FP7 Project

"ENergy Efficient Process pLANing system"

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MANAGEMENT BRIEF

The purpose of this document is to:

- Describe the simulation tools used by the industrial partners for the estimation of process characteristics (cost, time, energy consumption etc.)
- Review the existing CAM/CAPP tools
- Specify the desired functionalities and basic elements of the ENEPLAN meta-CAM tool.
- Specify the MetaCAM tool interface and format.
- Specify the MetaCAM tool data structure and acquisition.

Further outlook is provided in the following sections.

CONTENTS

1 INTRODUCTION

The goal of this deliverable is to define the requirements and the specifications of the Meta-CAM tool to be developed within the ENEPLAN project. It consists of three parts:

- description of the industrial partners' simulation tools
- review of the existing CAM/CAPP tools
- main functionalities and basic elements of the Meta-CAM tool

Meta-CAM is a manufacturing planning decision support tool for the optimization of the plant operation that will be able to be used from the conceptual phase of the product (final blueprints) to the final dispatch of the product to the customer. For this reason it will be able to handle and at the same time propose:

- Automatic or semiautomatic determination of materials, work sequences, cycles and process routes best suitable for the manufacturing of the workpiece.
- On-line (or short-time) configuration of the manufacturing system for that workpiece on the basis of modular, plug and produce, emergent functionality mechanisms based on the process steps and routes defined at the previous point
- Simulation of overall manufacturing system optimization and tuning for top production efficiency and minimum environmental impact

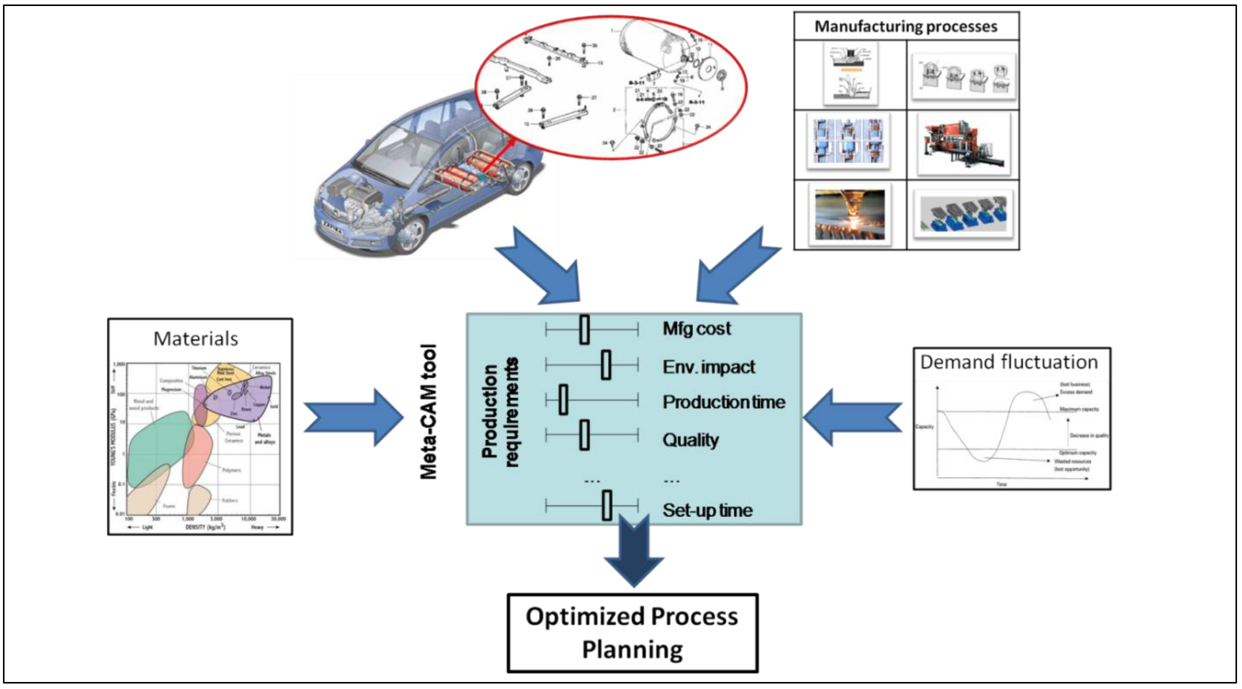


Figure 1: ENEPLAN concept

The Meta-CAM tool will be a bilateral tool. The "low-level" Meta-CAM module will assess a number of performance measures in order to optimize them at the process level (Figure 2), by altering process parameters in order to achieve optimization of the performance measure (e.g. cost, energy consumption etc.)

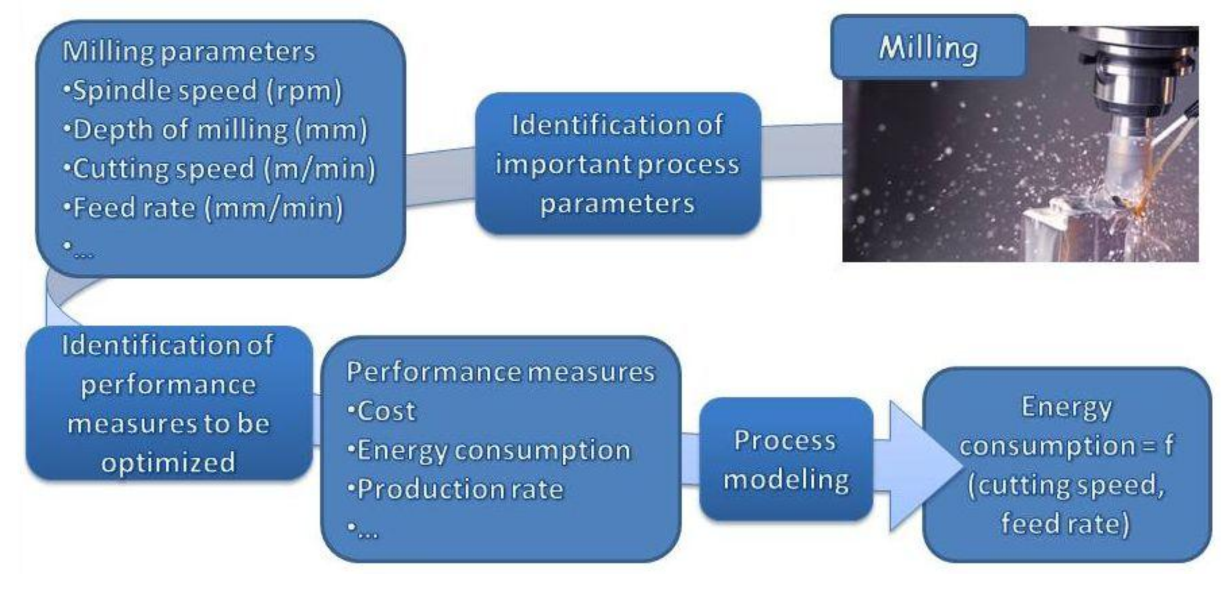


Figure 2: Low level Meta-CAM module approach (Milling example)

The "high-level" Meta-CAM module will perform process planning. This tool will select between alternate processes and different process sequence in order to optimize the production plan for a certain workpiece (Figure 3) based on an optimization criterion. The "high-level" module will control all the "low level" tools.

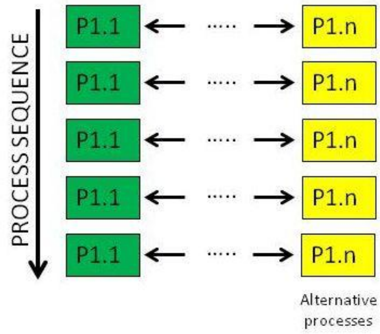


Figure 3: High level Meta-CAM module approach

2 STATE OF THE ART

2.1 INDUSTRIAL PARTNERS SIMULATION TOOLS

For conventional machining processes (mainly metal removing ones like milling, turning etc.), the simulation tools at the NC machine control level allow detecting tool path errors, inefficient motion mistakes and inefficiency before prove-out. During the part programming stage, is possible to eliminate errors that could ruin the part, damage the fixture, break the cutting tool, or crash the machine. Energy consumption must be derived from the calculated machine movements and through direct measuring at the machine motorization level.

For processes like laser cutting, punching, bending etc, the simulation tools at the NC machine control level create a virtual machine where the movements can be simulated. Analyzing the collection of movements returned back by the simulation engine allows calculating the energy consumption.

Paragraph 2.1 describes the NC simulation tools of the ENEPLAN partners PRIMA, FINN POWER, IDEKO, GIGANT and GIZELIS covering conventional, non-conventional and automation processes.

2.1.1 PRIMA

Machine virtualization

The simulation process starts with the creation of a virtual machine from a real machine. The virtual machine is a collection of files that identifies a specific machine, such as the calibration file (axes dynamics), the technology data (laser parameters), internal G-Code functions and more. The user has the possibility to create a Virtual Machine directly from the numerical control or using specialized software running in a normal computer. In the second case the virtual machine is created connecting the real machine over the network.

The simulation engine

The P20L/P30L numerical controls are developed internally to the Prima Power group. Thanks to this knowledge a set of libraries has been created from the NC kernel that gives us the possibility to run a part-program exactly in the same way of a real machine.

Simulation process

When the user launches a part-program simulation, the engine executes some preliminary operations:

- Loading of the calibration data
- Loading of the technology data
- Zeroing
- Homing
- Loading part-program

When the simulation is running, the engine returns back information such as the current NC code line, the current part/profile number, technology info, etc.

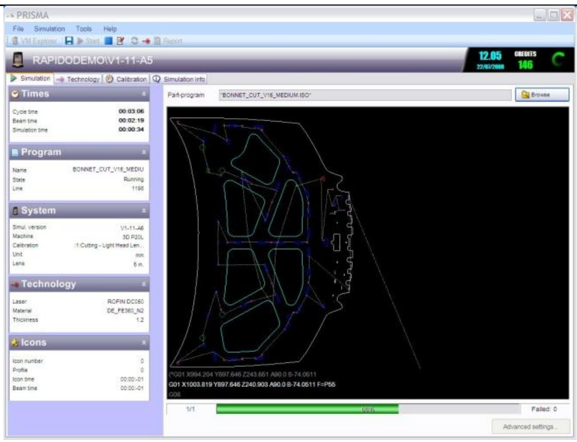


Figure 4: Screenshot from Prima Industrie simulation software

At the end of the simulation, a collection of machine movements is available for analysis. Each movement in the collection has properties. Following an example:

- MoveType: {RAPID, LINEAR, CIRCULAR,…}
- GCodeLine
- IntialPoint (x, y, z)
- TargetPoint (x, y, z)
- Length
- Time
- LaserMode: {CW, GP}
- LaserPower
- GasType
- GasPressure

Consumption and costs calculation

Analyzing the collection of movements returned back by the simulation engine is possible to calculate the energy and gas consumptions. For example, knowing how many bars of gas are commanded for the time of a single move is easy to calculate the consumption for the entire part-program and consequently the cost.

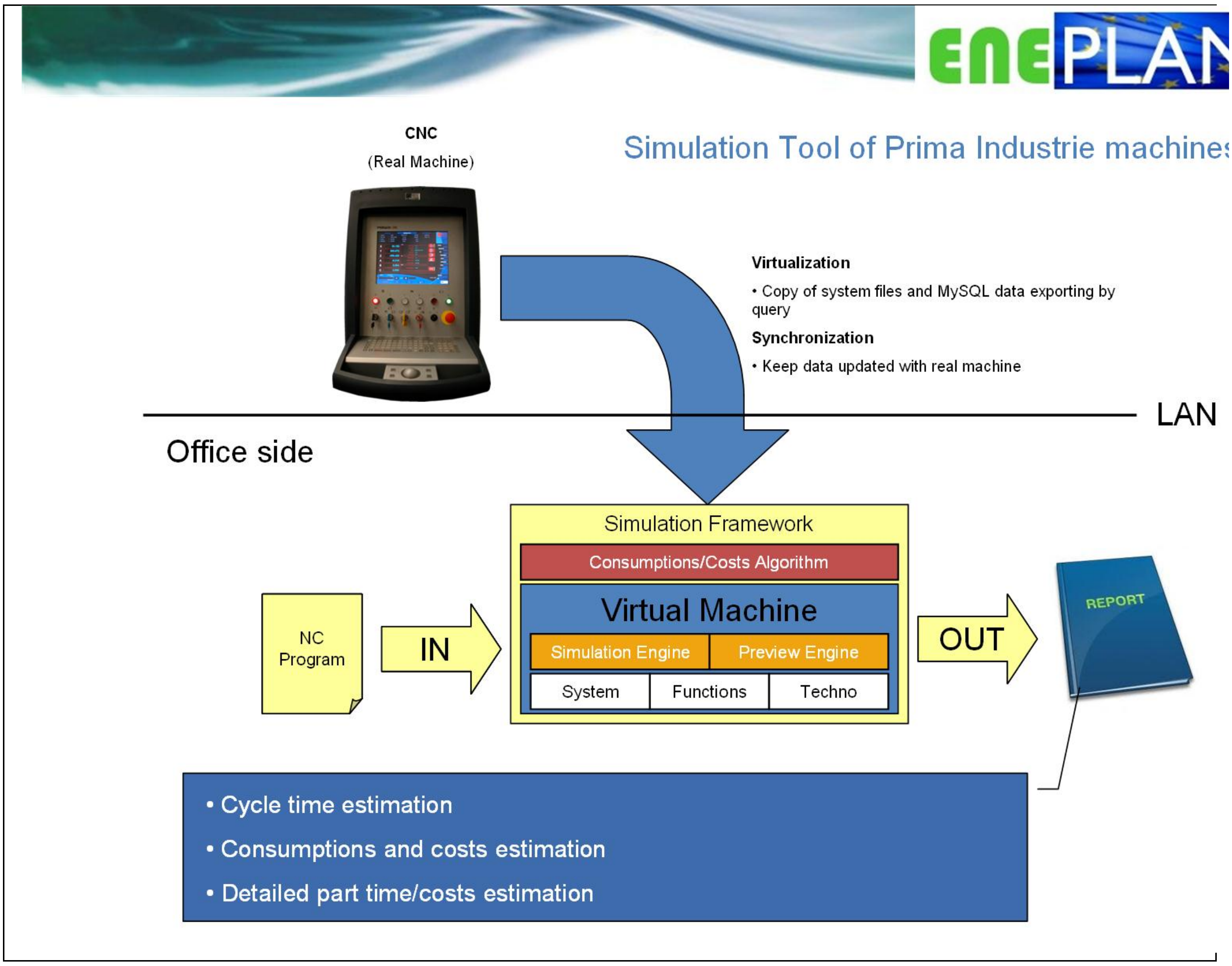


Figure 5: Simulation tool of Prima Industrie machines

2.1.2 FINN POWER

Finn-Power machine simulation is using machine parameters as measured from the actual machine, such as axes accelerations and speeds, required delays, etc. When the simulation module runs the NC-program, it uses the estimated part release times in the NC-code generated by the CAM software, as per the example below:

