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STEP FEATURE-BASED INTELLIGENT PROCESS PLANNING SYSTEM FOR PRISMATIC PARTS

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ABSTRACT

This paper presents an intelligent manufacturing system (ST-FIPPS: STEP Feature-based Intelligent Process Planning System) that integrates design and process planning. In the design stage, a STEP-based feature modeler (STEP-FM) has been developed for modeling prismatic parts. The modeler uses high-level 3D solid features as the basic entities for part design. The designed part is then exported as a STEP XML data format which can be passed directly to process planning without using a complex feature recognition process. In process planning stage, a hybrid intelligent process planning system (ST-FeatCAPP) has been developed. Neural network, fuzzy logic and rule-based approaches are used as the inference engines of the developed system. ST-FeatCAPP maps the STEP XML data generated by STEP-FM and produces the corresponding machining operations to generate the process plan and corresponding STEP-NC in XML format. This code contains all the data required to produce the designed part. An example is given to demonstrate and verify the proposed CAD/CAPP integrated system.

Keywords: Process planning, CAPP, STEP, neural networks, fuzzy logic.

1. INTRODUCTION

Modern manufacturing systems are challenged to increase productivity in the design and manufacture of products. At the same time, they are facing problems of increased product complexity, stiff global competition, the requirements of high product quality, and shorter lead time from design to manufacturing. Computer-aided design and manufacturing has provided a partial solution to these problems. However, as more and more users have turned to CAD/CAM systems to increase productivity, they have faced difficulties in the integration of

CAD and CAM software domains mainly due to their different information needs and the interface between these systems. CAD focuses on part specific geometry and topology while CAM needs process-specific features and their attributes [Patile and Pande, 2002]. Computerization of the process planning function will provide the automated CAD/CAM interface in order to produce an integrated system. Examining the recent developments in Computer-Aided Process Planning (CAPP), its aspect has been dramatically changed. Although the final goal of CAPP research remains in the same direction, its contents and emphases have gone through significant changes during the time period. Many new generations CAPP systems have been developed recently. In comparison with traditional CAPP systems, the new generations of CAPP systems have several advantages. First, artificial intelligence (AI) techniques have significantly impacted the development of CAPP systems. The implementation tools for the new generation systems have involved many new techniques, such as knowledge based techniques, object-oriented programming techniques, common product model, and virtual single manufacturing database techniques. In terms of the application of AI techniques in the development of CAPP, not only knowledge base and expert systems are used, but also fuzzy logic and neural network techniques have been involved. The second difference in comparing new generation CAPP systems with traditional CAPP systems is that the integrability has been dramatically improved. In terms of the integration of design and manufacturing, the feature techniques have been recognized as essential tools for eventually integrating process planning and design. Many researches have resulted in some applicable approaches such as feature recognition, feature-based design, etc. Many feature based process planning systems have been reported recently. Generally speaking, the difference between the new generation of CAPP and traditional CAPP lies in three aspects: (1) integrability, (2) intelligence, and (3) high techniques orientation [Zhang and Alting, 1994].

The objective of the present work is the development of a computerized system to integrate design and process planning, utilizing the concepts of STEP feature-based modeling and hybrid intelligent techniques. The methodology presented in this paper involves the development of a hybrid intelligent process planning system. The paper is organized as follows: section 2 presents the modular structure of the integrated system (ST-FIPPS). In section 3, the tasks of the process planning system (ST-FeatCAPP) and the intelligent techniques utilized are described. Section 5 describes the system implementation. In section 5, a sample example is presented to demonstrate the applicability of the developed system. Conclusions are provided in section 7.

2. MODULAR STRUCTURE OF ST-FIPPS

Figure 1 shows the modular structure of ST-FIPPS, STEP feature based process planning system developed in this work. It consists of the following subsystems:

