



Integration of CAD, CAM and NC with Step-NC

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VTT Industrial Systems

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Abstract <p>Modern manufacturing enterprises are built from facilities spread around the globe, which contain equipment from hundreds of different manufacturers. Immense volumes of product information must be transferred between the various facilities and machines. Today's digital communications standards have solved the problem of reliably transferring information across global networks. For mechanical parts, the description of product data has been standardized by ISO 10303 (STEP). This leads to the possibility of using standard data throughout the entire process chain in the manufacturing enterprise. Barriers to realizing this principle are the data formats used at the machine level. Most computer numerical control (CNC) machines are programmed in the ISO 6983 "G-code" language. Programs are typically generated by computer-aided manufacturing (CAM) systems that use computer-aided design (CAD) information. However, "G-code" limits program portability for three reasons. First, the language focuses on programming the tool centre path with respect to machine axes, rather than the machining process with respect to the part. Second, the standard defines the syntax of program statements, but in most cases leaves the semantics ambiguous. Third, vendors usually supplement the language with extensions that are not covered in the limited scope of "G-code".</p> <p>The replacement for G-code is so-called "STEP-NC", the name STEP-NC meaning the STEP standard extended for NC. STEP-NC is a new model of data transfer between CAD/CAM systems and CNC machines. It remedies the shortcomings of "G-code" by specifying machining processes rather than machine tool motion, using the concept of workingsteps. Workingsteps correspond to high-level machining features and associated process parameters. CNCs are responsible for translating workingsteps to axis motion and tool operation.</p>		
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Contents

1. Introduction.....	6
1.1 Research	7
2. STEP-NC	9
2.1 STEP-NC data model	13
3. Scenario.....	14
3.1 Design and manufacturing operations.....	15
3.2 Introducing new STEP-compliant controllers.....	16
3.3 Program simulation	17
3.4 Interactive programming	17
3.5 Remote interface to the enterprise.....	18
3.6 Extending functionality	18
4. STEP-NC benefits throughout the product development lifecycle.....	19
5. Summary.....	20
References	21

List of symbols

3D	3 dimension
CAD	Computer aided design
CAM	Computer aided manufacturing
CNC	Computer Numerical Control
DIS	Draft International Standard
EDM	Electric Discharge Machining
HTTP	HyperText Transfer Protocol
IDEF0	Integrated Definition for Process Modelling
I/O	Input / Output
ISO	International Organization for Standardization
IMS	Intelligent Manufacturing Systems
LAN	Local-area network
NC	Numerical control
PLM	Product Lifecycle Management
STEP	ISO 10303 standard family
STEP-NC	STEP standard extended for NC

1. Introduction

In the early 1960s Ivan Sutherland developed the SKETCHPAD system (Sutherland 1963), a milestone of research achievement in computer graphics. The evolution of computer graphics has since resulted in the development of Computer Aided Design (CAD). The early CAD systems were essentially for two-dimensional drawing and drafting. Solid modelling techniques emerged to describe three-dimensional products unambiguously (Requicha 1980), and it has been seen a increase of solid modellers and three-dimensional CAD systems. On the other hand, Numerical Control (NC) machines were first introduced in the early 1950s and sparked the research and development of Computer Aided Manufacturing (CAM). In industry, CAD techniques are extensively used to design products, and CAM techniques are used to manufacture the products. However, there has been very little communication between CAD and CAM (Bedworth et al. 1991, Jung Hyun Han 1996).

Computers were introduced into manufacturing to compute and control the cutter motions of machine tools. This required a new way of understanding and extracting the shape information of a part design from engineering drawings. Such a task was not possible until special languages were developed to translate the shape information from the drawing into computer-controlled machine tools (Mortensen 1985). Current NC programming is based on ISO 6983 (ISO 6983 1982), called "G-code", where the cutter motion is mainly specified in terms of position and the feedrate of axes (Suh et al. 2002, Suh et al. 2003).

Since numerical control technology was developed in early 1950s, it has undergone significant advancement to an extent that high speed machining with ultra-high precision is realized. However, modern CNC still needs further improvement especially to cope with the information-based modern manufacturing system, such as E-manufacturing. In particular, the current "G-code" is a low level language, which delivers only limited information to CNC excluding the valuable information, such as part geometry and process plan (Suh et al. 2003).

Even though "G-code" is a well-accepted standard world-wide it is in fact a bottleneck for today's CNC production chain. Despite the high performance of both modern CAD/CAM systems and CNC controllers the inadequate interface inhibits the expected increase in productivity and surface quality. Programming with "G-code" results huge programmes which are difficult to handle; last-minute changes or correction of machining problems on the shop floor are hardly possible and control of programme execution at the machine is severely limited. Even worse, due to many different "dialects" and vendor-specific additions to the programming language, part programmes are not interchangeable between different controls. As a result, porting

programs between machines is difficult (Philipson 2003, Proctor & Kramer 1998), Figure 1. The present standard also does not support today's demands in the area of five axis milling or high speed cutting which requires the processing of spline data (IMS 2003).

