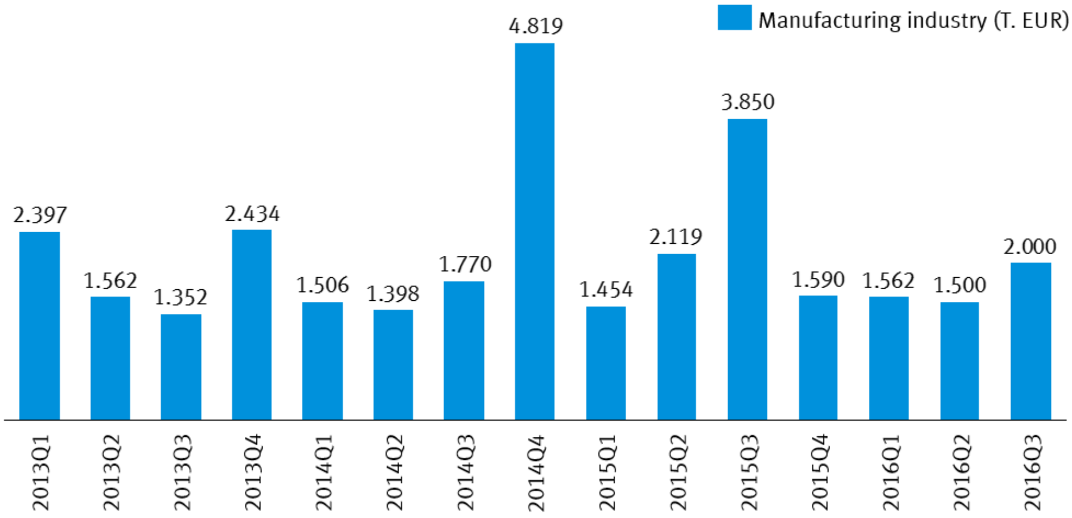


Fig. 3.19. Investment in software in manufacturing industry [38]

To see how Lithuanian companies look; Lithuanian metal manufacturing companies were analysed, with most of them being quite similar, five of them are showed in Table 3.4. to give an idea of what the companies look like. All five companies, even though fall into the medium enterprises category, use CAD software to design parts and read drawings, companies also offer to design unique parts for the customer. This shows that companies can not only mass produce parts, but also are very flexible in their production lines and processes to be able to produce unique or small batches of parts. This is due to companies using new automatic CNC machines and being able to offer a wide range of service ranging from milling to painting and assembling. CAD software paired up with CAM software for CNC machines enables them to go from the design phase to production in a very short period of time.

Table 3.4. Metal manufacturing companies in Lithuania

Company	Uses CAD software?	Types of services	Size (employees)	**Uses for CAD**
fortas	Yes, SolidWorks	Milling, cutting, stamping, bending, turning, coating	100	Designing parts, creating and reading drawings
Sargasas	yes	Milling, turning, coating, assembly	55	Designing parts, creating and reading drawings
Karbonas	Yes, SolidWorks	Cutting, bending	59	Designing parts, creating and reading drawings
Metaco	Yes	Cutting, bending, coating	44	Designing parts, creating and reading drawings
Kagneta	Yes	Milling, cutting, stamping, bending, turning, coating	42	Designing parts, creating and reading drawings

3.5. Final recommendations

After the analysis, it can be seen, that for today's company, some sort of process planning is needed. Most of the companies are upgrading their processes and equipment and installing CAD and CAM software to stay competitive and attract foreign customers. After looking at two types of different computer-aided process planning systems and finding out their strengths and shortcomings, it can be said that CAD software with integrated CAPP elements would be the most suited for Lithuania's market. Lithuanian companies are too small for a specialised stand-alone process planning software that would be tailored for that company's needs. Such systems are very big; their maintenance costs a lot and the systems are usually meant for very big enterprises working on big and expensive projects. A simple process planning add-in that is easy to use and requires little to no special training as students get all the basic training during their studies in technical universities. The price is low, maintenance is usually very low or there is none at all. Software is more flexible and thus does not limit the company to one type of products. The CAPP add-in is a great bridge between CAD and CAM software and makes the entire design to production process completely automated and computer-aided.

CONCLUSIONS

There was always a need for process planning to keep track of and control the processes involved in manufacturing. People have thought of the concepts way back at the first industrial revolution. With everything being automated and manual labour becoming a luxury, computer aided process planning system is a must in today's manufacturing enterprise as well. The aim of this work was divided into separate tasks in order to shed more light on the CAPP systems and situation in Lithuanian manufacturing enterprises, after the tasks completed such conclusions arose:

1. Throughout research has been carried out to find different computer aided process planning system out there. Most of the systems found were not available anymore and very outdated and mostly of variant type, just a few new generative type stand-alone CAPP systems were out there on the market. It was found that as CAPP was a bridge between CAD and CAM systems it was merged with CAD software into one package.
2. To simulate tasks for stand-alone variant CAPP system for which CAME SAT software as used and integrated generative process planning system that was merged with CAD software SolidWorks, three parts were selected for this analysis:
    1. bearing ring;
    2. cylindrical shaft;
    3. solid part.