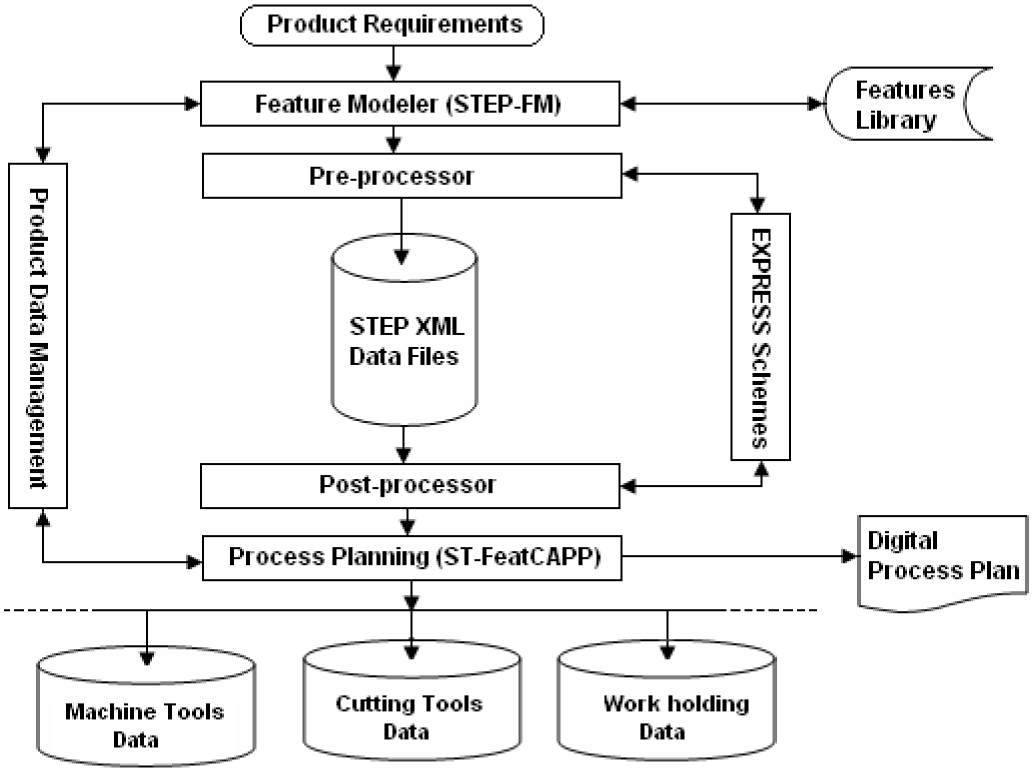


Figure 1. Modular Structure of ST-FIPPS

2.1 STEP Feature Modeler (STEP-FM): STEP-FM provides the design by feature approach for modeling prismatic parts. High-level 3D solid features are used as the basic entities for part design. The modeler relies on three main steps; (1) selection of the part base shape and overall size, (2) selection of the features to be added to or subtracted from the part being designed, and (3) providing information needed to define feature size, position, orientation and other attributes such as surface finish, tolerances, etc. The designed part is then exported as a STEP XML data format [ISO 10303-AP224, 2000]. This file can be passed directly to process planning without using a complex feature recognition process. The design philosophy of STEP-FM is discussed in more details in [Amaitik & Kiliç, 2002].

2.2 Hybrid Intelligent Process Planning (ST-FeatCAPP): ST-FeatCAPP maps the STEP XML data generated by STEP-FM and produces the corresponding machining operations to generate the process plan and corresponding STEP-NC in XML format. It carries out several stages of process planning such as operations selection, tool selection, machining parameters determination, machine tools selection, setup planning and fixture planning. Hybrid approach of most recent techniques of artificial intelligence is used as the inference engines of the developed system. ST-FeatCAPP is discussed in more details in section 3.

3. ST-FeatCAPP FRAMEWORK

ST-FeatCAPP, STEP Feature-based intelligent process planning maps STEP XML data generated by STEP-FM and performing intelligent process planning tasks to produce STEP-NC process plan. Various tasks of ST-FeatCAPP are shown in fig. 2 and briefly discussed in the following sections.

