OPEN SYSTEMS INTERFACE SPECIFICATION FOR MACHINING PROCESS PLANNING INTEGRATION

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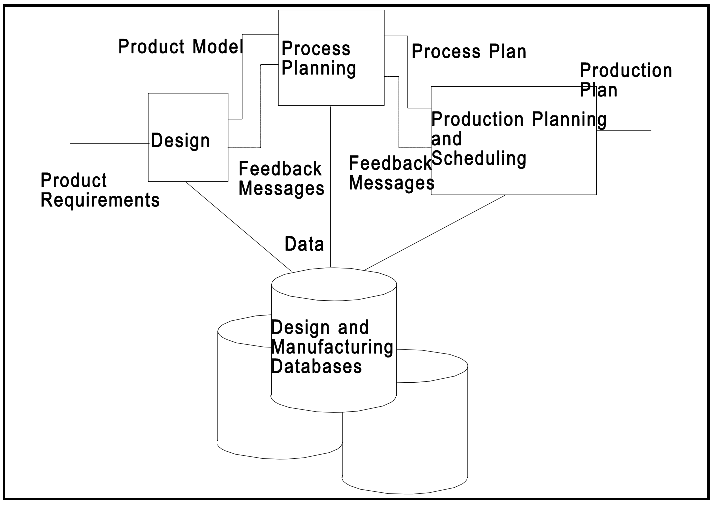
A key issue in integrating process planning systems with design systems and production planning systems is how to overcome barriers in data exchange and sharing amongst software systems. Each software system has its own proprietary data format and definition, which is often not available to users. This paper presents the activity model and a machining process plan data model developed as an international product data exchange standard (ISO 10303-213). These two models were designed and developed to enable the integration of process planning systems with other manufacturing software systems, such as computer-aided design systems, machine tool control programming systems, resource management systems, production scheduling systems, and factory simulation systems.

Introduction

Data incompatibility between currently available manufacturing software systems is a major barrier in systems integration. Data exchange between any two systems cannot always be efficiently done. Each manufacturing software system has its own proprietary data format, which is often not available to users. Even in systems which make their data formats available to users, data definitions provided by one system might be only suitable to that particular system and incompatible with others. In such a situation of data incompatibility, a smooth work flow from computer-aided design to computer-aided process planning to computer-aided production planning is not possible. Developing an integration mechanism is important to achieving design, process planning, and production planning systems integration.

An open, neutral, and extensible data model is an effective mechanism to resolve a data incompatibility problem. A data model is a data representation specification that captures the form, function, and definition of all the pieces of information. The data model also captures the relationships between pieces of information. In order to provide sharable data among commercial systems, the data should be available to all vendors in a neutral format that does not bias any particular product. In addition to the openness and neutrality, the extensibility of the data model is also a requirement. An extensible data model can incorporate new data that meet future data needs. With an open, neutral, and extensible data model, data sharing and smooth data exchange among software systems are possible.

Developing an activity model is the first step to develop a neutral data model. An activity model is a representation of the functions and data interface requirements for an engineering (or business) process. The activity model sets the context in which some data are exchanged between functions and other data, as resources, are shared by functions. Activity modeling allows data modelers to capture prerequisite information for developing data models.



Process planning is an essential link between design and production planning in the product development process. The high-level relationships between design, process planning, and production planning activities are shown in Figure 1, which represents a computer-integrated manufacturing system. In this system, design is an activity to generate the specification of a product based on the product's functional requirements. Process planning is an activity to generate process plans which is the detailed specification for the manufacture of a part meeting the design specification. Production planning is an activity that generates schedules for specific production facilities and resources to fulfill the process plan specifications. If there are manufacturability problems with the design, messages will be sent to the designer as feedback from process planning. If production plans and schedules cannot be created, messages will be sent to the process planner as feedback from production planning. As shown in the figure, the crucial transition from engineering design to shop-floor production is process planning, which converts the product design into a manufacturing action plan.