   Process plans were generated for all three parts using both systems to get the feeling and evaluate their functionality, ease of use, reliability and viability.
3. The results and impressions from both systems were analysed and compared. The integrated generative type system showed more flexibility, the entire process of was very quick and intuitive, it required very little input from the user. Meanwhile, variant stand-alone system was very rigid and not interactive, it required input from the user, which requires a lot of experience otherwise mistakes might occur. Generative type system can generate a plan in a matter of minutes and using variant system can even take hours, depending on the complexity and uniqueness of the part. Prices were also analysed and it was found that owning an integrated generative CAPP system is economically more efficient for a small or medium enterprise that does not specialize in one specific product.
4. To analyse the situation of Lithuanian manufacturing enterprises and their automation level and the need for computer aided software in general, the general data was researched to see the amount of companies in Lithuania and their investments into software as well as to consider individual companies to see their automation level and offered services. It was found that there are close to thousand small and medium heavily automated manufacturing

companies in Lithuania that have their own design departments and are using both CAD and CAM software to automate their manufacturing. Also, it was noticed that companies tend to invest into further automating their processes to meet the demands of their foreign customers.

5. To offer recommendations for which enterprises CAPP system would be most suited, the results from analysing two types of CAPP systems and looking at the situation in Lithuania's manufacturing industry, an integrated generative type computer aided process planning system would be recommended for Lithuanian small and medium manufacturing enterprises due to its flexibility, ease of use, low maintenance and affordable price.

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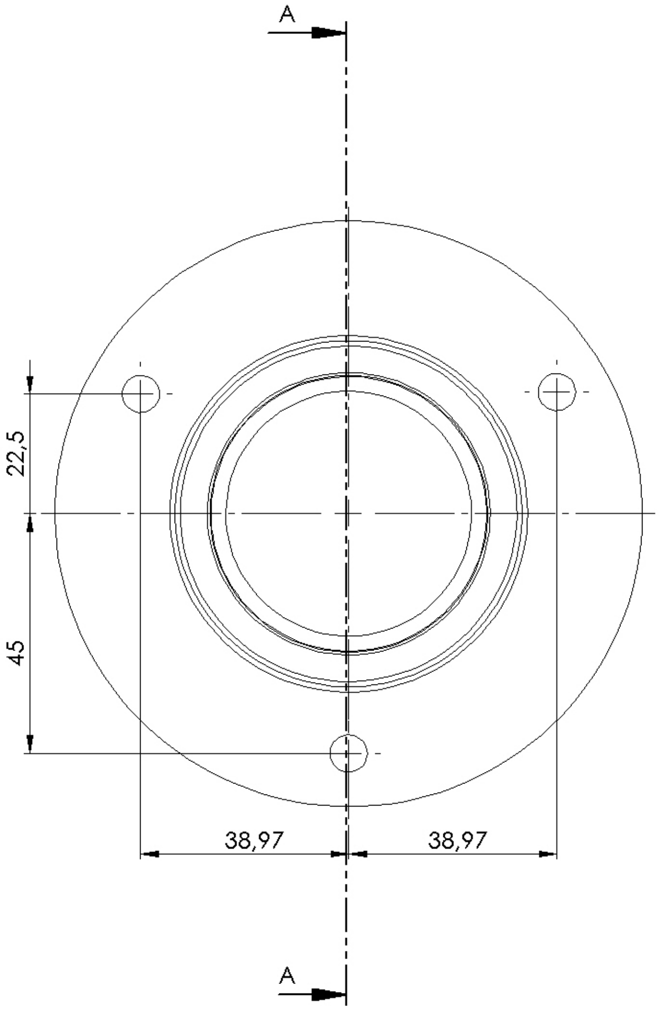
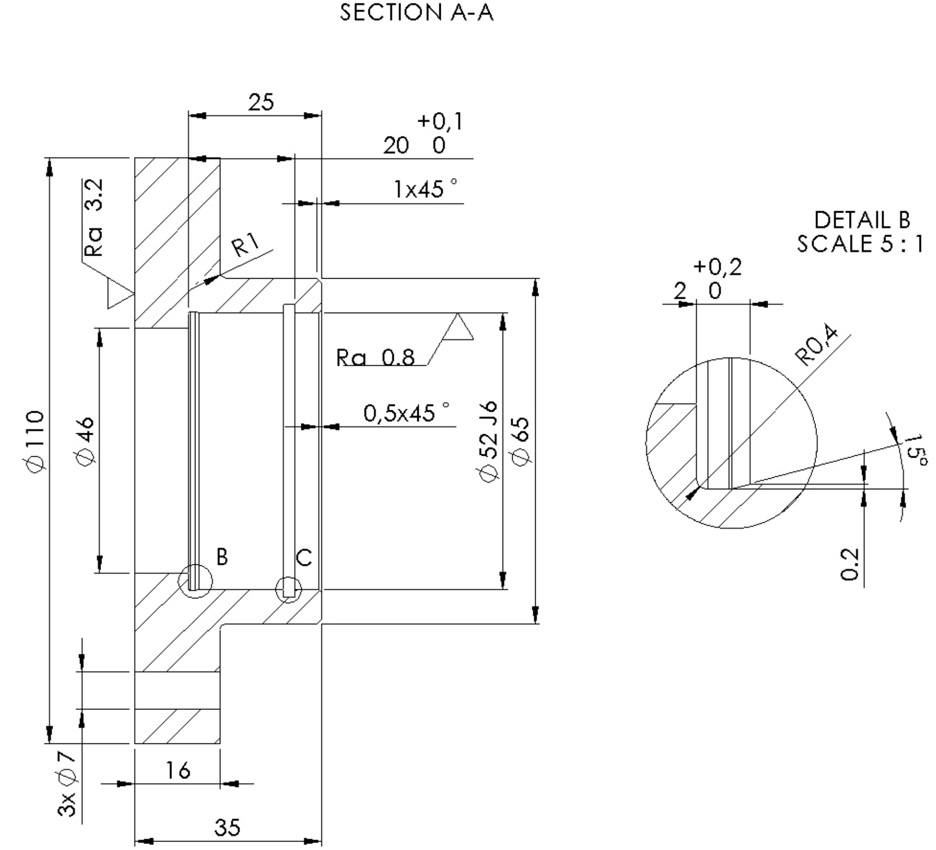
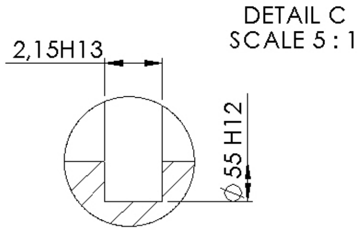
APPENDICES