<Times>

<PRESORTING FlowID="1" PartID="1" Time="19.3"/>

<SORTING FlowID="1" PartID="1" Time="22.1"/>

<PRESORTING FlowID="2" PartID="2" Time="22.3"/>

<SORTING FlowID="2" PartID="2" Time="26.7"/>

<SHEET_LIFT Time="30.9"/>

<SHEET_POSITIONING Time="41.1"/>

<SHEET_UNLOAD Time="5"/>

</Times>

Using this method it is possible to avoid running the actual NC-code for the simulation, which makes the simulation software easier to build. Moreover, given the fact that it is not important for the user to show all axes moves in the simulation, this approach significantly lowers execution time for the simulation, if the purpose is to simulate the total production time for several days. The simulation software also writes a report about the results of the production simulation and it is possible to analyze what could be improved.

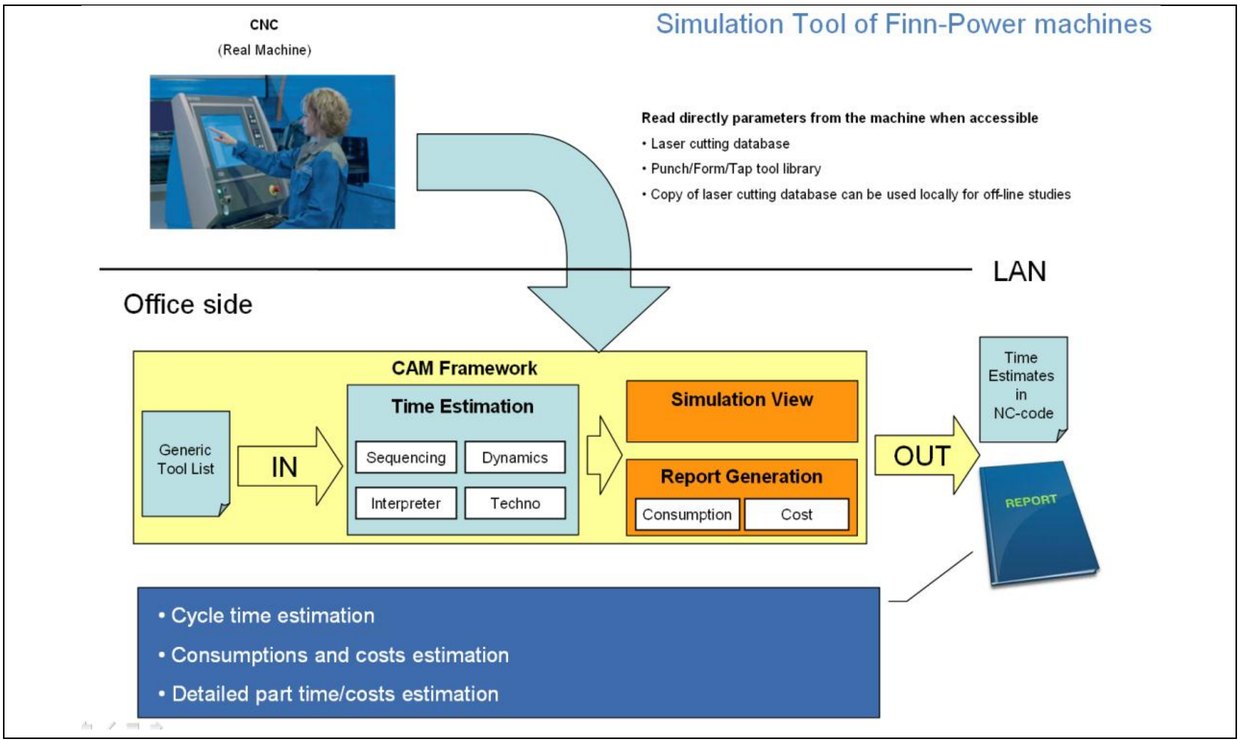


Figure 6: Simulation tool of Finn-Power machines

Finn-Power has a software product (Performance Reporting), in which it is possible to analyze the production afterwards. This allows investigating the results of the production and trying to improve the operating way. This is not a simulation tool; instead it is used only with real-life production.

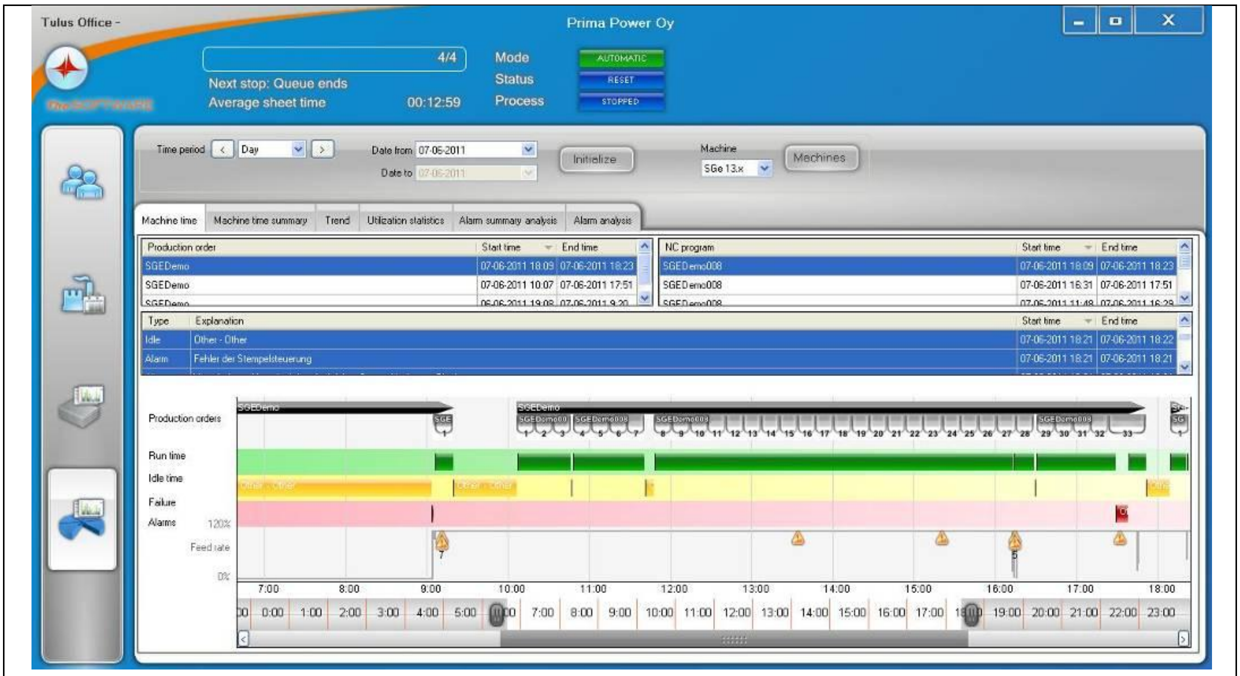


Figure 7: Screenshot from Finn-Power performance reporting software

Other important aspects of development:

- Operator module development, which contributed to operator delays.
- Develop a program capable of analyzing the simulation data. (Meta-CAM)
- Simulate tool changes at the machine in order to calculate their duration.

- Machine electric consumption monitoring and logging
- Energy consumption of the simulation. Need to figure out how consumer information can be transferred to the simulation model.
- Find out how material thickness affects energy consumption in punching. We already know that the punching the sheet does not contribute as much to the energy requirements as moving the sheets.

2.1.3 IDEKO

VERICUT

This software simulates NC machining to detect tool path errors, motion mistakes and inefficiency before prove-out. During the part programming stage, is possible to eliminate errors that could ruin the part, damage the fixture, break the cutting tool, or crash the machine. It is possible to model and simulate any machine (3 Axis, Multi Axis, Milling, Drilling, Turning, EDM…). The powerful 3D solid of the workpiece and NC machine tool simulation functionalities make possible to visualize the machining exactly as it is on the shop floor, enabling to:

- Correct tool path errors before machining.
- Detect fast feed errors, potential crashes/collisions, gouges, over/undercutting, etc.
- Verify dimensional accuracy

It is possible to run NC machine tools at the maximum efficiency level with the automatic determination of the optimum feed rates for every portion of the tool path and adjusts them based on the cutting conditions. It improves the programmed feed rates so the tool paths are faster, more efficient, cause less cutter wear, and produce better surface finishes.

Tecnomatix

The Tecnomatix Plant Design and Optimization solution gives 3D parametric-based smart objects to layout efficient factories faster. It enables to use 3D for factory layout to increase the ability to find design flaws during the planning process, and not during implementation. Material flow, handling, logistics and indirect labour can all be optimized using material flow analysis and event-driven simulation. These resource optimization techniques analyze elements such as part routing information and equipment capabilities against the factory layout. Even material storage needs and part packaging information can be used.

You can also manage the factory layout environment with standardized resources in a shared data environment on a product lifecycle management platform. Collectively, these capabilities promote increased planning accuracy and efficiency, helping to minimize capital investments and maximize production efficiency.

FORMA

We have also developed a tool that simulates the entire machine tool behaviour, based on the PLC program already installed on the real machine. This simulator communicates with a 3D virtual machine simulator which shows virtually the cinematic and the movements of all machine components like axis, workhead, tool changer, etc. The main objective of this platform is to create a virtual machine which simulates the behaviour and aspect of a real machine and use it to train experimented operators without the need of the real machine.

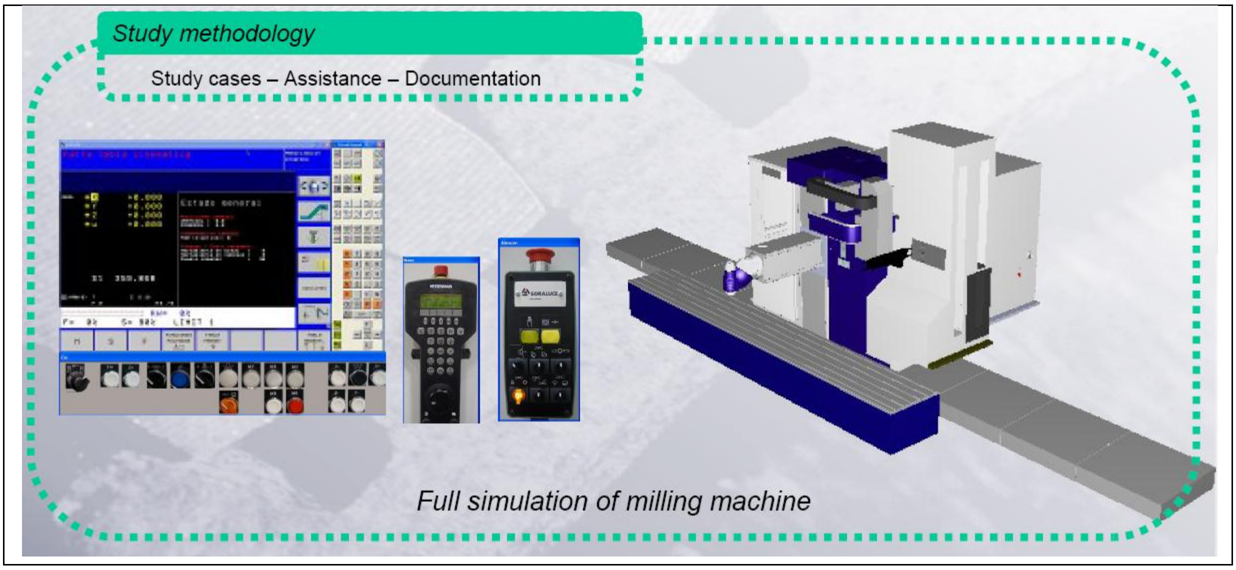


Figure 8: Methodology of the FORMA simulation software

Targeting machine tool manufacturers, industrial end-users, and education entities, this software makes it possible to simulate the preparation, use and first level maintenance operations of any machine working by means of movement and interaction of solid material.