This paper presents an activity model of a machining planning process and discusses a data model for numerical control machining process plan data. The two models represent the machining planning subactivity in the context of an effort at NIST for integration of manufacturing software systems [1]. The activity is documented using IDEF0, which is a functional modeling methodology [2]. In this model, the process planning activity is specifically designed for machining using numerically controlled machining centers, which are commonly used in automated production systems. The data model is defined in the EXPRESS data modeling language [3]. The data model was developed as part of the ISO 10303 standard for the exchange of product life-cycle data between computer aided application systems for product development and maintenance.

A Review of Process Planning Activity Models

There are several process planning activity models which have been previously developed. The CAM-I process planning activity model [4] describes the mechanical part manufacturing process planning activity with the following functions: extracting information from product model data for manufacturing, selecting processes and sequencing the processes, selecting machines and tools, specifying workpiece setups, developing a list of operations, and evaluating the generated process plans. A model defining an activity model and a data model was developed by the IMPPACT project [5]. The application area is in the manufacturing of discrete parts, such as machined, sheet metal, and cast parts. The Automated Airframe Assembly Program (AAAP) [6] developed an activity model to describe functions in airplane frame design, manufacturing planning, assembly planning, and inspection planning. Their model includes manufacturing process planning subactivities, such as the selection of machines, tools, and fixtures, the determination of operation sequences, tooling design, and the generation of machine tool control programs. The process planning portion of the AAAP activity model was not specifically created for machining. Thus, some essential functions are not included in the model, such as material stock selection, machining feature derivation, setup determination, tolerance analysis, and cost estimation. Draft ISO 10303 Part 213 [7] has an activity model for NC machining process planning. The model describes machining resource selection, machining operation plan development, process plan validation and approval. STEP AP 224 [8] includes an activity model for manufacturing mechanical parts. This model was developed for defining the context under which the data are transferred from computer aided design systems to computer aided process planning systems. The model includes the following major subactivities: managing the administrative data, packaging product definition data for process planning, generating manufacturing data, and creating shop floor operations. Only the subactivity of packaging product definition data is within the scope of the AP.

In summary, all the above mentioned models capture basic functions in process planning. However, each of them has some voids in addressing present industrial needs, such as shop-floor routing planning, tooling, cost estimation, machining feature derivation, intermediate feature generation, material stock selection, setup determination, and tolerance specification for intermediate features.

Machining Process Planning Activity Model

This paper describes a unified machining process planning activity model that consolidates all the activity models reviewed in the previous section and includes additional features that are needed to address the integration of current CAPP systems. The inspection activity is not addressed in this model, and an inspection activity model can be found in another report [9]. This model, developed using IDEF0, specifies functions and data requirements for machining process planning, for machining a single part in a factory. The model addresses the development of process sequences, machining operations, shop floor routings, numerically controlled machine tool program generation, and plan/program validation. It also includes cost/time estimation and material requirements.

The diagram in Figure 2 models the context in which the machining process planning activity takes place. Activity A0 performs machining process planning. The activity is to create process plans for part machining based on a part design. The activity has input data from product models (e.g., engineering drawings or CAD models), tooling and material inventory data, and process change requests. The activity also requires a control of cost constraints set by company or product planners. Mechanisms supporting the activity are machining resource descriptions, standard cost references, standard process models, machinability data, and material stock descriptions. The outputs of the machining process planning activity are cost estimation, validation run requirements, stock material specification, resource requirements, routing plans, process plans, maching control programs, and design change requests.

The overall activity on level A-0, in Figure 2, is decomposed into five activities (A1 — A5) in Figure 3. It shows the relationships among the activities and the data inherited from the upper level (A-0). Activity A1 generates process sequences. The activity is to select and sequence a set of processes to transform material stocks to finished parts. Alternative sets of sequenced processes may be produced. Activity A2 generates operations. The activity is to develop detailed machining instructions for each operation in the process routing. The information used in an operation includes machining surfaces/features, workpiece setups, machines, tools and fixtures selected, machining dimensions and tolerances, etc. Activity A3 generates shop-floor routings and means of workpiece transportation. Routings include work centers in which workpieces are machined and corresponding workpiece travel itineraries. Activity A4 generates control programs. The activity is to create computer programs that control machine tools and workpiece handling and transportation machines on the shop floor. The computer code includes the numerical control (NC) programs for the machining centers, robot programs, automatic guided vehicle (AGV) programs, etc. Activity A5 validates plans and programs. The activity is to verify, recommend changes to, approve or disapprove the generated process plans, routing plans, NC programs, robot programs, and AGV programs to ensure the correctness of these plans and programs for part production. Activity A1 through A5 can be further decomposed until the data elements are fine enough for creating a data model. A glossary for the model has also been developed. Details of the model and the complete glossary can be found in a report [10].