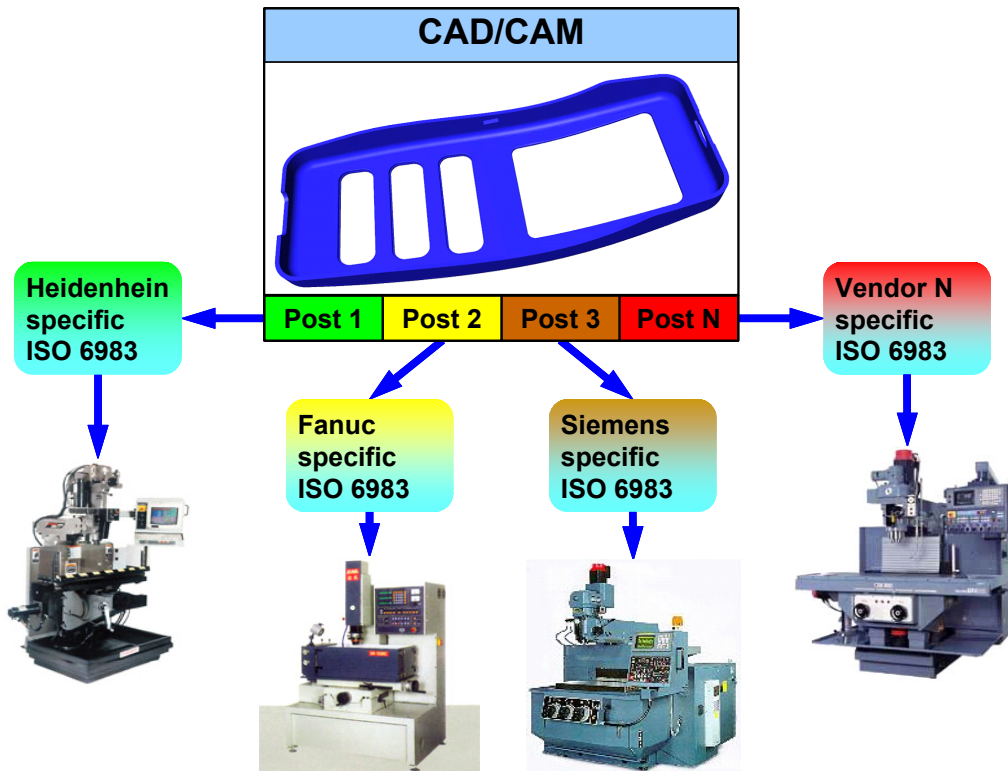


Figure 1. Current situation in CAM systems and CNC machines.

1.1 Research

STEP-NC has been developed as a result of several research projects carried out by companies and university institutes. The first of these was the ESPRIT III project OPTIMAL (Optimised Preparation of Manufacturing Information with Multi-Level CAM-CNC Coupling) which ran from 1994 to 1997. Next was the European STEP-NC project (EP 29708) during 1999–2001 (Weyrich 2001). Within the EC-funded STEP-NC project and the US Super Model Project, a large consortium validated and improved the existing data model for milling, and prepared models for additional technologies such as turning, wire-EDM (Electric Discharge Machining), wood and glass cutting. For further developments and exploitation of the results, a global collaborative project involving the EU, Korea, Switzerland and the USA (with links to the 1999-2002 Super Model Project) was started within the scope of the Intelligent Manufacturing Systems (IMS) Project in 2002. In addition to leading European participants it includes American and Korean organisations (Maeder et al. 2002, IMS 2003, Xu & He 2004).

Table 1 shows the participants and the distribution of the technological scope within the IMS STEP-NC project.

Table 1. The participants and the distribution of the technological scope.

Region	EU	Switzerland	Korea	USA
Technologies covered	Milling, Contour cutting, Turning & Inspection	Wire/Sink EDM	Rapid Prototyping	AIM for Milling & Turning
End-user	Daimler Chrysler	Derendinger	Samsung	Boeing
	Volvo	Wyss		Lockheed Martin
	Franci			General Electric
	Progetti			General Dynamics
				General Motors
Machine tool manufacturer	CMS	AGIE		
		Starrag		
Control manufacturer	Siemens			
	OSAI			
	Fidia			
CAM manufacturer	Open Mind	CADCAMation	Cubicek	STEP Tools
	Dassault			Gibbs
				BA Solutions
				Numerical Control Services
Research institute	WZL	EPFL	ERC-ACI	Louisiana Centre for Manufacturing Sciences
	ISW	EIG I-tech	KIST	Lawrence Livermore National Laboratories
	KTH		NRL-SNT	
Association	CECIMO	AMT		NIST
				Department of Energy
				Army's National Automotive Centre

2. STEP-NC

The STEP (ISO 10303), Product Data Representation and Exchange, standardization initiative covers computer-interpretable representation of product data, and its exchange. STEP is a synonym for all of the aspects of the international project that is developing the technology of product data representation, the methodology for creating the standards for information models and the standards themselves. The objective of STEP is to provide a means of describing product data throughout the life cycle of a product that is independent from any particular computer system. The nature of this description makes it suitable not only for neutral file exchange, but also as a basis for implementing product databases and for archiving data.

STEP is considered dismissively only a way to transfer data between different CAD-systems, but STEP has also developed towards manufacturing information management, the STEP-NC concept. STEP-NC provides not only a full description of the part, but the manufacturing process as well—annotating CAD design data with manufacturing information about the stock, its cutting characteristics, and tool requirements. STEP-NC defines data representing working steps, a library of specific machining operations performed at the CNC, so that any controller will be able to calculate the tool path based on definitions contained in formatted routines integrated within the controller itself (Lewis 2002).

STEP-NC is a new model of data transfer between CAD/CAM systems and CNC machines, which replaces "G-code". It remedies the shortcomings of "G-code" by specifying machining processes rather than machine tool motion, using the object-oriented concept of workingsteps. Workingsteps correspond to high-level machining features and associated process parameters. CNCs are responsible for translating workingsteps to axis motion and tool operation. A major benefit of STEP-NC is its use of existing data models from STEP. Basically, the standard is the smooth and seamless exchange of part information between CAD, CAM, and NC programming (Cai et al. 2004).