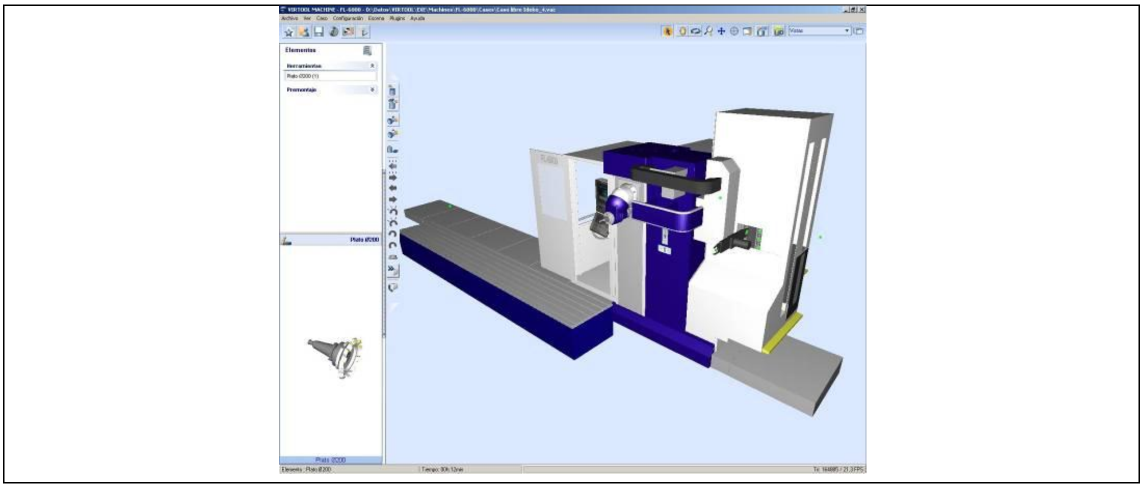


Figure 9: Screenshot from FORMA simulation software

2.1.4 GIGANT

Virtual Machine

The simulation process starts from the following SW inputs:

- Load (Average force during deformation stroke)
- RAM Stroke
- Approach Speed
- Working Speed
- Deformation stroke
- Average stroke for deformation
- Blank holder working force
- Specific data from special/optional devices

These inputs are checked by the SW logic that defines a virtual machine able to provide the required inputs. From the virtual machine are extracted those simulation data of the press production cycle from which are obtained the specific data of interest as:

- Motor power and number of motors
- Pump flow rate
- Cycle time
- Effects maximum speed
- Used energy per cycle
- Used energy in standby
- Press general dimensions

Thus the virtual press machine data are processed to sort the energy consumption and performance values of the virtual machine deriving the values for:

- Energy cycle/phase consumption rate
- Flow rate
- Stroke
- Speed

Real machine

The sorted values shall be evaluated against the real machine; the real time acquisition data system checks at every cycle and phase the correspondence to the theoretical values obtained from the virtual machine. These data shall be within a certain tolerance range vs the data defined at the beginning of the design.

Synchronization

The values are processed and optimized till they will fully fit the real ones. As an output it will be possible to obtain, as a function of the system performance requirements:

- The energy consumption vs. time;
- Heating production to be eliminated
- Total cycle time
- Single phase cycle time
- Output data vs. time

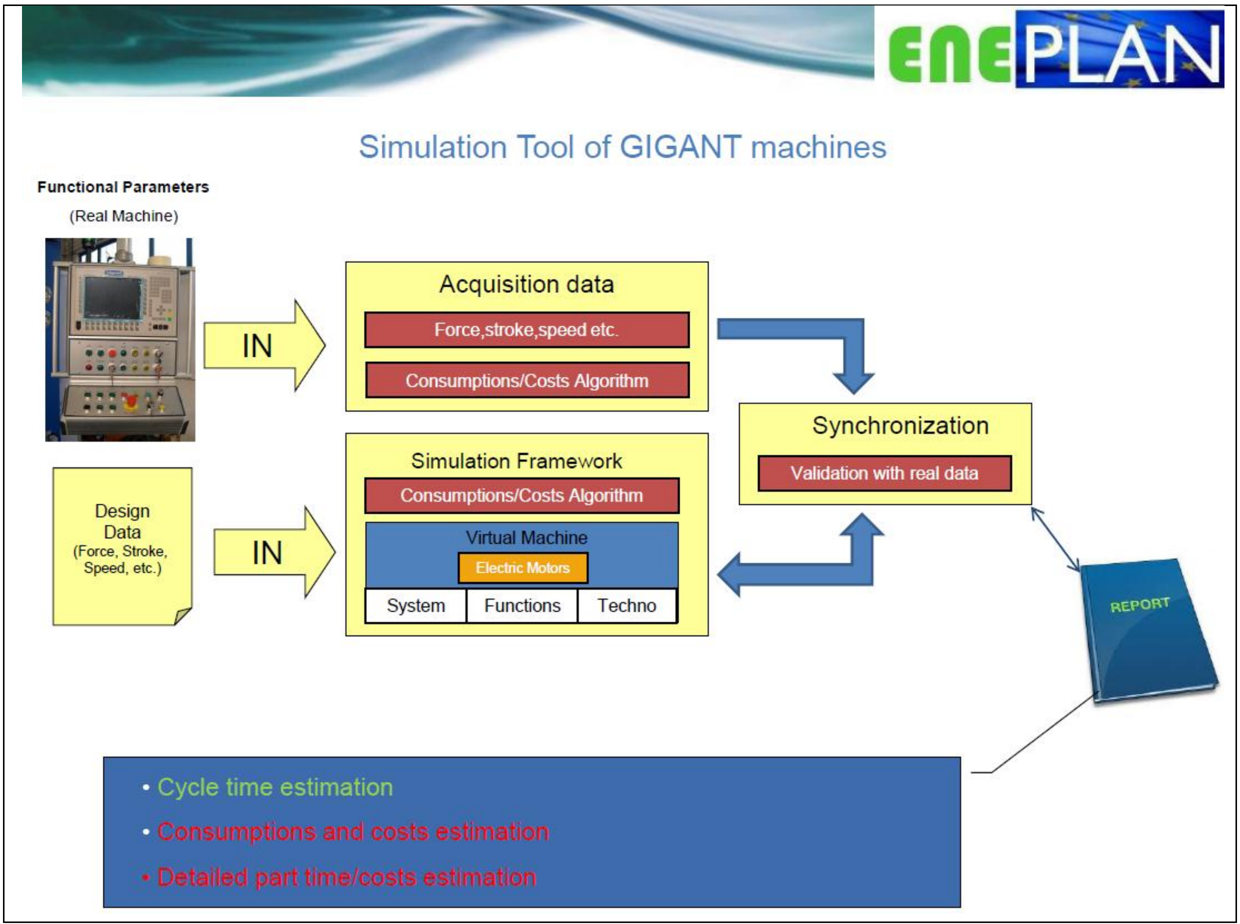


Figure 10: Simulation tool of GIGANT

2.1.5 GIZELIS

MotoSim® EG

MotoSim® EG (Motoman Simulator Enhanced Graphics) is a comprehensive software package that provides accurate 3D simulation of robot cells. MotoSim EG is off-line programming and real time 3D simulation software for MOTOMAN robots. This powerful simulation software can be used to optimize robot and equipment placement, as well as to perform collision detection, reach modeling and cycle calculations. It also provides accurate off-line programming of complex systems. MotoSim EG comes with a library of MOTOMAN robots and tools. With the included modeler it is also possible to make other models. Files can be transferred to the robot with a CF-card, or downloaded with communication software. However, for the NX100 control system it is possible to transmit files via a file transfer protocol. A program like Job Editor is recommended in order to be able to include INFORM-commands in the jobs with correct syntax. All INFORM-commands can be used for robot programming off-line, although certain commands like “Search” or “ComarcOn” are not actually executed in the simulation. The simulation makes it possible to calculate cycle times, detect collision risks and visualize the robot’s path. Due to the RRS (Real Robot Simulation) module, which is the same calculation method as in real robots, MotoSim EG’s cycle time estimations have a deviation of accuracy that is less than 5%. With MotoSim EG it is possible to export information as html code. This makes it possible to look at 3D models in a web browser such as Explorer without MotoSim software. This 3D model is possible to zoom in/out, rotate and to use a play button to animate the robot program.

- Provides cycle calculations, collision detection, reach analysis.

- Allows users to view and play back cell simulations. This free MotoSim EG HTML output file is built upon the same cutting-edge technology used by the MotoSim EG graphical interface package. It allows users to share simulations with customers or coworkers.
- Using a standard 3D graphics engine provides the ability to add markups/comments to the robot simulation and the ability to accurately measure distances.
- MotoSim EG reduces programming time, thus increasing uptime of the production equipment. New parts can be programmed off-line before production begins, and existing robot programs can be modified to increase efficiency and reduce cycle time – without sacrificing production schedules.
- Detailed path calculation function plots robot's trajectory to simplify programming. Robot paths, speeds and other program data – such as tool center points, user frames, and I/O monitors – can be defined on the PC.
- Creates process angles, allowing user to create programs that maintain the robot's tool orientation in relation to an uneven surface, such as a sharply angled part, or gradually changing shapes, such as propellers or motorcycle gas tanks.
- User can move the virtual robot, enter the data to create a robot program, and download it to the robot controller.
- When Motoman Robotics' MotoCal® software and optional filters are used, programs created in MotoSim EG can be downloaded to the robot controller with minimal or no touch-up.

Capabilities:

- Collision detection.
- Robot placement and path optimization.
- External axis control and coordination.
- Paint application-specific functions.
- Conveyor tracking programming.
- Same easy-to-use INFORM language instructions as the robot controller.
- Minimize fixturing errors.
- Reduce robot installation time.
- User-definable view.
- Cycle time and reach analysis.

Additional Supported Capabilities:

- Points Importer (XML file input process).
- G-Code Convertor (Post processes CNC G-Code Files to Robot Programs).
- AutoCAD Convertor (Converts AutoCAD Drawn object into Robot Programs).

2.2 *REVIEW OF EXISTING CAM TOOLS*

This chapter reviews the main functionalities of CAM and CAPP systems and contains a survey of the major vendors' products. The main benefits of CAM systems are:

- Increase in efficiency
- Reduction in lead and development times
- More accurate design and programming solutions from simulations
- Reduced, associated manufacturing costs
- Savings from waste that would typically occur as a result of human error
- Improved production quality and consistency
- Increase in overall manufacturing efficiency

The main benefits of CAPP systems are:

- Process planning translates design information (CAD) into the process steps and instructions to efficiently and effectively manufacture products.
- CAPP enables direct reuse and manipulation of engineering information in process plans to avoid data duplication
- CAPP software allows for improved production ramp-up and increases overall productivity
- CAPP reduces the cost of changes, scrap production and rework

CAM/CAPP software does not cover the energy consumption optimization process.

2.2.1 Computer Integrated Manufacturing

Introduction

Computer Integrated Manufacturing (CIM) represents the integration of traditional production and engineering technologies with computer technology. This combination enables the automation of all production and engineering activities, from product design to the creation of technological procedures, production planning, operative control, manufacturing of products, quality control, assembly and packaging.

The CIM system is not represented by a single entity – it is compiled by the integration of complex, independent, dedicated software packages and systems, which is shown in Figure 11. The data required for various functions are passed from one application software to another. For example, the product data is created during design. This data has to be transferred from the modelling software to manufacturing software without any loss of data. CIM uses a common Knowledge, Information and Data (KID) database (wherever feasible) and communication technologies to integrate design, manufacturing and associated business functions that combine the automated segments of a factory or a manufacturing facility.

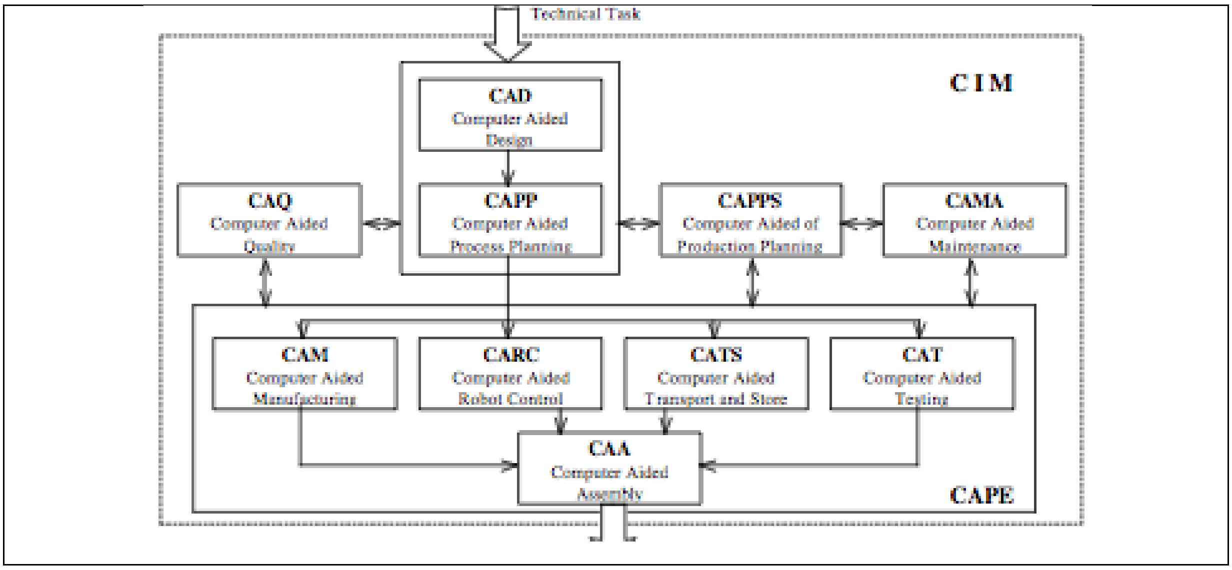


Figure 11: Organization of partially CA systems in CIM complex

There are many benefits to CIM, which include the:

- Reduction of human involvement - thereby relieving the design and engineering process of its slow, expensive and error-prone component
- Reduction of development and production time, and the time to market. Products are generally made "right first time"
- Increase product quality
- Minimization of material and energy consumption, which have a big impact on cost savings.