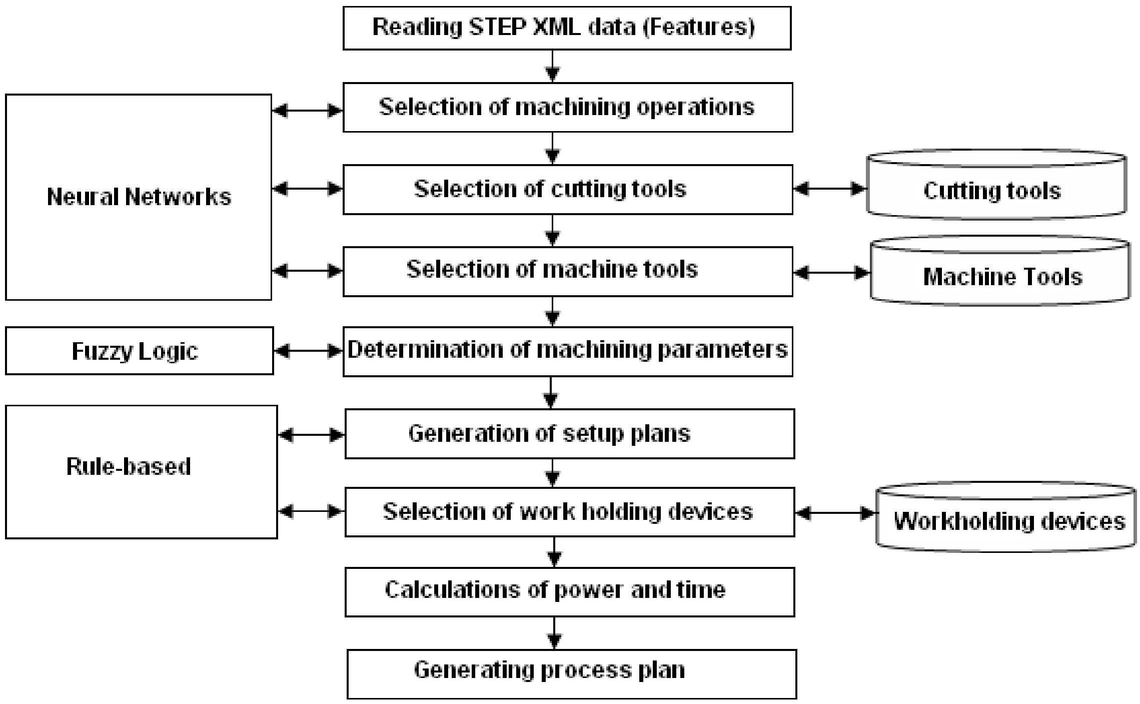
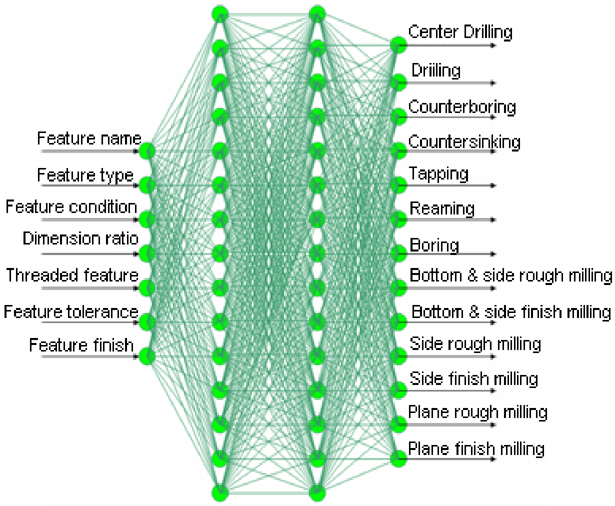
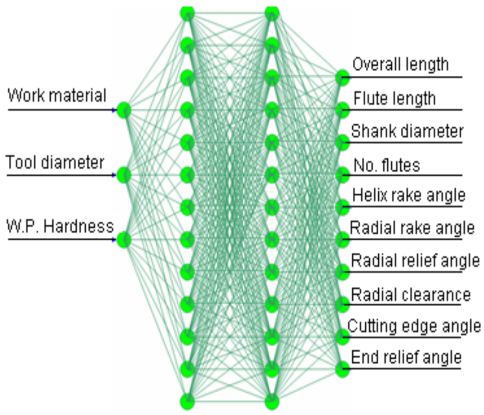


Figure 2. ST-FeatCAPP Structure

3.1 Reading STEP XML Data: The data integration between STEP-FM and ST-FeatCAPP is implemented through STEP XML file generated by STEP-FM. This data file is used in obtaining the type of features and their attributes, which are present in the part. This task converts STEP data into a suitable format to be used as input for process planning tasks of ST-FeatCAPP.

3.2 Selection of Machining Operations: This task functionally receives data for each feature in the part and generates the needed machining operations to realize the feature on the part. This is carried out using artificial neural network. The input vector of the neural network consists of seven variables, as shown in fig. 3(a). The output from the neural network consists of thirteen variables corresponding to the machining operations required for each feature on the part. The basic idea in this task is that for every machining feature there is a corresponding machining operation, depending upon the technological requirements of the feature. For example, for the same hole feature dimensions, if the tolerance or surface finish requirements are considered, simple drilling operation might be sufficient in one case, and drilling and reaming operations might be needed in the other case [Devireddy and Ghosh, 1999]. The developed neural network has been trained according to this criterion.