1. Drawings (3 pages)
2. SolidWorks Costing reports (13 pages)
3. CAME SAT process plan reports (4 pages)







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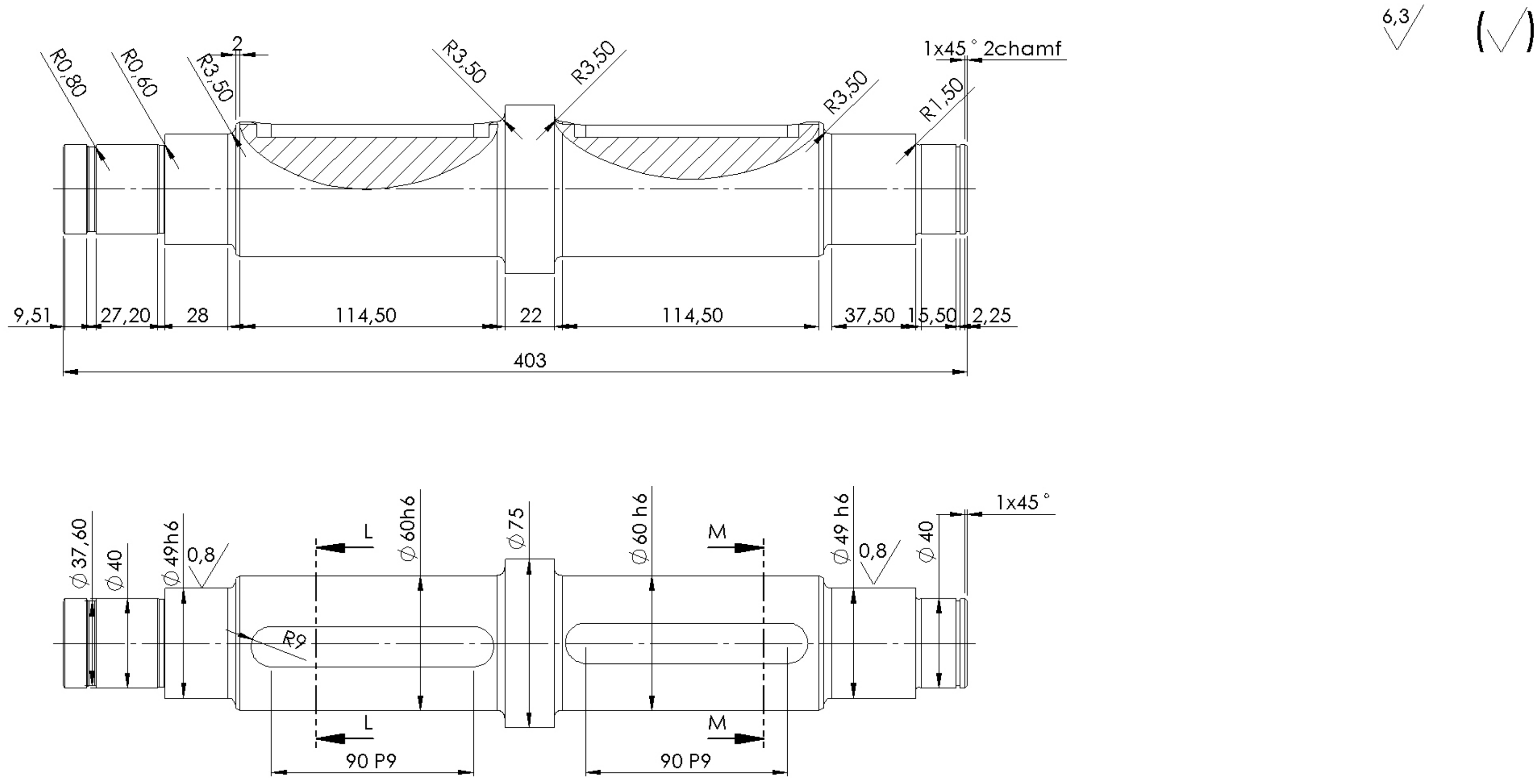
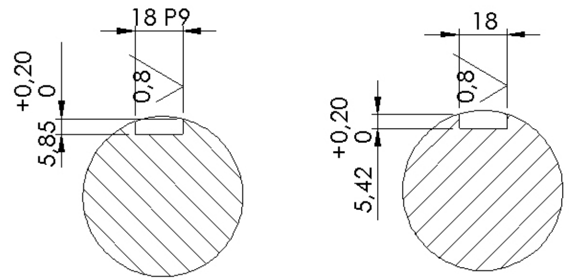
SHEET 1 OF 1