STEP-NC provides a comprehensive model of the manufacturing process. It is object and feature oriented and describes the machining operations executed on the workpiece, and not machine dependent axis motions. It will be running on different machine tools or controllers (Figure 2). This compatibility will spare all data adaptations by postprocessors, if the new data model is correctly implemented on the NC controllers. If old NC programs in "G-code" are to be used on such controllers, the corresponding interpreters shall be able to process the different NC program types in parallel.

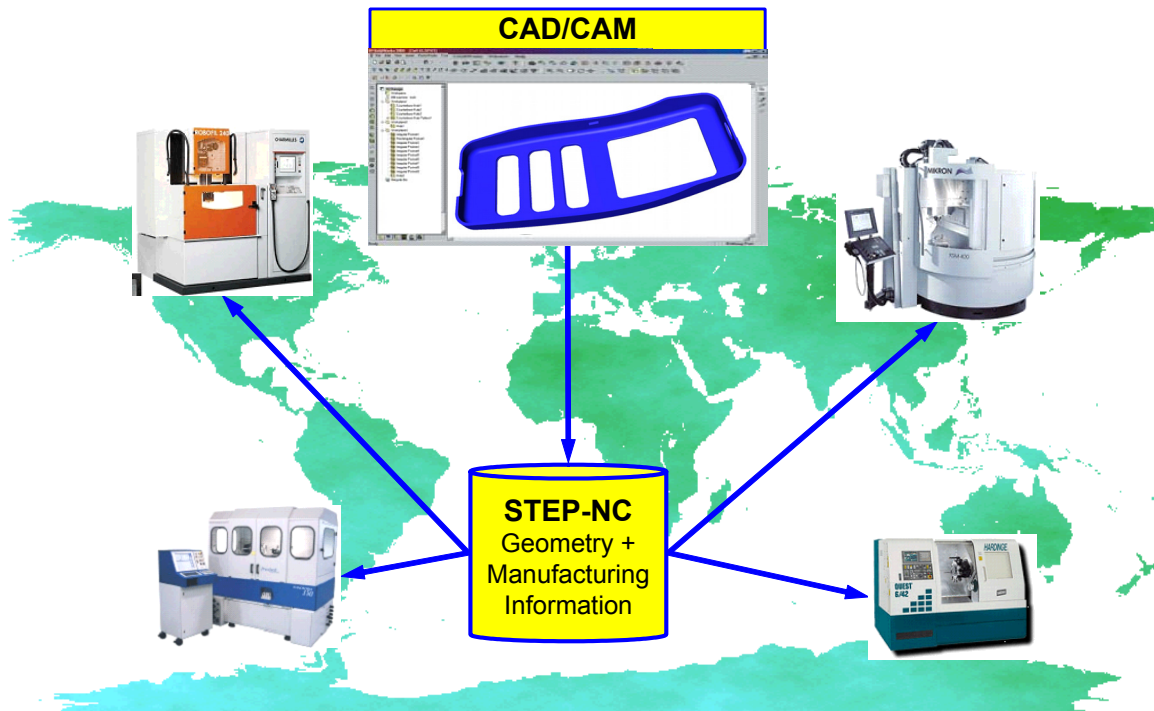


Figure 2. Tomorrow CAM and CNC.

It is envisioned a gradual evolution from "G-code" programming to portable feature-based programming. Early adopters of STEP-NC will certainly support data input of legacy "G-code" manually or through programs, just as modern controllers support both command-line interfaces and graphical user interfaces. This will likely be made easier as open-architecture controllers become more prevalent. Therefore, STEP-NC does not include legacy program statements, which would otherwise dilute the effectiveness of the standard (ISO 14649 2002, ISO/DIS 10303-238 2004).

The STEP data translation capabilities implemented in CAD systems today primarily support geometric models and configurations management as specified in Configuration controlled 3D designs of mechanical parts and assemblies (ISO 10303-203) and Core data for automotive mechanical design processes (ISO 10303-214). STEP-NC extends STEP into manufacturing domain by adding data structures that support computer-aided manufacturing (CAM) and computerized numerical controller (CNC) requirements (Feeney 2002).

The STEP architecture facilitates sharing of common data structures between STEP parts. For instance, a CAD system may output geometry, design features, and product identification data in STEP format. A CAM system may then input that data and use it to develop the detailed process data needed to manufacture the part. The CAM system does not need to redefine the geometry and features because these data structures are shared between STEP parts. The CAM systems output geometry, features, process sequence, and

tool requirement data in STEP-NC format. Because STEP-NC data is intended to be processed at run time, specific machine operations (e.g., cutter paths) are left to the machine controller. This offers some advantages over traditional methods (Feeney 2002):

- A STEP-NC file contains all data required to produce a part, therefore, manufacturing operations may be adjusted to maximize production efficiency.
- STEP-NC allows for complete safety checking because safety areas for fixtures can be defined as part of the setup.
- Documentation may be easily generated by the CAM or CNC system to show the state of the part before and after each working step.
- STEP-NC is easy to generate; specific tool paths need not to be defined in advance.
- A STEP-NC file is not machine specific; the STEP-NC file can be manufactured on any machine that meets the tooling requirements.

The current way of action is shown in Figure 3. The representation is based on the IDEF0 that is widely used to represent processes (IDEF0 1993). In this report IDEF0 method is augmented with swimlanes that represent different companies or different roles inside a company. The swimlane helps to understand different actors in the whole supply chain. Boxes represent activities or functions and arrows between boxes depict the information and material flow.