2.2.2 CAD/CAM

Introduction

CAD/CAM technology has played a vital role in improving the quality, precision and consistency of manufactured components. These technologies facilitate the modelling, simulation, planning and production of components as well as managing associated data. The use of this technology has made businesses more efficient at meeting their customer requirements thereby increasing productivity and reducing associated manufacturing costs.

Key factors that contribute to the successful use of CAD/CAM [1] of businesses are the technology, organization and people. These are also important to the success and future of CAD/CAM and its impact on manufacturing efficiency.

Capabilities of CAM systems

Available as either stand-alone or integrated CAD/CAM solutions, these systems are often used in conjunction with Enterprise Resource Planning (ERP) and similar enabling technologies in industry. Properly implemented, these technologies have the potential to create a seamless transition from the conception of an idea to the manufacture of a product and managing it through its lifecycle. A non-exhaustive list of current CAD/CAM capabilities is provided below.

Capability	Function
Modelling	
Part Modelling	Allows the user to create a solid / 3D model of a part
Sheet Metal Design	Sheet metal design tools allows the user to create sheet metal design and automatic flat patterns of sheet metal parts

Parametric Modelling	Feature based modelling that allows a user to refer to features instead of the underlying geometry.
Freeform Surface Modelling	For creating the skin/surface of a 3D geometric element such as automotive body panels
Assembly Design	Allows the user to create assemblies using individual parts and/or other assemblies.
CAM Part Modelling	Provides solid modelling capabilities to create, import, repair and automatically solidify surface data
Verification	
Model verification	Validation/verification of designs against specifications and design rules
Program Verification	To verify dimensional accuracy to make sure the machined part will exactly match the design intent
Program Inspection	To detect errors, potential crashes/collisions, gouges, over/undercutting, including detecting differences possible weaknesses or mistakes in the design
Program Editor	To correct tool path errors before machining
Simulation, Visualisation and Rendering	
Welding and Fabrication	Welds can be applied to a model in the assembly environment
Visual analysis	Sophisticated visual analysis routines for drafts, curvature
Rendering	For Photo-quality images
Simulation	Allows the user to simulate designs without building a physical prototype
Program Simulation	3D solid simulation of the work piece and NC machine tool to visualize the machining as it would occur
Data Management	
Integrated materials database	Allows user to input real materials for calculating mass properties of parts and assemblies
Standard parts libraries	For the automatic generation of standard design components
Code programming	Allows the inclusion of programming code in a model to control and relate desired attributes of the model
PDM	For the management and sharing of engineering design data
Bi-directional parametric associativity	Modification of any feature is reflected in all information relying on that feature such as properties, assemblies and drawings
Program Data Translation/ Exchange	CAD models can be imported, read, viewed and manipulated before machining.
Collaboration & file sharing	Output of engineering documentation, such as manufacturing drawings, Bills of Materials, CNC programs to reflect the BOM required to build the product
File Manager	For creating, storing, accessing and managing CAM data elements

Neutral data transfer	Import/Export routines to exchange data with other software packages
Free CAD viewer	For sharing product designs with suppliers and customers
Office (OLE) compatibility	Compatible with Microsoft office tools
Analysis	
Kinematics	Allows the user to constrain assembly and show motion based on constraints
Interference and clearance	Allows the user to check assemblies to determine clearances and interference fits
Stress analysis	Integrated analysis tools for carrying out stress analysis on models
Program Analysis	Comprehensive analysis tools for measuring, cross-sectioning and analysing the part
CAM	
Milling	For programming toolpaths and simulating milling machine operations and wireframe machining
Turning	For creating toolpaths and simulating turning operations
Mill/Turn	For simultaneous mill/turn operations on different spindles and workpieces
Wire EDM	Allows users to generate tool paths for Wire EDM operations
EDM Die Sinking	For producing complex dies and metal parts with high quality finish
Laser cutting	For nesting and cutting profiles with laser cutting machines
Programming Automation/ Optimisation	Routines such as work piece transfer and multi-task machining are performed automatically for maximum efficiency
Surface Finishing/ Surfacer	Provides high-level surface and solids modelling capabilities and advanced functionality for machining surfaces and solids.
Slotting/ Pocketing	Provides a broad variety of pocket machining and finishing patterns for pocket milling
Profiling/ Trimming	For roughing and finishing, lead in / out options and step down in z and common profile cutting tool paths
Mold and Die	For generating high quality for complex parts and free form shapes
Composite Applications	To lay-up composite parts for fabrication equipment
CNC Probing	Full simulation to allow visualisation of potential collisions or prior to code generation for ensuring protected positioning of probing tool.

Table 1: Non-exhaustive list of current CAD/CAM capabilities

CAD/CAM systems are widely available to users today with vendors offering numerous solutions with varying levels of capabilities. Price, system specification and specialisation are the main differentiating factors and these are broadly based on the targeted industry or specialisation and end users. While the higher end systems have higher specifications and cost more, entry level systems are low cost solutions that meet the basic requirements for such a system. The mid-range systems are capable of handling most of the requirements for a

CAD/CAM system. While this approach allows vendors to accommodate the needs of a range of industries and users, in some instances, their solutions are either too generic or specialised. With integrated and modular solutions, users can at least customise their system based on their budget and requirements resulting in a better fit. Below is a list of some of the most commonly used CAM software.

CAM Vendor	Software	Features and Modules
DELCAM	PowerMILL [2] PowerMILL is Delcam's core 3, 4 and 5 Axis milling product, a standalone CAM system that produces NC toolpaths from CAD models. PowerMILL can accept data from any CAD system, via IGES, VDA, STL or a variety of direct interfaces.	• Surface Finishing • Swarf Milling • Profiling • Trimming • Pocketing • Slotting • Multi axis Drilling • Integrated 5 Axis Post Processor
	FeatureCAM FeatureCAM offers a comprehensive solution for milling, turning, turn/mill and wire EDM. Machine tools can be programmed within a single user interface designed to shorten programming times and reduce the learning curve for new users. It has an integrated 3D machine simulation module, together with a library of over 350 fully customisable post-processors, that lets the user visualise exactly how parts will be machined.	• 2.5D Machining • 3D Machining • 5-axis Machining • Turning • Turn/Mill • Wire EDM • Tombstone Machining
	PartMaker PartMaker is complete a CAD/CAM programming solution for CNC applications including milling, turning, wire EMD, multi-tasking Turn-Mill and Swiss turning.	• SwissCAM • Turn-Mill • Mill • Turn • Wire EDM • Bar-Fed Milling • Modeling • Multi-Axis Machining • Post Processing • Shop Floor Documentation
Gibbs & Associates (Cimatron)	GibbsCAM [3] GibbsCAM® CAD/CAM software is a state-of-the art, PC-based CAM system for programming CNC machine tools. GibbsCAM software provides a powerful range of CNC programming functionality including Solid Modeling, 2-5 Axis Milling, High Speed Machining, Mill/Turn, Swiss, Wire-EDM, Multi-Task Machining	• Production Milling • Production turning • Solids Import • 2.5D Solids • Solids SUrfacer • Muti-task Machining • Machine simulation • Wire-EDM • 5-Axis Maching

CAM Vendor	Software	Features and Modules
		• VoluMill
Cimatron	CimatronE Manufacturing Provides a complete solution for NC Programming from 2.5-5 Axis Milling	• Data Translation • CAD for NC Programming • Automated Drilling • 3+2 Axis Machining • 5 - Axis Milling • Analysis & Preview • Simulation & verification • High Speed Machining • Micro Milling • Wire EDM • Post processors • Programming automation
CNC Software Inc	MasterCAM MasterCAM delivers CAD/CAM software tools for all types of programming, from the most basic to the extremely complex. 2-axis machining, multi-axis milling and turning, wire EDM, router applications, free-form artistic modelling and cutting, 3D design, drafting, surface and solid modelling	• Multi axis Milling • High-Speed Machining • Router cutting • Turning • Mill/Turn • Wire EDM • Plasma Cutting • Laser Cutting
Planit	EdgeCAM EdgeCAM is a market leading computer aided manufacturing (CAM) system for NC part programming. CAM system for milling, turning and mill-turn machining.	• Milling • Turning • Strategy Manager • Part Modeler • Mill Turn • Solid Machinist • 5 Axis • 4 Axis • Probing • Wire EDM • Mold and DIe
Surfware Inc	SURFCAM SURFCAM CAD/CAM Systems provide cutting edge technology for NC programming of 2-, 3-, 4- and 5-Axis mills, lathes, wire EDM, laser plasma and water-jet machines.	• SURFCAM, 2-Axis • SURFCAM, 3-Axis • SURFCAM, Multi-Axis • TRUEMill

CAM Vendor	Software	Features and Modules
Geometric Technologies	CAMWorks [4],[5] CAMWorks® is a 3D feature based CAM system with integrated automation tools to optimize CNC programming and machining. Provides a seamless integration with SolidWorks and can automatically accommodate changes to the part model. CAMWorks is a SolidWorks® Certified Gold Product	• 2½ Axis, 3 Axis, 3 Axis with undercut, • 4 Axis and 5 Axis Simultaneous Milling; • 2 and 4 Axis Turning; • Rotary Milling; • 2 and 4 Axis Wire EDM • VoluMill TM • ElectrodeWorks TM
SolidCAM Inc.	SolidCAM SolidCAM's CAM software, for all CNC applications, is seamlessly integrated in SolidWorks and with full toolpath associativity to the SolidWorks model. SolidCAM has the Certified Gold Product status from SolidWorks.	• iMachining • Milling – Entry level • Milling 2.5D • HSS (High Speed surface Milling) • 3D Mill/HSM High Speed Milling • Indexial Multi-sided Milling • Simultaneous 5-Axis Milling • Turning & Mill-Turn • Wire-EDM • Electrode Module
SmartCAMcnc	SmartCAM Provides a comprehensive CAM solution	• Milling • Turning • Fabrication • Wire EDM • Native Solidworks translator • Native Autodesk Inventor Data translator • Predator CNC Editor
CGTech	VERICUT Vericut is a modular CAM solution. The add-on modules add capabilities to the base Verification Module	• Verification • Machine simulation • Optipath • Model export • Multi Axis • CNC machine Probing • Inspection Sequence

CAM Vendor	Software	Features and Modules
		• Vericut Reviewer
CGTech	VERICUT	• EDM Die Sinking • AutoDIFF • Drilling and Fasterning (VDAF) • Composite Applications • Cutter / Grinder Verification • Cutter / Grinder Machine Simulation • Model interfaces

Table 2: State of the art

In COPERNICO a project funded by the EU under the FoF, a survey detailing the range and capabilities of modelling and CAM tools available was conducted [6]. The resulting matrix is comprehensive and suitable for reviewing machine- and process- models in the specification of the requirements for a Meta-CAM tool and has been made available for this project (Appendix A).

The focus of CAD/CAM technology - increasing productivity by automating associated activities and processes – has been a key driver for developments. While there are immediate benefits to implementing these systems for businesses, vendors are also aware of the value of available data from such systems and the potential benefits it holds for businesses. There is an increased focus on process capture and knowledge-based executions derived from available data[1]. Features such as the development of parametric design in CAD where existing data is re-used and programming automation in CAM, which also relies on existing data, and the expansion of collaboration and file sharing capabilities are typical examples of how software developers are incorporating these requirements into their products. These provide end-users with a means of involving stakeholders earlier on in all aspects of a product's design and manufacture. However, appears to be a secondary requirement; the lack of fully standardized data formats is becoming increasingly obvious and users deal with the challenge of working with and transferring data between the range of available solutions. These issues have presented an opportunity for software developers to utilize available data more efficiently by expanding their existing data capability including collection, organisation and storage. This is particularly useful for the end-user as it facilitates the identification and filtering of available data (and meta-data) making it easier to extract useful and relevant information. This should inform the decision making process for businesses, allowing them to identify greener and more efficient methods of meeting the requirements of their industry.