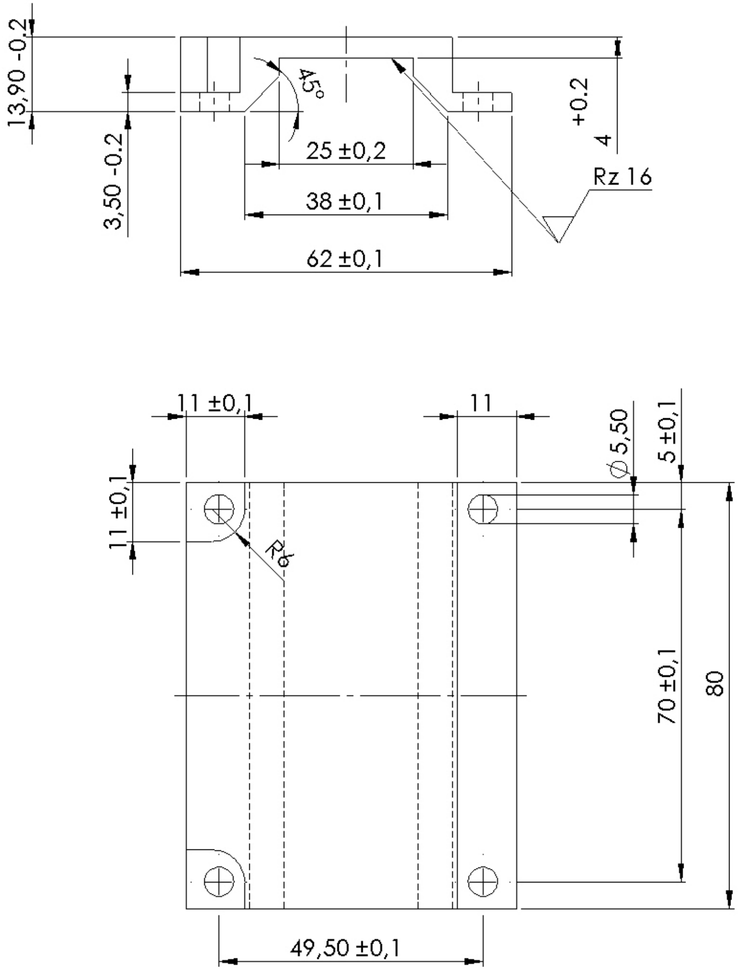


SECTION L-L
SCALE 1 : 2

SECTION M-M
SCALE 1 : 2

1. Sharp edges removed
2. Not shown tolerances according to LST EN 22768-1:2001.

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:		DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE	TITLE:	
DRAWN	L. Meilutis			Cylindrical shaft	
CHK'D					
APPV'D					
MFG					
Q.A			MATERIAL: Plain carbon steel	DWG NO.	A3
			WEIGHT: 7601.5	SCALE:1:5	SHEET 1 OF 1



Rz 63 (Rz 16)

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	L.Meilutis		2017.04.22
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

Solid part

MATERIAL:
Plain carbon steel

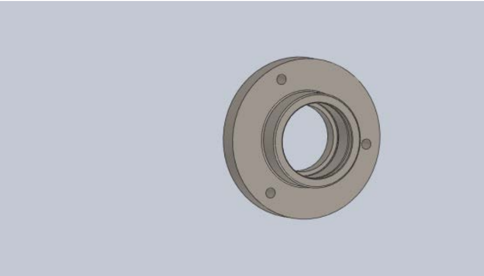
DWG NO.

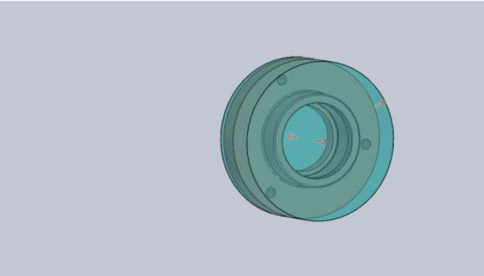
A3

WEIGHT: 264.6

SCALE:1:1

SHEET 1 OF 1





Model name:	Bearing part
Date and time of report:	2017.05.03 20:10:46
Material:	Plain Carbon Steel
Manufacturing process:	Machining
Finished part weight:	3.35 kg
Stock type:	Cylinder
Cylinder Size:	110.20x45.00 mm
Material cost/weight:	0.73 EUR/kg
Shop Rate:	30.00 EUR

Quantity to Produce

Total number of parts:	100
Lot size:	100

Estimated cost per part: 91.93 EUR

Costing template used:	costing.sldctm
Costing mode used:	Manufacturing Process Recognition
Comparison:	Current 91.93 EUR Baseline 91.93 EUR

Cost Breakdown

Material:	2.44 EUR	3%
Manufacturing:	89.49 EUR	97%
Markup	0.00 EUR	0%

Estimated time per part: 02:15:20

Setups:	00:33:36
Operations:	01:41:44

Cost Report

Model Name:	20 Rotational Laimonas Meilutis	Material:	Plain Carbon Steel	Material cost: Manufacturing cost: Markup	2.44 EUR 89.49 EUR 0.00 EUR	Total cost /part: Total time /part:	91.93 EUR 02:15:20

Manufacturing Cost Breakdown

Operation Setups	Time (hh:mm:ss)	Cost (EUR)
Setup Operation 3	00:00:36	0.40
Setup Operation 4	00:00:36	0.40
Setup Operation 10	00:00:36	0.30
Setup Operation 11	00:00:36	0.40
Setup Operation 12	00:00:36	0.40
Setup Operation 13	00:00:36	0.40
Total	00:03:36	2.30