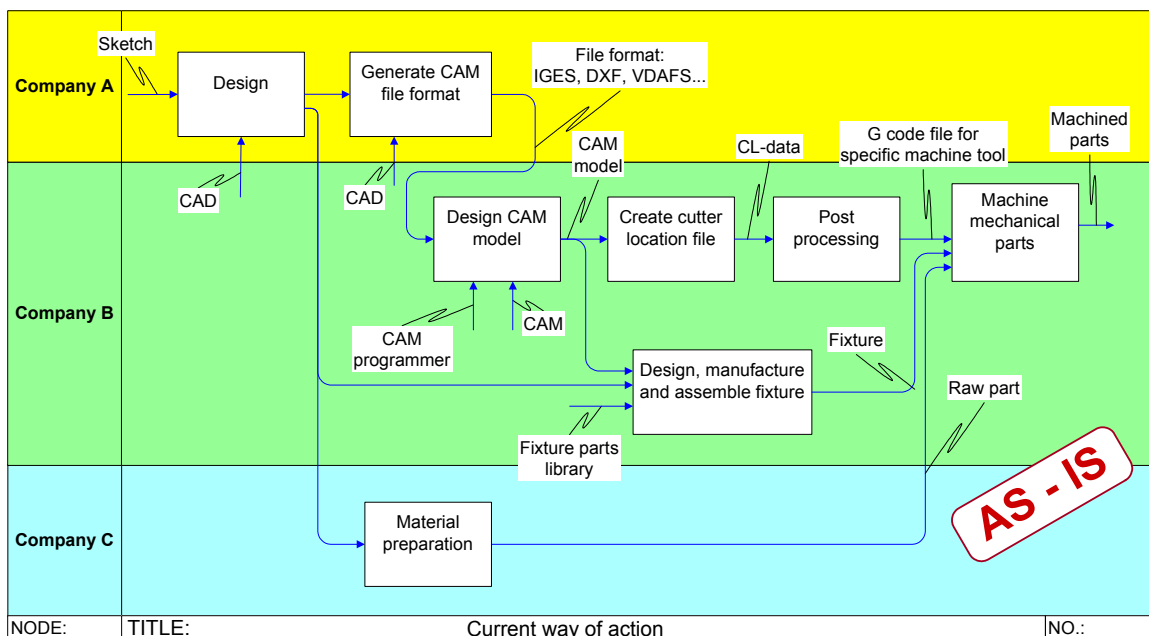


Figure 3. The current way of action in manufacturing life cycle, from design to fabrication is shown.

In Figure 4 it is shown the new way of action in manufacturing life cycle, from design to fabrication, and how STEP-NC is envisioned to be used within this cycle. The design phase results in STEP data and includes the geometry of the part. It is estimated that more than one million CAD stations contain STEP data translators (Hardwick & Loffredo 2001).

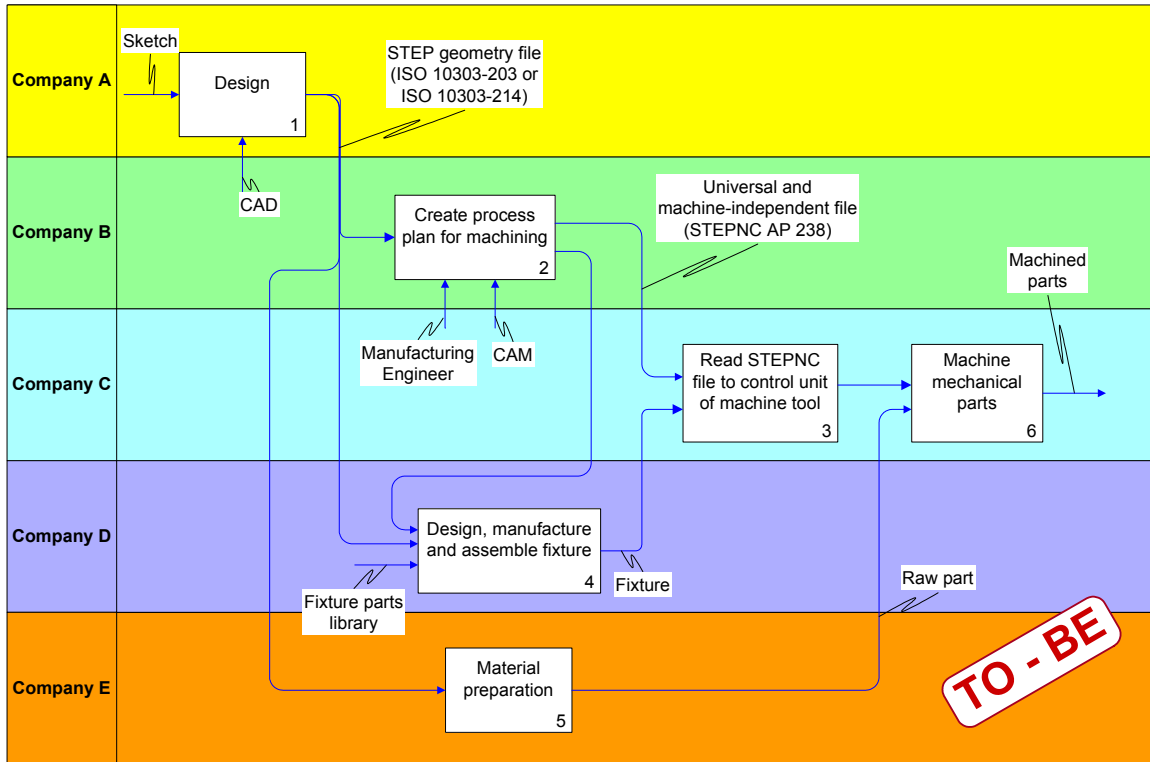


Figure 4. The manufacturing cycle is shown from design to fabrication and how STEP-NC is envisioned to be used within this cycle. STEP-NC can be simultaneously used to do work in different places. This accelerates designing and manufacturing as a whole. The machine tool is chosen only at a final stage. This way the resources of the different organisations are flexibly utilised.