With the use of CAD/CAM and similar technologies, manufacturing has become very highly automated and the data handling capability of these systems are important. Equally important are the accuracy and organisation of available data. In some cases, information gets lost during data conversions which can be an issue as end-users rely on information for planning and production purposes. STEP-NC standards will help to address some of these issues particularly with the interoperability of CAD CAM and CNC systems. ‘The STEP-NC effort began with a definition of the user requirements for turning and milling as part of ISO 14649. This work has been harmonized with the STEP standard in ISO10303-238, the application protocol for STEPNC. This standard defines the interface between CAM manufacturing features and CNC systems [7]. These developments are relevant to the development of a meta-CAM tool, which will rely on the data outputs from these systems.

The desired functionality of the meta-CAM tool will take into consideration, the current issues and challenges identified above. In particular, the usability of the system with regards to how it affects the extraction of data which will feed into to the meta-CAM tool. A survey was carried out to understand current issues and challenges from the end-users' perspective. The main issues identified were classified based on the limitations of the CAM features provided by vendors, and the challenges they pose to users as a consequence. The users' were also asked to rate these features according to how important they were to the business. The responses provided are presented below.

CAM Feature	Limitations	Challenges
Simulation	• *Simulation module not accurate enough*	• *To make the simulation module very accurate about time, costs, consumption computation*
Programming Automation	• *Programming automation connected to customer ERP too slow*	• *Speed the automatic process of nesting after receiving from customer ERP the list of orders production*
Laser cutting	• *Manual nesting too many clicks*	• *To improve manual operations to make the best manual nesting, less mouse clicks, intuitive mouse operations, functions shortcuts*
Laser cutting	• *Automatic multi-sheet multi-material nesting*	• *Development of automatic algorithms that performs the best use of sheets taking care of nesting multi-sheet multi-material distribution*
Laser cutting	• *Automatic Cutting*	• *Development of automatic algorithms that take care of best path creation according to strong techno options (Laser Head low in the piece/jump cut profiles)*
Machining	• *Thread features are difficult to program exactly how the programmer would like.* • *Additional machine features such as quills & facing heads are not supported and require addition external modification of code.*	• *Using EdgeCAM to program 100% of the machining of a component is difficult due to integrating different machine tool types & machine tool features (facing head work in particular as well as all thread production methods)*

CAM Feature	Limitations	Challenges
Turning	• *Sometimes difficult to make tool paths follow previously cut stock profile.* • *Thread cutting options are limited.* • *Little support for additional equipment (steady rests etc.).*	• *Generally good, relatively easy to create good tool paths, tool setup is very good.* • *Can be difficult to control stock removal/visibility. As mentioned above, thread cutting could be improved.* • *Little support for additional machine features such as steady rests or centre supports.*
Milling	• *Time is spent adjusting tool paths & adding extra geometry in order to get the desired tool path output.* • *Milling parts need to be set-up carefully in order to ensure all CAM features can be accessed (rotating tables etc.).* • *Tool creation for milling can also take extra time due to problems importing DXF files for rotating tool holders (milling arbors).*	• *Again, generally good. Can be difficult to control tool paths accurately (start & end points in particular).* • *Additional geometry sometimes required on the solid model to enable tool path creation.* • *Tool set-up is good but can be a difficult to add correct graphics to tool data.*
Post Processor	• *Post processor wizard is relatively powerful compared to other CAM systems, however it is difficult to use without appropriate training.* • *Some steps involved are not well laid out.* • *Some CAM features are not adequately supported within the post processor and require custom code.*	• *Getting the desired NC code output from the post processor is difficult and sometimes requires more complex programming work.* • *Machine kinematics can be difficult to set-up.*
Simulation	• *The EdgaCAM simulator only simulates the CAM instructions pre-post generation. Therefore the accuracy is entirely dependent on how well constructed & tested the post processor is.* • *There is little control over the simulation; an example of this is the inability to move forwards & backwards through*	• *The simulator can only really be used to check the basic running of the program and collisions due to the limitations outlined previously. It can be successfully used to check tool clearances & fixture collisions as long as the fixtures and tools have been accurately modelled.*

CAM Feature	Limitations	Challenges
	the program 1 instruction at a time.	

Table 3: Summary of users' feedback

Benefits

There are numerous benefits to having CAD/CAM systems and these are based on the capability and functionality of the system and how it relates to the goals of a business. Thus, it is important to verify and relate the capabilities of the system to the requirements of the business. The benefits identified include:

- Increase in efficiency
- Reduction in lead and development times
- More accurate design and programming solutions from simulations
- Reduced, associated manufacturing costs
- Savings from waste that would typically occur as a result of human error
- Improved production quality and consistency
- Increase in overall manufacturing efficiency

Limitations

Limitations to technology typically stem from the technology or improper management of utilisation of the technology. Limitations that stem from the technology can easily be referred to the vendors, but this is not within the users' control. However, issues that stem from improper implementation, utilisation and management of technology are typical and usually the cause of identified limitations. The following limitations have been identified:

- Data translation
- Cost
- Support
- Compatibility issues

2.2.3 CAPP

Introduction

Process planning is the activity which links design and manufacturing (as well as other business considerations). As such, the integration of computer-aided design & manufacturing (CAD/CAM) and computer-aided process planning (CAPP) systems is a critical element of rapid response manufacturing [8].

There are two basic approaches to computer-aided process planning (CAPP)- variant and generative.

Variant CAPP (Figure 12) was the first approach used to computerize planning techniques. It is based on the valid conjecture that similar parts will have similar process plans. Part coding and classification based on group technology are used to implement this concept. A "standard" plan is formulated and stored for each part "family" [9].

Variant CAPP has the following advantages:

- Easy to build, learn and use;
- Experienced process planners are still required to edit the process plan; and
- Cannot be used in an entirely automated manufacturing system without additional process planning.

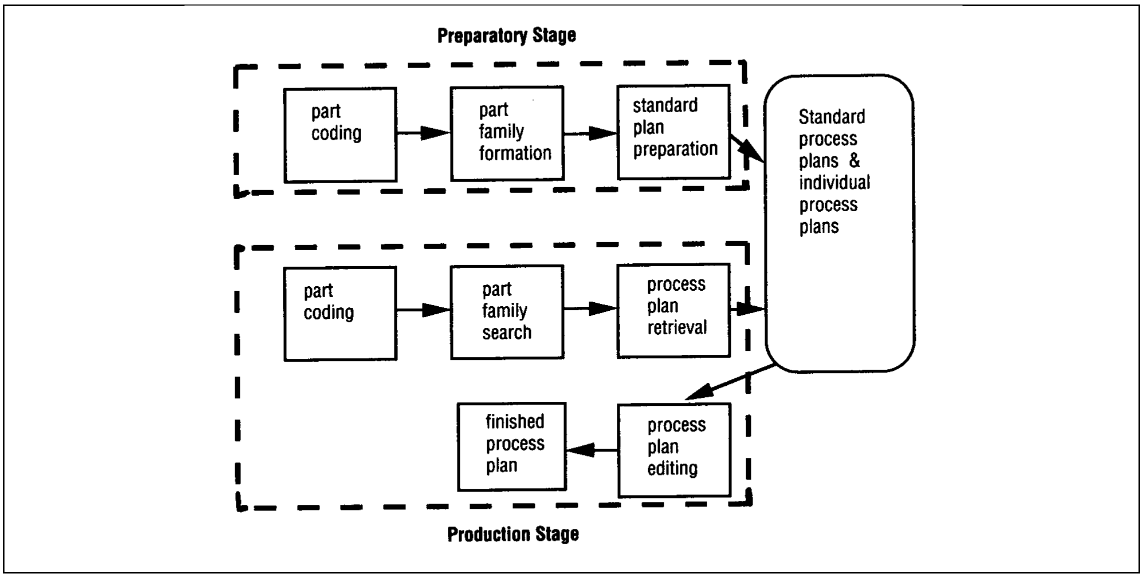


Figure 12: Variant Process Planning

However, there are also several problems associated with variant CAPP:

- The components to be planned are limited to previously planned similar components, and process optimization is not included;
- Experienced process planners are still required to modify the standard plan for a specific component;
- Variant planning cannot be used in an entirely automated manufacturing system without additional process planning [10].

Generative CAPP envisions creation of a process plan from information available in a manufacturing database (KID) without human intervention – i.e "a system that automatically synthesizes a process plan for a new component". Upon receiving the design model, the system is able to generate the required operations and operation sequence for the component. A generative process-planning system comprises three main components [11]:

- part description,
- manufacturing databases
- decision-making logic and algorithms

Because the definition of generative process planning used in industry today is somewhat relaxed, any system containing some decision-making capabilities on process selection is called a generative system.

Generative process planning is regarded as more advanced than variant process planning. Ideally, a generative process-planning system is a turnkey system with all the decision logic built in. However, due to differences among manufacturing shops, decision logics have to be customized for each shop. The generative process-planning approach has the following advantages:

- process plans are generated rapidly;
- new components can be planned without relying on previous similar parts; and
- there is potential for integrating with automated manufacturing facilities to provide detailed objective control information [12].

Some examples of process planning approaches & the interaction with CAD/CAM have been provided in Figure 13 below:

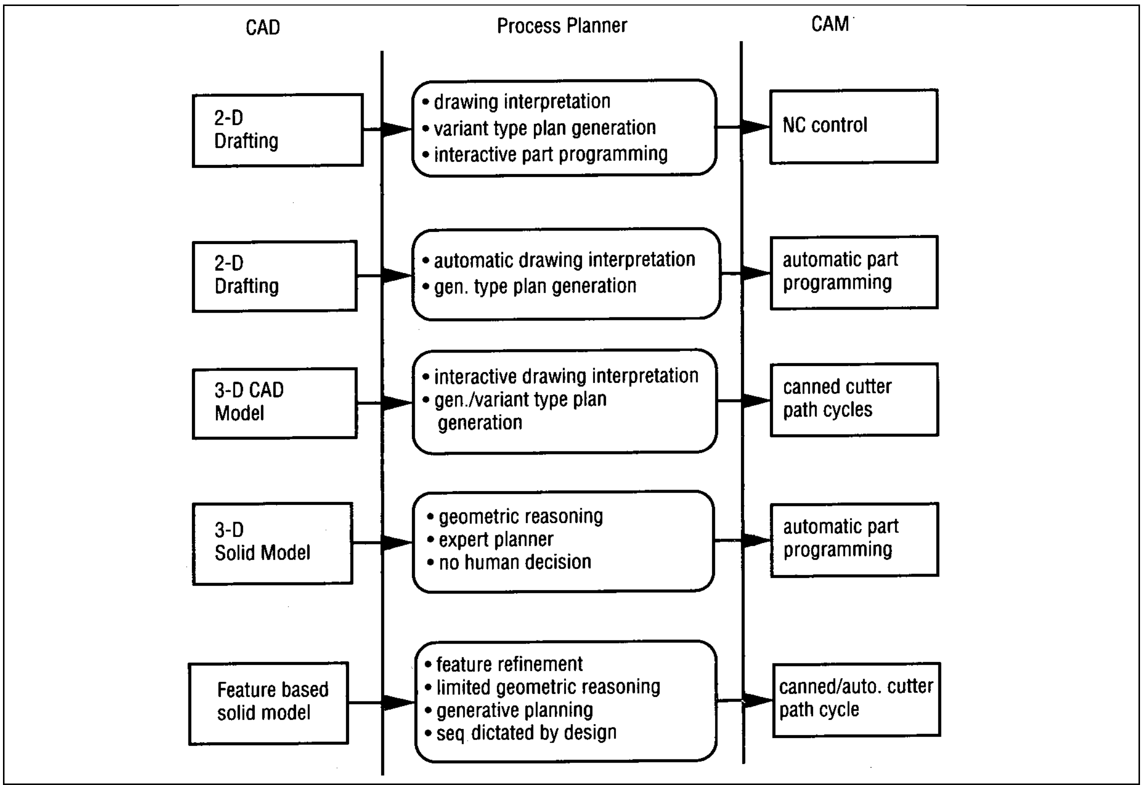


Figure 13: Process Planning Approaches

State of the Art

Among manufacturers, various levels of integration between CAD/CAM and CAPP systems exist. In the following section, CAD-CAPP-CAM integration is given below for a typical large scale manufacturing company and an SME.

Industry

Figure 14 (below) presents a typical CAD-CAPP-CAM system configuration for a large scale manufacturing company, as well as the strategic aim of future systems. Current and future solutions differ mainly in the applicability of the Product Lifecycle Management (PLM) and Digital Manufacturing component as the Knowledge Information and Data (KID) backbone to support CAD-CAPP-CAM systems and the not-yet-existing feedback loop for improving design and process planning productivity and profitability.

Current CAPP solutions are suited to mass production of specific product types, e.g., the power train market, the automotive industry, and, more recently, the aerospace industry.