Custom Setups	Time (hh:mm:ss)	Cost (EUR)
Setup Custom Operation 1	00:00:00	0.00
Total	00:00:00	0.00

Load and Unload Setups	Time (hh:mm:ss)	Cost (EUR)
Setup Operation 3	00:05:00	3.33
Setup Operation 4	00:05:00	3.33
Setup Operation 10	00:05:00	2.50
Setup Operation 11	00:05:00	3.33
Setup Operation 12	00:05:00	3.33
Setup Operation 13	00:05:00	3.33
Setup Custom Operation 1	00:00:00	0.00
Total	00:30:00	19.17

Turn Operation	Surface Finish	Volume Removed (mm^3)	Time (hh:mm:ss)	Cost (EUR)	Tooling	Cost-per-Volume (EUR/mm^3)
ID Groove 1	Roughing	321.58	00:00:01	0.01	ID Grooving	N/A
ID Groove 1	Semi - Finishing	183.38	00:00:00	0.01	ID Grooving	N/A
ID Groove 1	Finishing	37.08	00:00:00	0.00	ID Grooving	N/A
ID Turn 1	Roughing	0.00	00:00:00	0.00	ID Turning	N/A
ID Turn 1	Semi - Finishing	0.00	00:00:00	0.00	ID Turning	N/A
ID Turn 1	Finishing	69261.25	01:22:05	54.72	ID Turning	N/A
OD Turn 1	Roughing	1.14E+5	00:14:30	9.68	OD Turning	N/A
OD Turn 1	Semi - Finishing	3268.04	00:01:06	0.74	OD Turning	N/A

OD Turn 1	Finishing	1210.61	00:01:26	0.96	OD Turning	N/A
Volume 1	Roughing	0.00	00:00:00	0.10	OD Turn	N/A
Volume 1	Semi - Finishing	440.56	00:00:08	0.10	OD Turn	N/A
Volume 1	Finishing	78.37	00:00:05	0.06	OD Turn	N/A
Right Face	Roughing	41966.79	00:00:38	0.43	Facing	N/A
Right Face	Semi - Finishing	4768.95	00:00:10	0.11	Facing	N/A
Right Face	Finishing	953.79	00:00:02	0.03	Facing	N/A
Left Face	Roughing	41966.79	00:00:38	0.43	Facing	N/A
Left Face	Semi - Finishing	4768.95	00:00:10	0.11	Facing	N/A
Left Face	Finishing	953.79	00:00:02	0.03	Facing	N/A
Total		2.84E+5	01:41:08	67.52		

Hole Operation	Surface Finish	Volume Removed (mm^3)	Time (hh:mm:ss)	Cost (EUR)	Tooling	Cost-per-Volume (EUR/mm^3)
Hole 1	Drill	615.75	00:00:12	0.10	HSS Drill	N/A
Hole 2	Drill	615.75	00:00:12	0.10	HSS Drill	N/A
Hole 3	Drill	615.75	00:00:12	0.10	HSS Drill	N/A
Total		1847.26	00:00:36	0.30		

Custom Operations	Quantity	Cost (EUR)
Inspection <1>	1	0.20
Total	1	0.20

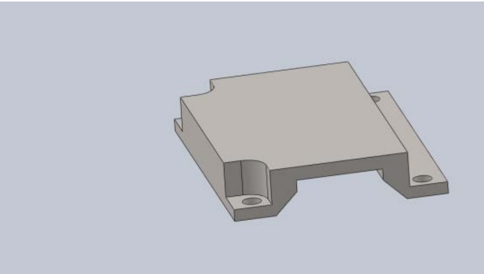
Setup Operations

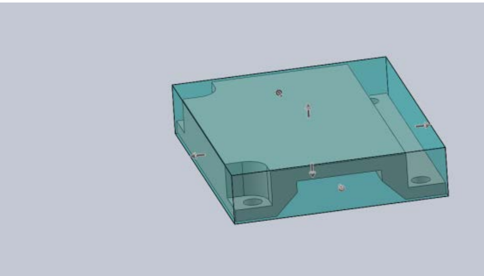
1. Setup Operation 3
   a. ID Turn 1
   b. ID Groove 1
2. Setup Operation 4
   a. OD Turn 1
3. Setup Operation 10
   a. Hole 1
   b. Hole 2
   c. Hole 3
4. Setup Operation 11
   a. Volume 1
5. Setup Operation 12

a. Right Face

6. Setup Operation 13

a. Left Face





Model name:	Solid shaft
Date and time of report:	2017.05.07 17:41:09
Material:	Plain Carbon Steel
Manufacturing process:	Machining
Finished part weight:	0.59 kg
Stock type:	Block
Block Size:	63.00x14.90x81.00 mm
Material cost/weight:	3.11 EUR/kg
Shop Rate:	30.00 EUR

Quantity to Produce

Total number of parts:	100
Lot size:	100

Estimated cost per part:	25.05 EUR
Costing template used:	costing.sldctm
Costing mode used:	Manufacturing Process Recognition
Comparison:	0% Current 25.05 EUR Baseline 25.05 EUR