The process planning phase generates the resource requirements for part fabrication. Process planning first makes the feature recognition and then splits the manufacturing features into sets suitable for various processes, e.g. milling, turning, electrical discharge machining (EDM), and inspection. The feature sets are used during the computer-aided manufacturing (CAM) phase. Based on this, machine independent STEP-NC files are generated that are executed by CNC machine tools.

2.1 STEP-NC data model

In STEP-NC, features are used to describe the volumes to be removed by machining, to get the final form of the workpiece described by CAD. These features are recognized by the CAM system and contain the final geometry and tolerances.

In many cases the final feature geometry can be used directly, completed with attributes like offsets, the needed technology, tools and machining strategies. However depending on the used technology, planned operations as e.g. number of roughing and finishing cuts, the sequence of workingsteps, quality targets like surface quality or shape enhancements additional machining features, must be created at the CAM system.

These features are based on the geometry of the raw part and the final geometry derived from the design features. Intelligent CAM systems are able to do this automatically when operations and workingsteps are specified by the planning engineer.

Manufacturing and machining is planned with CAM systems, which add manufacturing information and provide CNC's with executable and interchangeable programs. CAM systems are typically located in the manufacturing planning department but they can be used also on the shop floor, or integrated in modern CNC-Controllers.

The data model (Figure 5) contains geometry data, manufacturing feature data, and manufacturing process data. Geometry data typically originates from CAD, and is described in STEP. It includes all the information necessary to define the finished geometry of the workpiece.

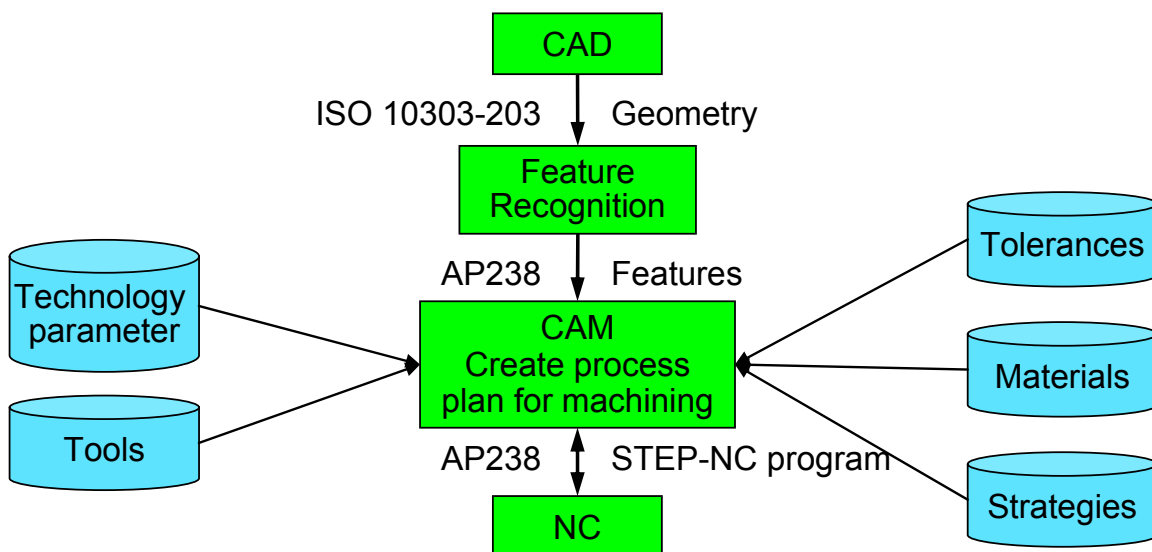


Figure 5. General description of the data model and the data flow.

3. Scenario

This hypothetical scenario is intended to illustrate the life cycle application of STEP-NC to a manufacturing enterprise (Figure 6). It is a vision of the future of manufacturing data transfer. This scenario is based on standard data model for computerized numerical controllers (ISO 14649-1 2003, ISO 14649-10 2003, ISO 14649-11 2003, ISO/FDIS 14649-111 2002).

Players in this scenario:

Consumer Product Corporation Inc. (Consumer Inc)

Consumer Product Corporation Inc is a company that is manufacturing consumer products world-wide. Dozens types of new products are introduced annually.

Module Supplier Inc. (Supplier Inc)

Module Supplier Inc is a company that is supplying parts to many industries. Parts are mainly fabricated from plastic using injection moulding technology. The company knows mould manufacturing and machine workshop technology.

Mould Designers Inc. (Designer Inc)

Mould Designers Inc is a company that is designing moulds especially for injection moulding technology. The company knows how to take into consideration client's requirements and convert them into manufacturable moulds.

Digital Controller Inc. (Controller Inc)

Digital Controller Inc is a company that supplies computer numerical controls (CNC) machining applications.