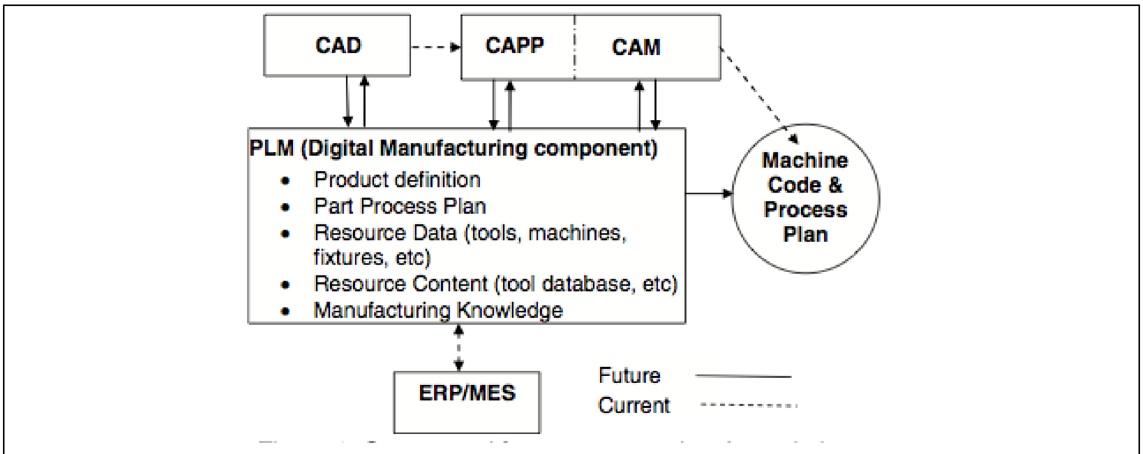


Figure 14: Current and future process planning solutions.

Small-Medium Enterprises

A survey on SME process-planning considerations, carried out by Denkena et al. [13], determined that:

- Contrary to CAD/CAM tools, CAPP is not typically implemented in SMEs.
- Management of infrastructure knowledge (machining equipment and tools) is lacking.
- Production process knowledge is not managed, but rather only documentation of work performed.
- Difficulties exist in identifying similar jobs (e.g., in case of significant engineering change, job is considered entirely new), with reliance only on employee memory.
- Digital information is transferred from designer to manufacturer (i.e. STEP and PDF files), but there is no digital data collaboration for transferring feedback from manufacturer to designer.

State-of-the-Art CAPP Software

The table below provides details of 5 CAPP software tools. For each tool, a list of modules and functionalities has been provided. What is clear is that all software tools have a capacity-planning module, a machine / shop floor data monitoring system, a stock and inventory control module, and non-technical quality control functionalities. However, from the list below, it is unclear exactly how these CAPP software tools interact with CAD CAM tools.

CAPP Vendor	Software	Description	Features and Modules	URL
Stone Technology Ltd	RedAnt Production Control Software	RedAnt is made up of core modules covering day-to-day manufacturing requirements. Benefits of the REDANT System. • Improved time management & cost control. • Maintain quality control to ISO, AS9100 and UKAS accreditation. • Detailed records and tailored analysis reports. • Improved time delivery. • Integration with most accounts packages. • Reduced stock levels. • Make to Stock or to Order • Easy to Setup, Learn and Use	• Machine Monitoring • Capacity Planning • Quotations, • Customer Orders, • Delivery/Invoices, • Purchasing and Stock. • Quality control modules including ○ Certificates of Conformity, ○ Calibration, ○ Customer/ ○ Supplier Non-Conformances and ○ Concessions.	http://www.redantsoftware.co.uk/index.html
Match-IT Ltd	Match-IT Manufacturing Management Software	Match-IT is production control software. Match-IT will help you to improve:- • Efficiency. • On-time delivery. • Cost reduction. • Quality assurance.	• finite capacity scheduler • enquiries & tenders, • sales orders, • purchase orders, • goods-in, • purchase invoices, • multi-dimensioned stock control, • manufacturing (including shop floor data collection), • sales dispatch and • sales invoicing Layered around those are more generic facilities for • quality & traceability (ISO 9000 & motor/aerospace/military standards), • scripting, • access security, • designing reports &	http://match-it.com/

			paperwork and • general systems management.	
MIE Solutions UK Limited	MIETrak	Production control software for sheet metal workers, manufacturers, fabricators and engineers that simply wish to increase operating profits without increasing overheads. MIETrak is easy to use production control and job tracking software which can be implemented throughout the entire organisation to provide vital management information in a real time setting.	• Quotaton and estimating • Slaes order processing • Router design • Works orders • Purchasing • Shop floor data capture • Scheduling • Shipping/invoicing • Costings • Stock control • Reporting • HR	http://www.mie-solutions.co.uk/
Prodman	Prodman 4	Prodman is a complete production management suite designed for the needs of small to medium sized manufacturing enterprises, or subcontractors with assembly operations. The software suite contains all you need to computerise and control all aspects of your business.	• Sales Order Processing • Works Order Processing • Stock and Inventory control • MRP • Manufacturing Route Card • Bill of Materials (BOM) • Job Costing • Scheduling • Capacity loading / Capacity planning • Shop Floor Documentation • Certificates of Conformity	http://www.prodman.com/
Berkeley Myles Solutions	ProgressPlus	ProgressPlus is a business and production control system with the power and flexibility to meet a wide range of manufacturing requirements.	• Estimating • Shop Floor Loading/SFDC • Time & Attendance • E-Business/Web Interface • CRM • Sales Orders • Works Orders • Purchase Orders • Job Costing • Inventory/Stock Control	http://www.progress-plus.co.uk/

			• Delivery Recording • Invoicing • Quality	

Table 4: State of the art

Benefits

The benefits of CAPP systems and software are provided below; however, the information is taken from software developers themselves and, therefore, one has to be careful as regards objectivity –the information must be taken at face value.

- Firstly, Process planning translates design information (CAD) into the process steps and instructions to efficiently and effectively manufacture products. As the design process is supported by many computer-aided tools, computer-aided process planning (CAPP) has evolved to simplify and improve process planning and achieve more effective use of manufacturing resources.
- Secondly, there is often an improved efficiency of manufacturing engineers. CAPP [14]:
    - Enables direct reuse and manipulation of engineering information in process plans, to avoid data duplication
    - Enables reuse of standardized and normalized processes and resources
    - Reduces time required to create and update work instructions though their dynamic generation
- Thirdly, CAPP software allows for improved production ramp-up and increases overall productivity, by:
    - Reducing training time and learning curve with accurate and meaningful 3D work instructions
    - Reducing production trial and error method of optimizing of the manufacturing processes with digital validation
- In addition, CAPP reduced the cost of changes.
    - Identifies required design changes earlier in the design, with timely feedback from manufacturing
    - Streamlines change impact identification and propagation
    - Increases engineering visibility to the potential manufacturing impact of a change, to facilitate cost effective design decisions
    - Provides an integral change management system, which supports both engineering and manufacturing needs
- Finally, CAPP can reduce scrap production and rework:
    - Reduces the risk of producing incorrect product configurations by eliminating discrepancies between the latest process definition and the work instructions used on the shop floor

Limitations

The problem of integrated process planning has been of major importance for the industry for more than 25 years now. Some of the limitations with CAPP systems are provided below:

- Lack of integration with other software packages & cost of changes:
    - Although the issue of the integration and cooperation of all these systems has been thoroughly investigated, even today, in practice all this systems work independently.
    - Design information exists on paper in the form of engineering drawings and specifications. These drawings, which may be produced as prints from master

drawings or as pen plots from a CAD system, are passed "over the wall" to manufacturing engineers who produce process plans, tool paths, and numerical code (NC) programs.
  - This practice is time consuming, error prone, labour intensive and, therefore, expensive. It often results in the redesign and re-engineering of products (Figure 15, below)
  - Moreover, this scenario does not support a concurrent engineering approach as the systems are not interoperable.

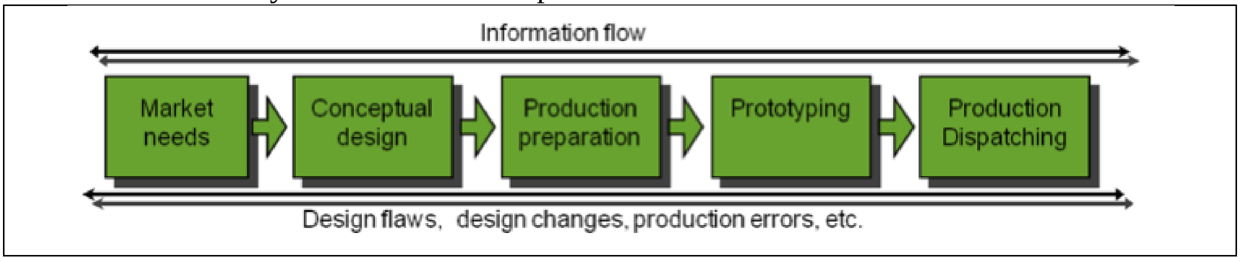


Figure 15: Product Lifecycle

- Few studies have been presented on the development of alternative process plans and on the production scheduling [15][16][17][18]; their basic approach focus on:
  - the resources of the production system, neglecting (in most cases) the potential collaboration alternatives with the subcontractors
  - the production phases as subsequent stages of processing, without considering the technological parameters of the processes incorporated in each phase, and the different market needs during the life cycle of the product
- Furthermore, the theoretical models and software systems developed for the construction of alternative process plans present a high degree of complexity and require a vast amount of highly accurate input data, prohibiting their adoption from SMEs.
  - So the current industrial practice on the construction of process plans is mostly empirical, taking into consideration only basic data for the market orders and the quality characteristics of the products to be produced.
  - Thus, the process plans that are delivered are in general inflexible and cannot take into consideration alternative market demand profiles or different quality requirements as a function of different market orientations.
  - Therefore, there are no alternative process plans, through which it would be possible to optimize the resources of the production system in the most efficient way (e.g. use of alternative resources such as hardware, personnel or even subcontractors, under different market needs and orders) satisfying in parallel the different quality requirements and specifications.
  - At the same time, the information pertaining to the market needs and the quality requirements fluctuates during a products lifecycle in a way that the process plans need to be altered in order for the cost and market penetration criteria to be met.

3 MAIN FUNCTIONALITIES AND BASIC ELEMENTS OF THE META-CAM TOOL

Meta-CAM is a manufacturing planning decision support tool for the optimization of the plant operation that will be able to be used from the conceptual phase of the product (final blueprints) to the final dispatch of the product to the customer. For this reason it will be able to handle and at the same time propose:

- Automatic or semiautomatic determination of materials, work sequences, cycles and process routes best suitable for the manufacturing of the workpiece.
- On-line (or short-time) configuration of the manufacturing system for that workpiece on the basis of modular, plug and produce, emergent functionality mechanisms based on the process steps and routes defined at the previous point
- Simulation of overall manufacturing system optimization and tuning for top production efficiency and minimum environmental impact

This paragraph describes the concept and the overall architecture of the meta-CAM tool and its data structure:

- Machining process selection
- Evaluation of the machining processes
- Multi-criteria optimization
- NC-machines / Meta-CAM tool interface and format
- Meta-CAM tool data structure and acquisition

The next figure shows the global architecture of the meta-CAM tool and the data flow from the CAD and ERP systems and to the CAM modules of the different technologies.