Cost Breakdown

Material:	1.84 EUR	7%
Manufacturing:	23.20 EUR	93%
Markup	0.00 EUR	0%

Estimated time per part:	00:46:07
Setups:	00:39:12
Operations:	00:06:55

Cost Report

Model Name:	21 Solid Laimonas Meilutis	Material:	Plain Carbon Steel	Material cost:	1.84 EUR	Total cost /part:	25.05 EUR
				Manufacturing cost:	23.20 EUR	Total time /part:	00:46:07
				Markup	0.00 EUR		

Manufacturing Cost Breakdown

Operation Setups	Time (hh:mm:ss)	Cost (EUR)
Setup Operation 1	00:00:36	0.30
Setup Operation 2	00:00:36	0.30
Setup Operation 3	00:00:36	0.30
Setup Operation 4	00:00:36	0.30
Setup Operation 5	00:00:36	0.30
Setup Operation 6	00:00:36	0.30
Setup Operation 7	00:00:36	0.30
Total	00:04:12	2.10

Load and Unload Setups	Time (hh:mm:ss)	Cost (EUR)
Setup Operation 1	00:05:00	2.50
Setup Operation 2	00:05:00	2.50
Setup Operation 3	00:05:00	2.50
Setup Operation 4	00:05:00	2.50
Setup Operation 5	00:05:00	2.50
Setup Operation 6	00:05:00	2.50
Setup Operation 7	00:05:00	2.50
Total	00:35:00	17.50

Mill Operation	Surface Finish	Volume Removed (mm^3)	Time (hh:mm:ss)	Cost (EUR)	Tooling	Cost-per-Volume (EUR/mm^3)
Slot 3	Roughing	9014.73	00:01:05	0.54	Flat End Mill	N/A
Slot 3	Semi - Finishing	12268.31	00:00:40	0.34	Flat End Mill	N/A
Slot 3	Finishing	1896.96	00:01:23	0.69	Flat End Mill	N/A
Right Face	Roughing	0.00	00:00:00	0.00	Face Mill	N/A
Right Face	Finishing	294.44	00:00:12	0.11	Face Mill	N/A
Left Face	Roughing	0.00	00:00:00	0.00	Face Mill	N/A
Left Face	Finishing	294.44	00:00:12	0.11	Face Mill	N/A
Top Face	Roughing	0.00	00:00:00	0.00	Face Mill	N/A

Top Face	Finishing	1267.71	00:00:55	0.46	Face Mill	N/A
Bottom Face	Roughing	0.00	00:00:00	0.00	Face Mill	N/A
Bottom Face	Finishing	1267.71	00:00:55	0.46	Face Mill	N/A
Volume 1	Roughing	499.98	00:00:03	0.03	Flat End Mill	N/A
Volume 1	Semi - Finishing	598.52	00:00:01	0.02	Flat End Mill	N/A
Volume 1	Finishing	79.56	00:00:03	0.03	Flat End Mill	N/A
Volume 2	Roughing	499.98	00:00:03	0.03	Flat End Mill	N/A
Volume 2	Semi - Finishing	598.52	00:00:01	0.02	Flat End Mill	N/A
Volume 2	Finishing	79.56	00:00:03	0.03	Flat End Mill	N/A
Volume 3	Roughing	5238.37	00:00:34	0.29	Flat End Mill	N/A
Volume 3	Semi - Finishing	3478.78	00:00:11	0.10	Flat End Mill	N/A
Volume 3	Finishing	434.85	00:00:19	0.16	Flat End Mill	N/A
Total		37812.41	00:06:47	3.40		

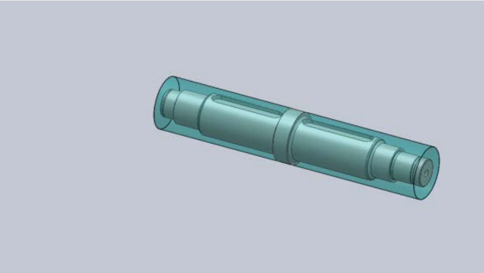
Hole Operation	Surface Finish	Volume Removed (mm^3)	Time (hh:mm:ss)	Cost (EUR)	Tooling	Cost-per-Volume (EUR/mm^3)
Hole Pattern 1	Drill	332.62	00:00:08	0.07	HSS Drill	N/A
Total		332.62	00:00:08	0.07		

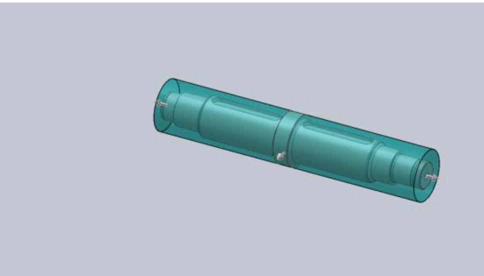
No Cost Features
Slot 1
Slot 2
Slot 4
Near Face
Far Face

Setup Operations

1. Setup Operation 1
   a. Slot 3
   b. Near Face
2. Setup Operation 2
   a. Hole Pattern 1 - 3

   b. Hole Pattern 1 - 1
   c. Hole Pattern 1 - 4
   d. Hole Pattern 1 - 2
   e. Top Face
3. Setup Operation 3
   a. Volume 3
   b. Volume 2
   c. Volume 1
4. Setup Operation 4
   a. Right Face
5. Setup Operation 5
   a. Left Face
6. Setup Operation 6
   a. Bottom Face
7. Setup Operation 7
   a. Far Face





Model name:	Cylindrical shaft
Date and time of report:	2017.05.07 20:58:09
Material:	Plain Carbon Steel
Manufacturing process:	Machining
Finished part weight:	13.98 kg
Stock type:	Cylinder
Cylinder Size:	75.20x403.40 mm
Material cost/weight:	3.11 EUR/kg
Shop Rate:	30.00 EUR