(a) Machining operations network (b) End mill network

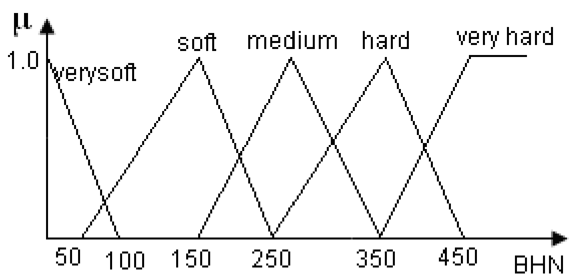
Figure 3 Neural Network Models

3.3 Selection of Cutting Tools: The selection of the cutting tool is one of the major tasks of ST-FeatCAPP system. The selection process is carried out according to the work material and machining feature size. The objective of tool selection is to determine the appropriate tool size and geometry. This task has been implemented using neural networks such that for each cutting tool a neural network was designed, trained and tested. Each neural network receives input vector consists of information about work material and feature size and generates output vector contains information about cutting tool size and geometry. Figure 3(b) shows the neural network model for selecting the appropriate end mill for milling operation.

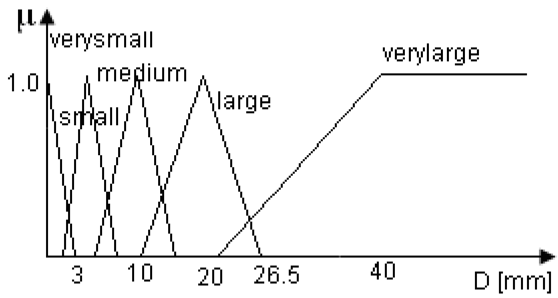
3.4 Determination of Machining Parameters: In ST-FeatCAPP system, several fuzzy models for determining machining parameters have been implemented [Amaitik and Kilic, 2002]. An example of one of these models capable of determining the machining parameters of twist drilling operation is presented, in order to explain the steps in development of the fuzzy model. There are three basic components of the fuzzy model; fuzzification of the input, fuzzy rules application and defuzzification of the output [Wong et al, 1999]. The hardness of the work material and the hole diameter are the input variables and cutting speed and feed rate are the output variables of the fuzzy model for twist drilling. The fuzzy sets of the input and output variables are shown in Table 1. Triangular shape membership functions were employed to describe the fuzzy sets. Figure 4 shows the membership functions for the input and output variables. The universe of input, material hardness and hole diameter has been partitioned according to the minimum and maximum values allowed to control the model. Similarly, the universe of output, cutting speed and feed rate has been partitioned according to the required range for each output. A set of fuzzy rules has been developed for different work materials with high speed steel tool combinations. Table 2 shows the fuzzy rules for twist drilling operation with high speed steel tool. Several defuzzification techniques are available in the literature. The choice of defuzzification method may have a significant impact on the accuracy of the fuzzy model output. The most frequently used one is the *centroid or center of area* (COA) which is used in the developed fuzzy models.

Table1. Fuzzy Sets of Input and Output Variables

Input variables			**Output variables**		
Fuzzy set	Range	Abbreviation	Fuzzy set	Range	Abbreviation
Material Hardness [BHN]			*Cutting Speed [m/min]*		
Very Soft	< 100	VS	Very Low	< 15	VL
Soft	50 – 250	S	Low	10 – 40	L
Medium	150 – 350	M	Medium	25 – 80	M
Hard	250 – 450	H	High	52- 110	H
Very Hard	> 350	VH	Very High	> 80	VH
Hole Diameter [mm]			*Feed Rate [mm/r]*		
Very Small	< 3	VS	Very Slow	< 0.1	VS
Small	2 – 10	S	Slow	0.05 – 0.3	S
Medium	6 – 20	M	Medium	0.15 – 0.45	M
Large	13 – 40	L	Fast	0.3 – 0.9	F
Very Large	> 26.5	VL	Very Fast	> 0.45	VF