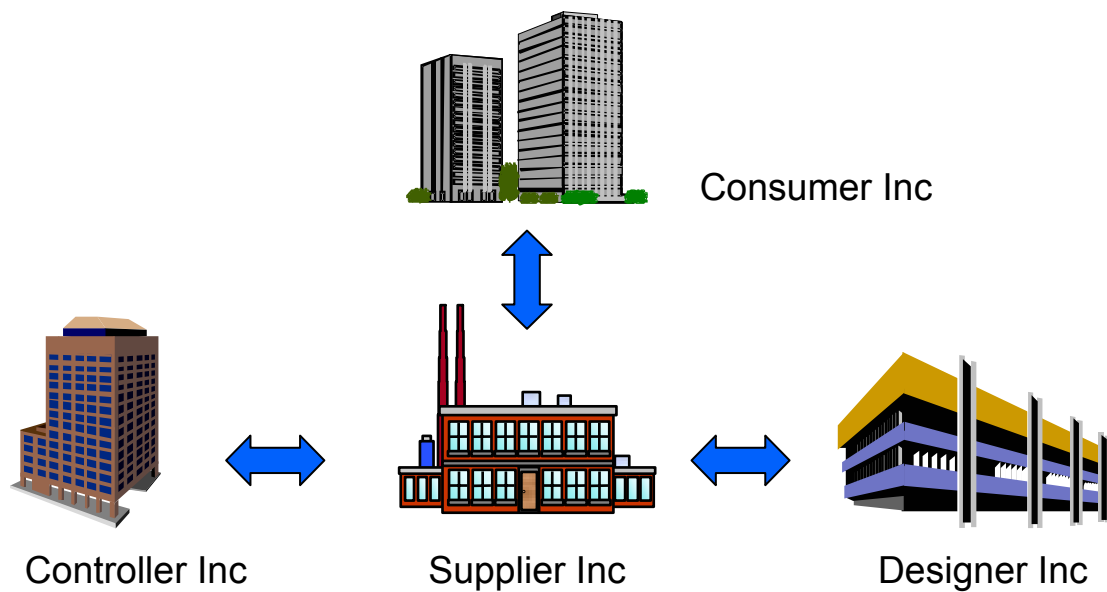


Figure 6. Consumer Product Corporation Inc. (Consumer Inc), Module Supplier Inc. (Supplier Inc), Mould Designers Inc. (Designer Inc) and Digital Controller Inc. (Controller Inc) are the players in this scenario.

3.1 Design and manufacturing operations

The Consumer Product Corporation Inc. (Consumer Inc) has broadened its product portfolio by launching a number of new products during last year with an emphasis on advanced devices. Consumer Inc has also made good progress in improving the quality of its processes and products. To gain even more market share and profit Consumer Inc develops its manufacturing and logistics operations. Consumer Inc has a supplier network that has facilities in Europe and Far East. Supplier network rely heavily on CNC machining centres to produce moulds for injection moulding technology. Moulds are designed in Northern Europe using CAD software that generates STEP format, i.e., ISO defined standard to exchange digital product data between CAD/CAM-Systems.

Consumer Inc engineers design a new generation product with the requirements and functionality fulfilling the market demands. Consumer Inc design organizations are using high-end PLM systems that are capable of expressing the engineering and industrial design intent. Consumer Inc is using three different PLM systems because of company mergers some years ago. The management of Consumer Inc considered that coercing company into one PLM system has more disadvantages than using three different systems one reason being that the existing CAD-models (i.e. design base) in each of the CAD-system can be capitalized fully. Also, there may be more company mergers in future and, therefore, the strategy towards heterogeneous PLM systems is more profitable. Interoperability is seen as a key asset in future.

Consumer Inc engineers design products in concert with the Module Supplier Inc., a manufacturing company (Supplier Inc) that is using injection moulding technology for producing Consumer Inc parts. The Consumer Inc designed product model is uploaded to Supplier Inc site. Supplier Inc uses its own sub-contractors in mould design and the product model is transferred to a mould design company (Designer Inc). Designer Inc suggests some minor modifications to original Consumer Inc design to take into account mould technology requirements (Designer Inc can import Consumer Inc CAD model in STEP format into their own CAD-system). The suggestions are updated to the original CAD-model and sent to Supplier Inc and Consumer Inc. After approval a mould design is frozen and transferred to Supplier Inc that uploads the CAD-model with no problems as the STEP format capability is also in their CAD-systems. Supplier Inc's process engineers develop process plans for each part of the mould. The manufacturing information is attached to geometric CAD-model, in other words, STEP-NC files are generated for the CNC machines.

The Supplier Inc European and Far Eastern facilities each will produce mould parts, and the STEP-NC programs are provided electronically to them. Each facility uses machining centres from different manufacturers and with different capabilities, although all of them support STEP-NC input. During initial production runs, the programs are tested at each facility and the parts are verified to be within the tolerances specified.

3.2 Introducing new STEP-compliant controllers

Supplier Inc has just purchased new CNCs that will be integrated onto the supplier's five-axis machining centres that support STEP-NC input, a Consumer Inc requirement.

Since STEP-NC is relatively new, Controller Inc decided to add support for this data transfer standard to an existing line of CNCs. CNC vendor provides tools to tune performance, program auxiliary I/O functions, and calibrate and compensate the machine.

Once the initial configuration of each machine is complete, the supplier runs a suite of custom STEP-NC programs to verify the static and dynamic performance of each machine using laser metrology and ball bar calibration setups. A second suite of STEP-NC programs is run on each machine, verifying that the controllers properly execute workingsteps.

At Supplier Inc's European facility, the CNCs have been delivered and set up in the production area. The Controller Inc CNCs are connected to the Supplier Inc network, the factory LAN, and the built-in networking lets the programming staff copy programs

to the CNCs as if they were any other computer on the network. Performance checking ensures that the axes specified in the program are present, that their ranges are within the volume of the machine, and that the required tooling is present.

Prior to running the programs, machine operators load and fixture the part stock and set up coordinate system offsets. The Advanced Controller Inc CNCs have RFID (Radio Frequency Identification) readers that allow machine operators to scan in the tags on the fixturing and stock. The scanned tags are compared with the STEP-NC program to verify that the required resources are present.