Quantity to Produce

Total number of parts:	100
Lot size:	100

Estimated cost per part:	121.40 EUR
Costing template used:	costing.sldctm
Costing mode used:	Manufacturing Process Recognition
Comparison:	

Cost Breakdown

Material:	43.46 EUR	36%
Manufacturing:	77.93 EUR	64%
Markup	0.00 EUR	0%

Estimated time per part:	02:10:33
Setups:	00:33:36
Operations:	01:36:57

Cost Report

Model Name:	3a - osovina	Material:	Plain Carbon Steel	Material cost: Manufacturing cost: Markup	43.46 EUR 77.93 EUR 0.00 EUR	Total cost /part: Total time /part:	121.40 EUR 02:10:33

Manufacturing Cost Breakdown

Operation Setups	Time (hh:mm:ss)	Cost (EUR)
Setup Operation 1	00:00:36	0.30
Setup Operation 5	00:00:36	0.40
Setup Operation 6	00:00:36	0.40
Setup Operation 7	00:00:36	0.40
Setup Operation 8	00:00:36	0.40
Setup Operation 9	00:00:36	0.30
Total	00:03:36	2.20

Load and Unload Setups	Time (hh:mm:ss)	Cost (EUR)
Setup Operation 1	00:05:00	2.50
Setup Operation 5	00:05:00	3.33
Setup Operation 6	00:05:00	3.33
Setup Operation 7	00:05:00	3.33
Setup Operation 8	00:05:00	3.33
Setup Operation 9	00:05:00	2.50
Total	00:30:00	18.33

Mill Operation	Surface Finish	Volume Removed (mm^3)	Time (hh:mm:ss)	Cost (EUR)	Tooling	Cost-per-Volume (EUR/mm^3)
Pocket 1	Roughing	11843.99	00:01:25	0.72	Flat End Mill	N/A
Pocket 2	Roughing	11920.04	00:01:26	0.72	Flat End Mill	N/A
Volume 1	Roughing	3.72E+5	00:40:32	20.27	Flat End Mill	N/A
Total		3.95E+5	00:43:24	21.70		

Turn Operation	Surface Finish	Volume Removed (mm^3)	Time (hh:mm:ss)	Cost (EUR)	Tooling	Cost-per-Volume (EUR/mm^3)
OD Groove 1	Roughing	586.14	00:00:03	0.04	OD Grooving	N/A
OD Groove 2	Roughing	281.52	00:00:01	0.02	OD Grooving	N/A
OD Turn 1	Roughing	1.34E+5	00:17:04	11.38	OD Turning	N/A
ID Turn 1	Roughing	259.50	00:00:01	0.02	ID Turning	N/A

OD Turn 2	Roughing	1664.63	00:00:12	0.14	OD Turning	N/A
OD Turn 3	Roughing	7992.39	00:01:00	0.68	OD Turning	N/A
OD Turn 4	Roughing	1810.47	00:00:13	0.15	OD Turning	N/A
OD Turn 5	Roughing	810.78	00:00:06	0.07	OD Turning	N/A
OD Turn 6	Roughing	71560.09	00:09:05	6.06	OD Turning	N/A
OD Turn 7	Roughing	8527.08	00:01:04	0.72	OD Turning	N/A
OD Turn 8	Roughing	3442.91	00:00:26	0.29	OD Turning	N/A
OD Turn 9	Roughing	1.85E+5	00:23:28	15.64	OD Turning	N/A
OD Turn 10	Roughing	5140.24	00:00:39	0.44	OD Turning	N/A
ID Turn 2	Roughing	259.50	00:00:01	0.02	ID Turning	N/A
Right Face	Roughing	888.29	00:00:00	0.01	Facing	N/A
Left Face	Roughing	888.29	00:00:00	0.01	Facing	N/A
Total		4.23E+5	00:53:32	35.70		

Setup Operations

1. Setup Operation 1
    a. Pocket 2
    b. Pocket 1
2. Setup Operation 5
    a. OD Turn 9
    b. OD Turn 4
    c. OD Groove 1
    d. OD Turn 3
    e. OD Turn 5
    f. ID Turn 2
    g. OD Turn 8
    h. OD Groove 2
    i. OD Turn 2
    j. OD Turn 10
    k. OD Turn 6
    l. OD Turn 7
3. Setup Operation 6
    a. ID Turn 1
    b. OD Turn 1
4. Setup Operation 7
    a. Right Face
5. Setup Operation 8

a. Left Face

6. Setup Operation 9

a. Volume 1

PROCESS SHEET

Printed 2017.05.07 20:26

Faculty of Mechanical Engineering and Design Department of Manufacturing Engineering		Designer Laimonas Meilutis, 92 Examiner Mankute Rasa	
PRODUCT	**1**	Bearing ring G_Bearing ring	Quantity 100 unit
PART	**1**	Bearing ring D_Bearing ring	Quantity 1 in product
PRIMARY BLANK	**030613-112-2**	Round bar 112x6000 GOST 7511	65g GOST 1050
MASS	Mass of part 1,1197 Mass of blank 467,2740		Norm of material use for 1 part 2.749