Material hardness membership function



Hole diameter membership function

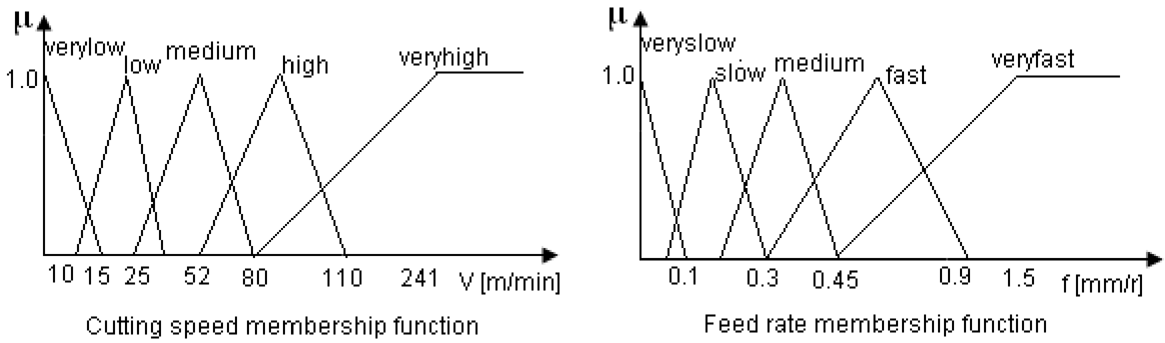


Figure 4. Membership Functions for Input and Output Variables

Table 2. Fuzzy Rules for Cutting Speed and Feed Rate with High Speed Steel Tool

Material Hardness		Hole Diameter				
		S	VS	M	L	VL
VS	V	M	M	M	M	M
	f	VS	S	M	F	F
S	V	L	L	L	L	L
	f	VS	S	M	F	F
M	V	L	L	L	L	L
	f	VS	S	M	M	F
H	V	VS	VL	VL	VL	VL
	f	VL	S	S	M	F
VH	V	VL	VL	VL	VL	VL
	f	VS	S	S	M	M

3.5 Selection of Machine Tools: This task of ST-FeatCAPP selects the machine tools on which the machining operations can be performed to produce the machining features. This task is implemented using a neural network [Joo et al, 2001]. The input vector of the neural network includes machining feature characteristics (i.e. feature type, feature size, feature tolerance, feature finish) and machining operation characteristics (i.e. operation type, cutting tool, machining power). The output vector of the neural network contains recommended specifications of the machine tool to be used to perform the task. These recommended specifications can be used as keys for search available machine tool database to find the proper machine tool. Figure 7 shows the neural networks structure.

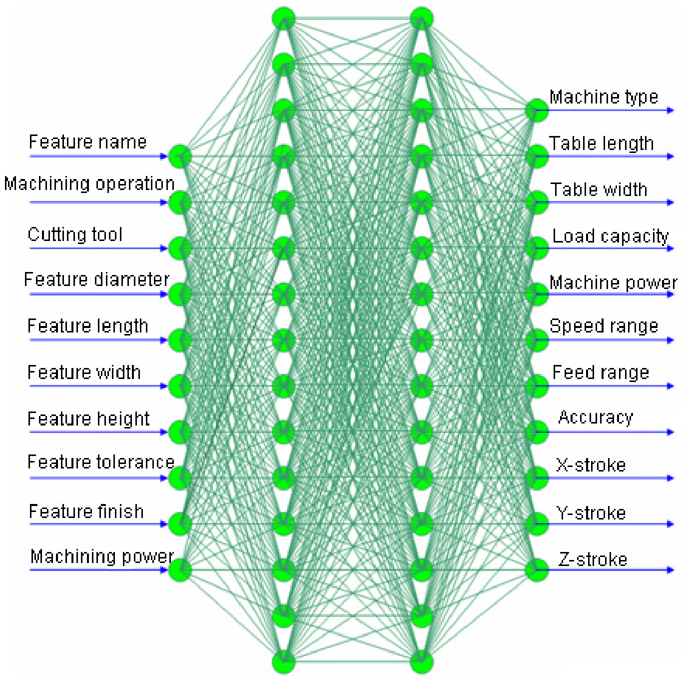


Figure 5. Machine Tool Selection Neural Networks

3.6 Setup Planning: The setup planning activity in ST-FeatCAPP is composed of three steps; i.e., setup generation, operation sequence, and setup sequence [Ming and Mak, 2000]. The *setup generation* is a procedure to group the machining operations into setups such that the manufacturing features which have common approach directions are grouped into the same setup. The *operation sequence* arranges the machining operations in each generated setup into order, so that the constraint of the feature precedence relationships in each setup is satisfied. In addition, the cutting tool changes among the operations are reduced to a minimum. The *setup sequence* is to arrange the generated setups in order so that setups with less number of machining features are machined first. A set of rules guiding the setup planning have been developed for prismatic parts and implemented in ST-FeatCAPP system.