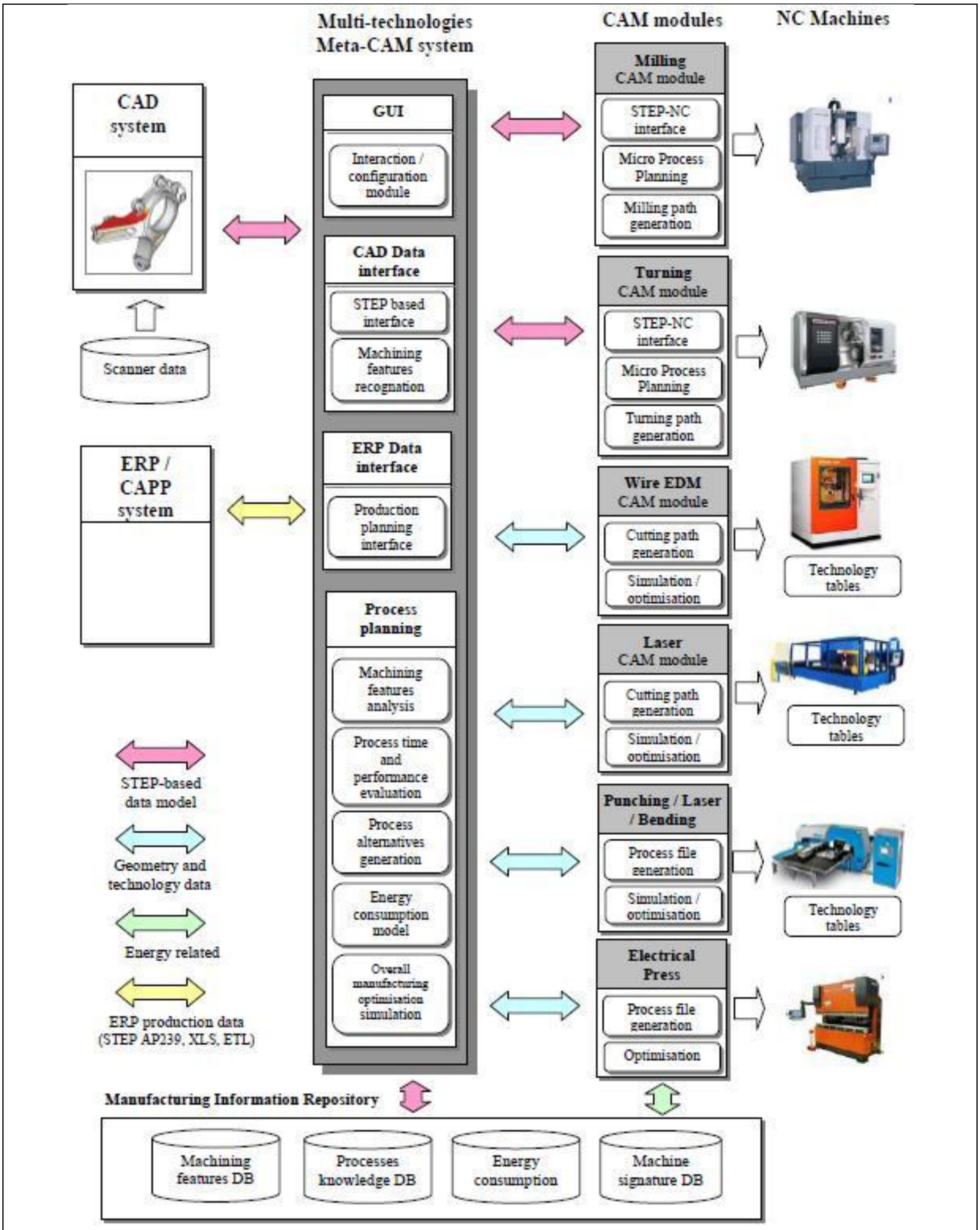


Figure 16: MetaCAM tool outline

Meta-CAM main functions

The main function of the MetaCAM is the optimization of process and production planning that allows alternative plans to be found. This main function requires that the possible space of feasible process and production plans can be generated and that optimization algorithms can systematically explore this space. Thus it is necessary to clearly define the content of a node in this space of feasible plans. A node here is a process plan that can be represented on different levels of abstraction. Abstracting away unnecessary details from such a plan allows the system to deal with the complexity of process planning in general. The abstract process/production planning is done in the MetaCAM level and this plan will be refined and evaluated on the micro level. The proposed architecture with the data/information flow between macro and micro level as described in Figure 16 follows the theory of abstractions as described in [19]. So there will be typical ENEPLAN scenario, where a macro plan calls for a process refinement/evaluation on the micro level. The result is either "not feasible" meaning that the plan cannot be refined resp. executed in the current machine environment or the result is "feasible with the cost xyz", where the cost can be expressed in terms of energy consumption, time etc. These costs are determined by the simulation systems that are available for each technology and should ideally reflect the real cost of running the plan. The models of the CAM/simulation systems will be considered as black boxes from the MetaCAM point of view. So MetaCAM doesn't care how the results are determined as long as they are correct. These CAM/simulations however provide the necessary input for applying optimization algorithms in the MetaCAM. The models for integrated product and process planning are the key for the success of the MetaCAM system and with every simulation the optimizer in the MetaCAM obtains more knowledge to perform the task. Whenever complete or heuristic search within the space of feasible plans should be performed, then it is necessary, that the costs are available for each node.

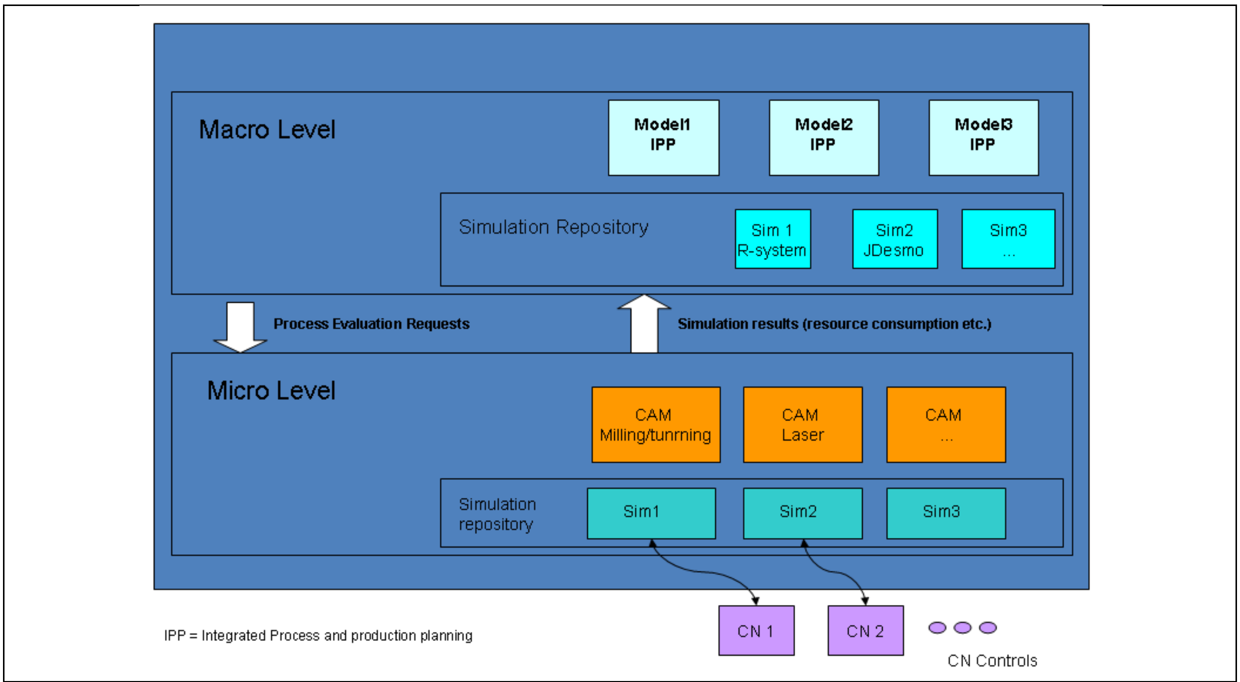


Figure 17: Macro and micro level with evaluation/simulation cycle

As argued above process and production planning can be separated into two different planning levels. Macro Process Planning will be performed on the Meta CAM level, while Micro Process Planning is responsible for the activities on the CAM/Machine level. According to I. Kuric [20] the tasks on the two levels are the following: Macro Process Planning includes:

- review of common machining processes,
- accessibility of manufacturing features,
- process and machine selection,
- operations sequencing methods,
- work piece set-up planning.

Micro Process Planning are activities as following:

- advanced process models for prediction of machining performance
- process optimization,
- optimum tool path planning algorithms,
- analysis of Part-process-work holding design trade-off.

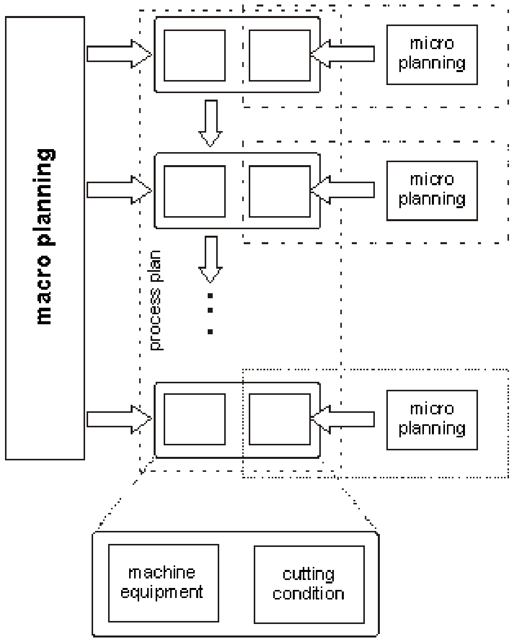


Figure 18: Macro and micro planning according to [20]

As already mentioned, we do not care about models on the micro level and thus concentrate on the models for integrated process and production planning on the macro level. To verify a model it is often helpful to look at to some real cases with alternative plans to see if these cases can be represented within the current model. Furthermore it allows the user to better understand the architecture and responsibilities of the various elements. We consider two cases from standard milling/turning domain and another coming from the sheet metal field.

Milling/turning case: Based on the 3D part model, the features must be identified that allows the part to be manufactured. The plan should allow alternative features to be formulated. Features are related to machine types in the sense that a machine knows what it can do and about the possible precision related to the part tolerances. Dependent on machine availability it can be very advantageous to do roughing operations on less expensive 3-axis machines, while complex freeform features must be handled by expensive a 5-axis machines. So given a feature based process plan it can easily be deduced on which machine the part can be produced. In the case of splitting the production over more than one machine the model must automatically introduce nodes for handling the work piece etc.

Sheet-metal case: The part consists of features including elements that can be manufactured either by laser cutting or by punching. So a flexible process plan allows switching between different machines, dependent on their availability. In fact the part might be produced on a single laser machine, a single punching machine or on a combined machine that allows laser cutting and punching. It might be in some situation even better (dependent on number of parts to be produced) to handle the machining on two 2 machines by doing first the punch operations followed be laser cutting. Like in the case above, the costs for material handing must be taken into account. metaCAM must be able to access a technology process DB to perform the feature technology mapping. It is not clear yet how much feature and process planning knowledge metaCAM must have to perform the optimization.

Machining processes selection: The possible alternative machining processes will be selected first according to the technical aspects only:

- More than one technology might be possible or even necessary to manufacture the part
- Recognition of the machining features from the CAD data file.
- Determination of all the possible fitting processes using the machining features database
- Determination of the corresponding operation lists

At the end of this first step, the meta-CAM tool generates the machining alternatives that are technically able to produce the workpiece.

Evaluation of the machining processes: The meta-CAM tool evaluates the possible alternatives using the following criteria:

- Manufacturing costs
- Energy consumption
- Environmental aspects
- Set up time
- Quality

under the delivery schedule condition,

The meta-CAM tool uses the following developed models:

- demand definition function of the status within the life cycle
- energy consumption using the results on the NC internal models, if existing, or the developed ones.

At the end of this step, the meta-CAM tool has characterized the machining alternatives defined in the previous step.

Multi-criteria optimization: Through the multi-objective simulation methods that will be developed, the optimization of production planning procedure will be achieved, taking into consideration various aspects such as energy efficiency, production time, quality etc. Moreover, by tailoring each time these aspects according to the product requirements, the respective tuning at the manufacturing system will be taking place, so as to comply with these new requirements.

NC-machines / meta-CAM tool interface and format

A communication protocol based on XML will be defined that allows data and commands be exchanged between the metaCAM and the CAM/Simulation modules. Data exchange requirements in the architecture can be separated into process plan data to be sent from macro to the micro level and data returned from micro level simulations to support optimization on the macro level. The detailed data structures for simulation results will be deduced from the requirements on the integrated process and production planning model to be defined in work package 2. Data representing process plans are dependent on capabilities of the CAM /Simulation modules. Data exchange with metal removing process machine tools (milling, turning etc.) will be ideally done using STEP-NC, while for the other processes like laser cutting, wire EDM, punching, bending and compound processes only require geometric data that can be transferred for instance in the DXF format. Additional technology data can also be transferred using appropriate xml data structures.

Meta-CAM tool data structure and acquisition

Product unique signature: The "product unique signature" describes the "what-to-do" function: geometry of the product, (workpiece) either from its physical model by using 3D scanning technologies or from its CAD model, other engineering requirements like tolerances, stiffness, functionalities etc. and material definition. These data will be transferred from the different CAD and/or digitalization systems under STEP format.

For the sheet metal it is proposed to realize unfolding algorithms to have different view (3D /2D) available that facilitates process planning.

Machine signature: The "machine signature" describes the operation parameters like minimum and maximum dimensions of the parts and the machining operations (diameter, depth etc.) as well as technical parameters like cutting speed, spindle speed, tolerances and precision etc. All these parameters are defined on the basis of an available "library of machine modules", each one implementing an elementary process function (this may be an open library, in the sense that some missing modules that might be of great use should be able to be developed and/or made available in a reduced time). A lot of work in the field of manufacturing resource modelling is done in other FP7 projects and also in the ISO TC184 SC4, STEP-NC project.

Machining features database: This database contains the different machining features associated to specific machines for the selection of fitting processes. Features for various technologies are already defined in ISO 14649. These features will be represented within the metaCAM system to allow process planning. Furthermore functionality that supports a user to identify the features as described in the machining selection task above will be implemented.

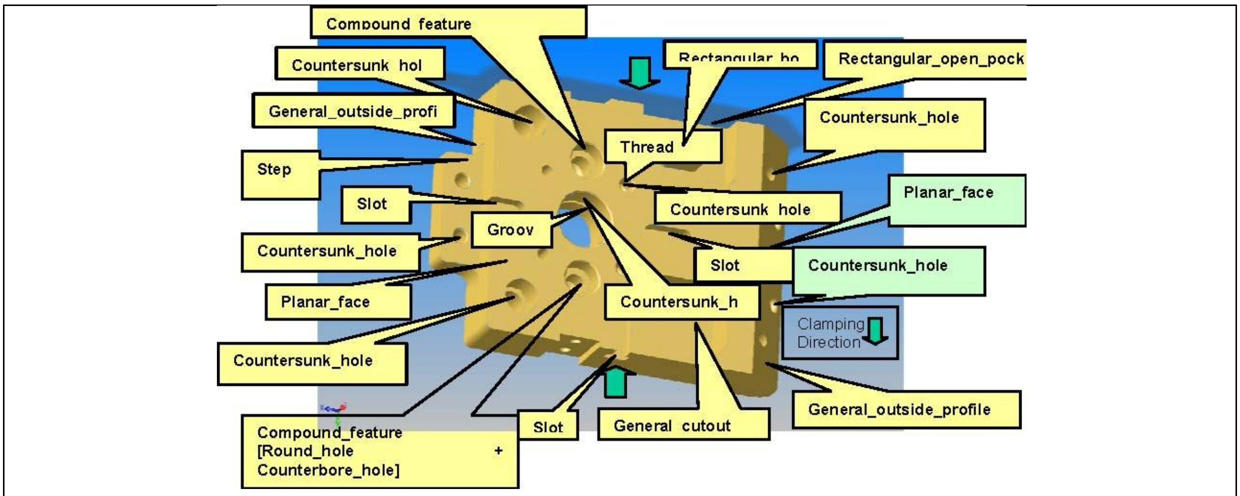


Figure 19: Example of machining features

Features for other processes like are not defined in the detail yet. Feature definitions for sheet metal working proposed by [21] are coming from different STEP parts; they are not standardized in ISO14649 for example. Nevertheless they provide an interesting starting point for a STEP compliant data model for process planning in this domain.