3.3 Program simulation

Program verification begins with the machinist running the program entirely in simulation. During simulation, a graphical animation of the tool path is shown superimposed on the working STEP geometry. The simulation also includes solid modelling software, which allows the machinist to pause the simulation and use the cursor to inspect feature dimensions.

Once the program simulation has completed, the machinist runs the program at a reduced feed rate. The machinist has the option of viewing the STEP-NC program while it is running, with the current working step highlighted. This highlighting is also mirrored in the 3D workpiece view so that the operator can anticipate which region will be milled next. Both the execution of the program and its simulation can be paused, stepped, and resumed independently.

3.4 Interactive programming

In some cases the input program is insufficient and must be modified. While modifications ultimately need to be reflected back to the designers or process planners, machinists can be given the authorization to interactively test alternatives on the machine.

This way of working has been found especially useful when optimizing technological parameters during the setup of a new NC program. STEP-NC allows both for a rather high-level description of manufacturing features and for a detailed description of tool paths and cutting conditions, if needed. This way, once the parameters have been optimized at the machine, they can be stored in all detail in the very same data model which was handed down from the process planning department.

This mechanism allows to give feedback to the planning department in a consistent manner. At the same time, it allows the planning department to prescribe exact tool paths in cases where the CAD/CAM system's output has been found to be more efficient than Controller Inc's internal feature resolution and path generation. This has greatly helped Supplier Inc to improve its overall information management and to avoid double work when re-using programs.

3.5 Remote interface to the enterprise

STEP-NC does not specify the means by which data gets to or is read from CNCs. As described in the preceding section, vendors are free to provide whatever means their customers desire, e.g., local area networking. The same is true for remote control of machine operation, uploading of machine data such as tooling information, and access to maintenance information such as coolant and lubrication levels.

The Controller Inc controller appears as any other computer in the factory LAN, and files can be copied to the controller as they would any other computer. Additionally, Controller Inc provides an application that can be run on any desktop machine that lets an operator select a command file from a browse able list, open it, and run it remotely. The status of the machine is continually updated. Supplier Inc policy is that remote operation of a machine can only be done under strictly controlled conditions in the interest of safety. Password protection on the Advanced Controller Inc software ensures that only authorized staff can initiate remote programs.

Controller Inc also builds into each CNC an HTTP server similar to that found in many networked printers. Supplier Inc staff can select each CNC as the target for their Internet browser, and a page is displayed showing the status of any program that may be executing, the tools that are present in the carousel, and the levels of coolant and lubrication.

3.6 Extending functionality

Supplier Inc/Europe recently finished integrating a non-contact probe intended for on-machine inspection. The code for this has been converted into a working step consistent with the STEP-NC approach, although it is not part of the current standard. The probing working step has been loaded onto the production Advanced Controller Incs as a “plug in” extension. Now, STEP-NC programs supplemented with this new working step pass the conformance checking phase and can be run in production.

4. STEP-NC benefits throughout the product development lifecycle

Benefits can be derived throughout the product development and production processes with the use STEP-NC to streamline the feed-back of information that augments product improvement. The benefits of STEP-NC are compelling and have been verified by independent studies by Lockheed Martin and other manufacturers (OMAC 2002). It is estimated that STEP-NC can reduced the machine planning process by up to 75 percent. This is due to a significant reduction in drawing information usually generated for producibility. Additionally, STEP-NC can increase the task of cutter path generation up to 35 percent faster because less information has to be defined since 3D feature recognition is used. And lastly, mid-sized machining jobs can actually be completed in 50 percent less time since STEP-NC provides automation computation for feeds and speeds compensation. Additional benefits can be derived from being able to reuse data more often, and from the controller being intelligent enough to prevent errors, optimize operations and dynamically re-create tool paths.

It is also assumed that using the whole STEP-NC process may lead to a new paradigm, i.e., “The paradigm change from personal intensive production to capital intensive production” (Deiter 2003). But, when this will happen there are diverse opinions. In some speculations STEP-NC will take over very soon, and there are views that it will take a decade (see f.ex. Andersson 2003).

5. Summary

Numerical Control (NC) machines were first introduced in the early 1950s and sparked the research and development of Computer Aided Manufacturing (CAM). In industry, CAD techniques are extensively used to design products, and CAM techniques are used to manufacture the products. Special languages were developed to translate the shape information from the drawing into computer-controlled machine tools. Current NC programming is based on ISO 6983, called "G-code", where the cutter motion is mainly specified in terms of position and the feedrate of axes.

Even though "G-code" is a well-accepted standard world-wide it is in fact a bottleneck for today's CNC production chain. Programming with "G-code" results huge programmes which are difficult to handle; last-minute changes or correction of machining problems on the shop floor are hardly possible and control of programme execution at the machine is severely limited. Even worse, due to many different "dialects" and vendor-specific additions to the programming language, part programmes are not interchangeable between different controls. As a result, porting programs between machines is difficult

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STEP-NC is a new model of data transfer between CAD/CAM systems and CNC machines, which replaces "G-code". It remedies the shortcomings of "G-code" by specifying machining processes rather than machine tool motion. Workingsteps correspond to high-level machining features and associated process parameters. CNCs are responsible for translating workingsteps to axis motion and tool operation. Basically, the standard is the smooth and seamless exchange of part information between CAD, CAM, and NC programming.

At the moment STEP-NC standardization is in ISO/DIS phase (Draft International Standard) and international development work continues in many countries. Many end-users have started their pilot-projects concerning utilization of STEP-NC and also CAD/CAM software vendors have made implementations for research projects.