3.7 Generation of STEP-NC Process Plan: A preprocessor has been developed to generate a physical STEP-NC process plan file. The main function of this preprocessor is to receive information related to workpiece (features, tolerances, material, etc.) and information produced by process planning (machining operations, cutting tools, machining parameters, etc.) to generate STEP-NC process plan which defines the sequence of the working steps. These working steps provide the basis of the process plan to manufacture the component. Each working step defines an operation to be performed on a machining feature. The machining features describe what the machine shall do and the working steps and operations describe how the features should be manufactured [Suh et al, 2002].

4. SYSTEM IMPLEMENTAION

ST-FIPPS system is developed as an integrated CAD/CAPP system in CIM lab of Middle East Technical University in Ankara, Turkey. The use of an object-oriented approach for the implementation of the entire system (ST-FIPPS) was chosen. Object-oriented approach helps in the representation and encapsulation of part feature geometry and related process information to achieve the desired part-process integration. Microsoft Visual Basic and ActiveX technology are used in the implementation of ST-FIPPS in AutoCAD environment. This implementation is done by adding STEP-FM and ST-FeatCAPP commands to AutoCAD. By this way, AutoCAD became capable of providing geometrical modeling, feature modeling and performing intelligent process planning tasks.

5. EXAMPLE

Consider the example part shown in fig. 6 of appendix A. This part was modeled using STEP-FM and was then processed by ST-FeatCAPP to generate STEP-NC process plan [ISO/DIS 14649-10 and ISO/DIS 14649-11, 2000]. Appendix A illustrates the partial physical file in STEP XML format for the example part. This one file contains the definition of the part, the machining features, the cutting tools, the material and tolerances, machine tool instructions, etc. Some of the important features of this STEP-NC process plan are as follows.

- STEP-NC process plan provides an object oriented data model for CNC's with a detailed and structured data interface that incorporates feature based programming where there is a range of information such as the feature to be machined, type of tools used and the operations to perform [Newman et al, 2002].
- STEP-NC process plan not only eliminates the costly and inefficient process of generating post processors, but also establishes a collaborative environment for the exchange of information between product design applications, manufacturing process planning, and the machine tool on the factory floor.
- STEP-NC process plan would be used to control the next generation of intelligent machine tool controllers.

6. CONCLUSIONS

Integration of CAPP with CAD systems will greatly improve the efficiency of manufacturing enterprise. In addition, the development of STEP-based intelligent CAPP systems will be very useful to the manufacturing engineering specialists working in concurrent engineering environment. The present work demonstrates a STEP-based intelligent CAPP system (ST-FIPPS) for prismatic parts. The ST-FIPPS provides a STEP-based integrated environment for the feature-based design and manufacturing of prismatic parts. The STEP-FM provides a design by feature tool for synthesis of a feature-based solid part model. The ST-FeatCAPP provides an integration of the feature to process planning in order to produce STEP-NC process plan. The use of neural network and fuzzy logic approaches has enabled the development of flexible CAPP system that can be trained to handle new knowledge.

7. ACKNOWLEDGEMENT

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12. **International Organization for Standardization [2000]**, ISO/DIS 14649-11 Industrial automation systems and integration – Physical device control – Data model for computerized numerical controllers – Process data for milling.

13. **International Organization for Standardization [2000]**, ISO 10303-224 Industrial Automation Systems and Integration-Product Data Representation and Exchange - Application Protocol: Mechanical Product Definition for Process Planning Using Machining Features.

APPENDIX A

EXAMPLE PART

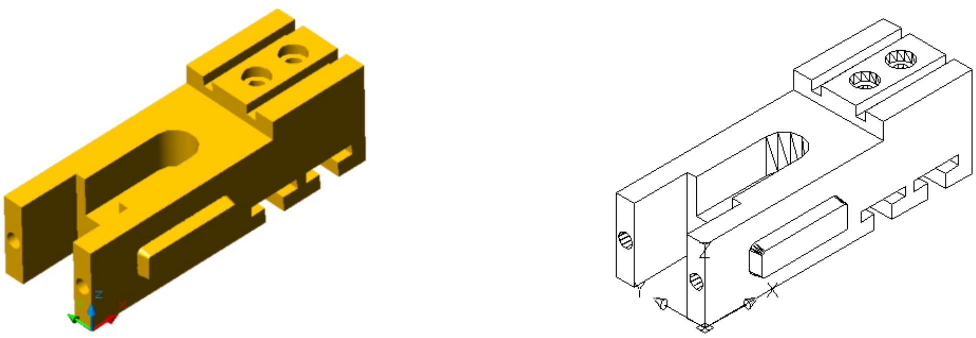

Figure 6. Example Part Model


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