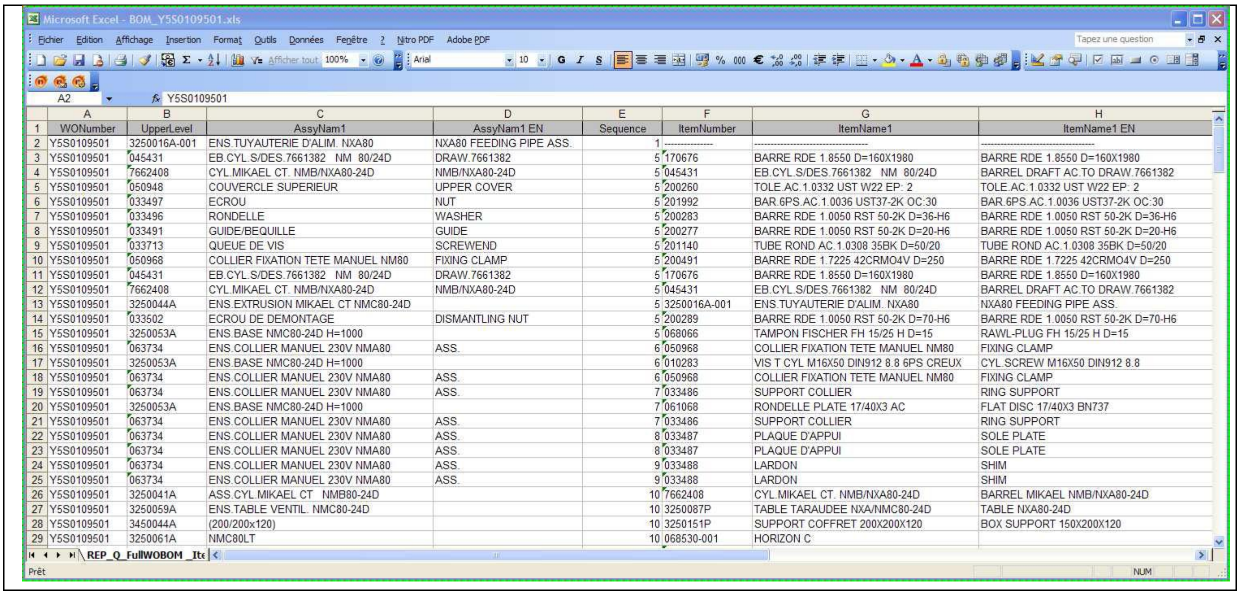
Process knowledge database: This database contains information about the capabilities of the different available processes (e.g. surface finish, corner radii, width of cut, length to diameter ratio, tolerance etc.) and related to input parameters such as material type, shape applications, process economy, etc. It will be useful for identifying the most appropriate machining process in the process planning.

Energy consumption database: This database will include all data concerning energy consumption and delivered by the corresponding CNC and the data monitoring and acquisition system to be developed.

Production related data: The production requirement data as manufacturing cost, lot size, lead time, production orders schedules, production time, machine availability etc. are delivered by the different ERP/CAPP systems in the supply chain. ERP are software product that gather and manage information concerning several processes of an enterprise. The ERP market for large companies is dominated by few vendors such as SAP and Oracle (figures for 2006 show a market share of SAP of 27%).

Several companies develop ETL solutions (Extract, Transform and Load) in order to allow SAP products to connect with a wide variety of third party applications, servers and databases. Among developers, we can cite Iway, Seeburger and Informatica. These companies have agreements with SAP and their solutions are sold and maintained through SAP services. Another company such as "ETL Solutions ltd" proposes a java-based ETL application. SAP provides users with a home-made application called Netweaver which allows organizations to make disparate applications and business partners systems exchange information and execute transactions smoothly, operating as if they were a single system. Netweaver enables technical connectivity using techniques and protocols such as FTP, JDBC, JMS, SOAP, WS, mail and also use SAP protocols and programming languages such as Business Application Programming. Basic extraction functions allow users to extract data from any table available in SAPgui (client GUI) to several formats such as Excel, Word, XML, html, etc.

The SME landscape is quite different as they cannot afford complete ERP solutions like SAP but use a large palette of different ERP systems, sometimes activity specific and sometimes rather old. All these legacy systems are able to support extraction through Excel™. When an ERP extraction is made in Excel format, the extraction result is a table in which the first line represents the tags of ERP interface, and following lines contain the related data.



	A	B	C	D	E	F	G	H
1	WONumber	UpperLevel	AssyNam1	AssyNam1 EN	Sequence	ItemNumber	ItemName1	ItemName1 EN
2	Y5S0109501	3250016A-001	ENS.TUYAUTERIE D'ALIM. NXA80	NXA80 FEEDING PIPE ASS.	1	--------------	----------------------------------	----------------------------------
3	Y5S0109501	045431	EB.CYL.S/DES.7661382 NM 80/24D	DRAW.7661382	5	170676	BARRE RDE 1.8550 D=160X1980	BARRE RDE 1.8550 D=160X1980
4	Y5S0109501	7662408	CYL.MIKAEL CT. NMB/NXA80-24D	NMB/NXA80-24D	5	045431	EB.CYL.S/DES.7661382 NM 80/24D	BARREL DRAFT AC.TO DRAW.7661382
5	Y5S0109501	050948	COUVERCLE SUPERIEUR	UPPER COVER	5	200260	TOLE.AC.1.0332 UST W22 EP: 2	TOLE.AC.1.0332 UST W22 EP: 2
6	Y5S0109501	033497	ECROU	NUT	5	201992	BAR.6PS.AC.1.0036 UST37-2K OC:30	BAR.6PS.AC.1.0036 UST37-2K OC:30
7	Y5S0109501	033496	RONDELLE	WASHER	5	200283	BARRE RDE 1.0050 RST 50-2K D=36-H6	BARRE RDE 1.0050 RST 50-2K D=36-H6
8	Y5S0109501	033491	GUIDE/BEQUILLE	GUIDE	5	200277	BARRE RDE 1.0050 RST 50-2K D=20-H6	BARRE RDE 1.0050 RST 50-2K D=20-H6
9	Y5S0109501	033713	QUEUE DE VIS	SCREWEND	5	201140	TUBE ROND AC.1.0308 35BK D=50/20	TUBE ROND AC.1.0308 35BK D=50/20
10	Y5S0109501	050968	COLLIER FIXATION TETE MANUEL NM80	FIXING CLAMP	5	200491	BARRE RDE 1.7225 42CRMO4V D=250	BARRE RDE 1.7225 42CRMO4V D=250
11	Y5S0109501	045431	EB.CYL.S/DES.7661382 NM 80/24D	DRAW.7661382	5	170676	BARRE RDE 1.8550 D=160X1980	BARRE RDE 1.8550 D=160X1980
12	Y5S0109501	7662408	CYL.MIKAEL CT. NMB/NXA80-24D	NMB/NXA80-24D	5	045431	EB.CYL.S/DES.7661382 NM 80/24D	BARREL DRAFT AC.TO DRAW.7661382
13	Y5S0109501	3250044A	ENS.EXTRUSION MIKAEL CT NMC80-24D		5	3250016A-001	ENS.TUYAUTERIE D'ALIM. NXA80	NXA80 FEEDING PIPE ASS.
14	Y5S0109501	033502	ECROU DE DEMONTAGE	DISMANTLING NUT	5	200289	BARRE RDE 1.0050 RST 50-2K D=70-H6	BARRE RDE 1.0050 RST 50-2K D=70-H6
15	Y5S0109501	3250053A	ENS.BASE NMC80-24D H=1000		5	068066	TAMPON FISCHER FH 15/25 H D=15	RAWL-PLUG FH 15/25 H D=15
16	Y5S0109501	063734	ENS.COLLIER MANUEL 230V NMA80	ASS.	6	050968	COLLIER FIXATION TETE MANUEL NM80	FIXING CLAMP
17	Y5S0109501	3250053A	ENS.BASE NMC80-24D H=1000		6	010283	VIS T CYL M16X50 DIN912 8.8 6PS CREUX	CYL.SCREW M16X50 DIN912 8.8
18	Y5S0109501	063734	ENS.COLLIER MANUEL 230V NMA80	ASS.	6	050968	COLLIER FIXATION TETE MANUEL NM80	FIXING CLAMP
19	Y5S0109501	063734	ENS.COLLIER MANUEL 230V NMA80	ASS.	7	033486	SUPPORT COLLIER	RING SUPPORT
20	Y5S0109501	3250053A	ENS.BASE NMC80-24D H=1000		7	061068	RONDELLE PLATE 17/40X3 AC	FLAT DISC 17/40X3 BN737
21	Y5S0109501	063734	ENS.COLLIER MANUEL 230V NMA80	ASS.	7	033486	SUPPORT COLLIER	RING SUPPORT
22	Y5S0109501	063734	ENS.COLLIER MANUEL 230V NMA80	ASS.	8	033487	PLAQUE D'APPUI	SOLE PLATE
23	Y5S0109501	063734	ENS.COLLIER MANUEL 230V NMA80	ASS.	8	033487	PLAQUE D'APPUI	SOLE PLATE
24	Y5S0109501	063734	ENS.COLLIER MANUEL 230V NMA80	ASS.	9	033488	LARDON	SHIM
25	Y5S0109501	063734	ENS.COLLIER MANUEL 230V NMA80	ASS.	9	033488	LARDON	SHIM
26	Y5S0109501	3250041A	ASS.CYL.MIKAEL CT NMB80-24D		10	7662408	CYL.MIKAEL CT. NMB/NXA80-24D	BARREL MIKAEL NMB/NXA80-24D
27	Y5S0109501	3250059A	ENS.TABLE VENTIL. NMC80-24D		10	3250087P	TABLE TARAUDEE NXA/NMC80-24D	TABLE NXA80-24D
28	Y5S0109501	3450044A	(200/200x120)		10	3250151P	SUPPORT COFFRET 200X200X120	BOX SUPPORT 150X200X120
29	Y5S0109501	3250061A	NMC80LT		10	068530-001	HORIZON C	

Figure 20: Extracted data in excel format

The extracted data will be converted to the STEP-AP 239 (ISO 10303-239:2005) format specifying the application protocol for Product life cycle support. Some detailed information about the content of AP239 can be found in the appendix.

4 CONCLUSIONS

This deliverable presented the main functionalities of existing CAM/CAPP software and of the industrial partners' simulation tools at NC machine level. It also outlined the main functions of the Meta-CAM tool and its interfaces with the different NC controls. A bilateral approach was agreed, focusing both on process as well as production planning level. Data exchange with metal removing process machine tools (milling, turning etc.) will be ideally done using STEP-NC, while for the other processes like laser cutting, wire EDM, punching, bending and compound processes only required geometric data that can be transferred for instance in the DXF format. Additional technology data can also be transferred using appropriate xml data structures. This deliverable will serve as a basis for the implementation of the Met-CAM tool in WP4.

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6 APPENDIX A

Detail on content of STEP AP 239 Product life cycle support PLC

- information for defining a complex product and its support solution;
- information required to maintain a complex product;
- information required for through life configuration change management of a product and its support solution;
- the representation of product assemblies including:
    - the identification and representation of parts, their versions, definitions, and documentation and management information, such as dates and approvals assigned to parts;
    - the representation of multiple product structure views and product breakdowns;
    - the representation of the shape of an assembly as the composition of the shape representation of its components;
    - the identification of positions within an assembly of parts to which component parts may be attached;
    - the association of valued properties to a part or to an assembly;
    - the representation of interfaces between products;
    - the classification of parts, documents and assemblies.
- the representation of a product through life including:
    - the representation of product requirements and their fulfilment;
    - the representation of existing or potential future products;
    - the identification of the configuration of a product for a given role;
    - the specification of effectivity constraints applied to configuration of a product;
    - the representation of predicted and observed states of products.
- the specification and planning of activities for a product including:
    - the specification of tasks to be performed on a product;
    - the representation of conditions for performing the tasks, including the resources required and the location of the resources and product;
    - the representation of the type of person and skills required for performing a task;
    - the representation of planning and scheduling of the tasks and the management and authorization of the subsequent work.
- the representation of the activity history of a product including:
    - the recording of the usage of a product and the resource usage;
    - the recording of the activities performed on a product and the resource usage.
- the representation of the product history including:
    - a historical record of the states of a product;
    - a historical record of the configuration status of the product;
- the location of product data;
- the observation of product data.