	Op. No.	Enterp., shop, cell	Operation	Category	T. unit
O					
D		Documents, instructions			
S		Machine-tools			
P		Technological steps			
I		Fixtures and tools			
O	010	10	Cutting off and facing	3	2,33
D		SI 2 S 2			
S		Semiautomatic turret lathe 1H318			
P		Cut workpiece length 36			
P		Turn end face diameter 65			
I		Screwjig OE6530-4009			
I		Die jig OE6530-4016			
I		Drill jig			
I		Vice for clamp OE7222-4043			
I		Vice of heave OE7222-4044			
I		Support OE6530-4017			
I		Knife 10x12 OE-212-031			
O	015	10	Machining	3	4,30
D		SI 2 S 2			
S		Semiautomatic turret lathe 1H318			
P		Turn external diameter 65 length 19			
P		Turn internal diameter 52 length 35			
P		Drill 3 holes diameter 7 through			
P		Turn end surface			
I		Screwjig OE6530-4009			
I		Die jig OE6530-4016			
I		Drill jig			
I		Vice for clamp OE7222-4043			
I		Vice of heave OE7222-4044			
I		Support OE6530-4017			
I		Knife 10x12 OE-212-031			

ktu 1922

PROCESS SHEET

SAT

Printed 2017.05.07 20:34

Faculty of Mechanical Engineering and Design Department of Manufacturing Engineering			Designer Laimonas Meilutis, 92 Examiner Mankute Rasa	
PRODUCT	**2**	Box G_Box		Quantity 1 unit
PART	**1**	Box D_Box		Quantity in product 1
PRIMARY BLANK	**030513-150-1**	Plate 15x1000x2000	65g GOST 1050	
MASS	Mass of part 0,2634 Mass of blank 234,0000		Norm of material use for 1 part 0.585	

O D S P I	Op. No.	Enterp., shop, cell / Documents, instructions / Machine-tools / Technological steps / Fixtures and tools	Operation	Category	T. unit
O	010		Cutting of workpieces	3	28,16
S		Milling machine 675M			
P		Cut bands for workiepes 50 x 80			
I		Clamp 7200-0215			
I		Sliding sc-I-125-0.1 sc-I-125-0.1			
I		Sliding sc-II-250-0.05 sc-II-250-0.05			
O	020		Shoulder and face milling	3	28,70
S		Milling machine 675M			
P		Shoulder milling 11 by depth 10,5			
P		Slot milling 2 slots 11 x 11 by depth 10,5			
P		Remove 5 faces			
P		Drill 4 holes diameter 5,5			
I		Clamp 7200-0215			
I		Sliding sc-I-125-0.1 sc-I-125-0.1			
I		Sliding sc-II-250-0.05 sc-II-250-0.05			
O	025		Slot milling and ramping	3	27,30
S		Milling machine 675M			
P		Mill slot width 25 depth 10			
P		Ramping 6,5 x 45 degrees			
P		Remove 1 face			
I		Clamp 7200-0215			
I		Sliding sc-I-125-0.1 sc-I-125-0.1			
I		Sliding sc-II-250-0.05 sc-II-250-0.05			

PROCESS SHEET

ktu 1922

SAT

Printed 2017.05.07 20:37

Faculty of Mechanical Engineering and Design Department of Manufacturing Engineering		Designer Laimonas Meilutis, 92 Examiner Mankute Rasa	
PRODUCT	**3**	Shaft G_Shaft	Quantity 1 unit
PART	**1**	Shaft D_Shaft	Quantity 1 in product
PRIMARY BLANK	**030613-111-1**	Round bar 76x3000 GOST 7511	65g GOST 1050
MASS	Mass of part 7,5901 Mass of blank 107,6908		Norm of material use for 1 part 15.384

ODSPI	Op. No.	Enterp., shop, cell / Documents, instructions / Machine-tools / Technological steps / Fixtures and tools	Operation	Category	T. unit
O **D** **S** **P** **I**					
O	010	10	Turning right side	3	33,53
S		Turning lathe 16K20			
P		Turn external diameter 40 length 23			
P		Turn external diameter 49 length 41			
P		Turn external diameter 60 length 120			
P		Turn external diameter 75 length 22			
P		Turn end surface			
P		Cut workpiece length 404			
I		Vice 7100-0009			
I		Knife 20x25 2130-0009 T15L6			
I		Knife 20x25 2102-0029 T15L6			
I		Knife 20x25 2103-0023 T15L6			
I		Knife 20x25 2112-0015 T15L6			
I		Knife 20x25 2140-0006 T15L6			
I		Knife 20x25 2141-0007 T15L6			
I		Sliding sc-II-250-0.05 sc-II-250-0.05			
O	015	10	Turning left side	3	29,91
S		Turning lathe 16K20			
P		Turn external diameter 49 length 31,5			
P		Turn external diameter 40 length 45,5			
P		Turn end surface			
I		Vice 7100-0009			
I		Knife 20x25 2102-0029 T15L6			
I		Knife 20x25 2130-0009 T15L6			
I		Knife 20x25 2103-0023 T15L6			
I		Knife 20x25 2112-0015 T15L6			
I		Knife 20x25 2140-0006 T15L6			
I		Knife 20x25 2141-0007 T15L6			
I		Sliding sc-II-250-0.05 sc-II-250-0.05			

O	020	Slots milling	3	29,55
S		Milling machine 675M		
P		Mill 2 slots 18 x 90 depth 6,8		
I		Clamp 7200-0215		
I		Sliding sc-I-125-0.1 sc-I-125-0.1		
I		Sliding sc-II-250-0.05 sc-II-250-0.05		