References

- Andersson, G. 2003. Från CAD till-NC-maskin: datakommunikation. Verkstäderna nr. 5, pp. 52–54.
- Bedworth, D. D., Henderson, M. R. & Wolfe, P. M. 1991. Computer-Integrated Design and Manufacturing. McGraw-Hill, Inc.
- Cai, J., Weyrich M. & Berger, U. 2004. STEP-Referenced Ontological Machinig Process Data Modelling for Powertrain Production in Extended Enterprise. Proceedings of Mechatronics & Robotics 2004, edited by Paul Drews, Aachen, Germany. Pp. 235–240.
- Deiter, F. 2003. STEP-NC revolutioniert die Zerspanung. WB Werkstatt und Betrieb. WB 3. Pp. 68–70.
- Feeney, A. B. & Frechette, S. 2002. Testing STEP-NC implementations. World Automation Congress, 2002. Proceedings of the 5th Biannual, Volume: 14, 9–13 June 2002. Pp. 39–44.
- Hardwick, M. & Loffredo, D. 2001. STEP Into NC, Manufacturing Engineering, January 2001. Pp. 38–50.
- IDEF0 1993. The Computer Systems Laboratory of the National Institute of Standards and Technology (NIST). FIPS Publication 183. 1993.
- IMS Project 97006. 2003. STEP-Compliant Data Interface for Numerical Controls (STEP-NC). Technical Report 3. [refer 10.2.2005].
URL: <http://www.ims.org/projects/projects.html>.
- ISO 10303-203. 1994. Industrial automation systems and integration – Product data representation and exchange – Part 203: Application protocol: Configuration controlled 3D designs of mechanical parts and assemblies. Geneva, Switzerland: ISO. 581 p.
- ISO 10303-214. 2001. Industrial automation systems and integration – Product data representation and exchange – Part 214: Application protocol: Core data for automotive mechanical design processes. Geneva, Switzerland: ISO. 3496 p.
- ISO 14649-1. 2003. Industrial automation systems and integration — Physical device control — Data model for computerized numerical controllers — Part 1: Overview and fundamental principles. Geneva, Switzerland: ISO. 28 p.

ISO 14649-10. 2003. Industrial automation systems and integration – Physical device control – Data model for computerized numerical controllers – Part 10: General process data. Geneva, Switzerland: ISO. 181 p.

ISO 14649-11. 2003. Industrial automation systems and integration – Physical device control – Data model for computerized numerical controllers – Part 11: Process data for milling. Geneva, Switzerland: ISO. 81 p.

ISO/FDIS 14649-111. 2002. Industrial automation systems and integration – Physical device control – Data model for computerized numerical controllers – Part 111: Tools for milling. Geneva, Switzerland: ISO. 21 p.

ISO 6983-1. 1982. Numerical control of machines – Program format and definition of address words – Part 1: Data format for positioning, line motion and contouring control systems. Geneva, Switzerland: ISO. 14 p.

ISO/DIS 10303-238. 2004. Industrial automation systems and integration. Product data representation and exchange. Part 238: Application protocol: Application interpreted model for computerized numerical controllers. Geneva, Switzerland: ISO. 1368 p.

Jung, H. H. 1996. Survey of Feature Research. Technical Report IRIS-96-346, Institute for Robotics and Intelligent Systems, USC, USA.

Lewis, J. 2002. One step closer. Design News. [refer 10.2.2005].
URL: <http://www.designnews.com/article/CA241152.html>

Maeder, W., Nguyen, V., Richard, J. & Stark, J. 2002. Standardisation of the Manufacturing Process: the IMS STEP-NC project. [refer 10.2.2005]. URL: http://eig.unige.ch/itech/publications/iplnetworkshop2002_paper_27082002.pdf

Mortensen, M. E. 1985. Geometric Modeling. New York. Wiley & Sons.

OMAC 2002. The Value Proposition for STEP-NC. [refer 10.2.2005] URL: <http://www.omac.org/wgs/MachTool/STEP-NC/Deliverables/STEP-NCValuePropDraftV.4.pdf>

Philipson, C. 2003. Nygammalt CAM 40 procent snabbare. Verkstäderna nr. 5, pp. 71–74.

Proctor, F. & Kramer, T. 1998. A Feature-based Machining System using STEP. In: Proceedings of SPIE Conference on Sensors and Controls for Intelligent Machining, Agile Manufacturing and Mechatronics. Boston, Massachusetts. SPIE Vol. 3518, pp. 156–163.

Requicha, A. A. G. 1980. Representation for Rigid Solids: Theory, Methods, and Systems. *Computing Surveys*, Vol. 12, No. 4, pp. 437–464.

Suh, S. H., Cho, J. H. & Hong, H. D. 2002. On the architecture of intelligent STEP-compliant CNC. *International Journal of Computer Integrated Manufacturing*, Vol. 15, no 2, pp 168–177.

Suh, S. H., Lee, B. E., Chung, D. H. & Cheon, S. U. 2003. Architecture and implementation of a shop-floor programming system for STEP-compliant CNC. *Computer-Aided Design*, Vol. 35, pp. 1069–1083.

Sutherland, I. E. 1963. Sketchpad: A man-machine graphical communication system. *Proc. of Spring Joint Computer Conference*. 23. Pp. 329–349.

Weyrich, M. 2001. The ultimate STEP. *American Machinist*. May 2001.

Xu, X. W. & He, Q. 2004. Striving for a total integration of CAD, CAPP, CAM and CNC. *Robotics and Computer-Integrated Manufacturing*, Vol. 20, Issue 2, pp. 101–109.

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