The activity model defines the scope, functional components, and data requirements for developing machining process planning systems. It is important to note that IDEF0 diagrams are often interpreted to imply a strict sequence of activities. That is not the intention in this case. Rather, the numerous data flows representing feedback from one activity to another are expressly omitted to avoid cluttering the diagrams. Thus, for example, in Figure 3, each of the activities A1 - A5 should be considered to be providing data to each of the other activities in the figure.

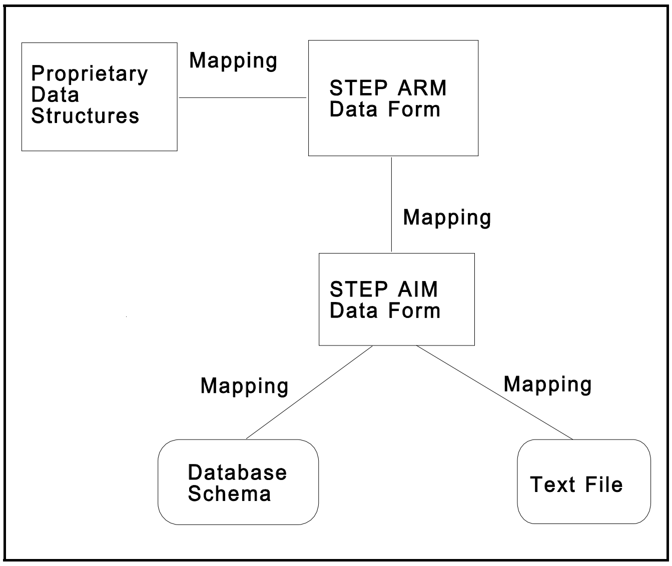
Machining Process Plan Data Model

A process plan model for NC machining has been developed under ISO/Technical Committee 184/Subcommittee 4. The standard is to provide a neutral, open data format for capturing process plan data. This model contains the following technical data categories: process plan header, administrative data, operation and sequence, part definition relating to process planning, and manufacturing resource data. The process plan data elements and relationships are characterized in the application reference model (ARM). The ARM is then mapped to the ISO 10303 resource model which contains generic data, such as product administrative and support, shape, material, dimension, tolerance, surface conditions, and process definitions. The mapped model is called an application interpreted model (AIM). The mapping between ARM and AIM is performed to identify a subset of generic data to represent an NC machining process plan. This ISO Part is intended, but not limited, to (1) exchange data between computer aided process planning systems, (2) transmit process plan data from a computer aided process planning system to a NC program generation system, or (3) archive process plan data for future use. Once a data model is completed, the next logical step is to implement system interfaces for systems that need to exchange or share process plan data with other systems that have different representations of the data.

Implementation of the Standard Data Model

The implementation of data interfaces to systems that deliver or receive process plan data can be based on a standard data model such as the above mentioned Part 213 of ISO 10303. Initially, system developers have to decide whether their data can be transformed to the standard format. If their data can not be fully mapped to the standard data, a portion of the data can be implemented. Secondly, the system's process plan data, or subset, need to be mapped to the standard data format. A convenient way to do the mapping from a system's format to the standard format is to map the system data to the ARM, map the ARM to the

AIM, and map the AIM to a physical representation, such as a text file or database schema. Figure 4 shows the mapping. Lastly, a test of the system interface implementation needs to be performed to ensure the conformance of the system interface to the specification.



Concluding Remarks

Integration of process planning systems with NC generation or production planning systems requires the development of system interfaces that translate data from proprietary form to standard form and vice versa. Development of standard data includes defining data requirements, creating an open and neutral data model, and implementing the data model with software systems. Activity models, data models, and implementations of the data models are essential elements for systems interface development, which enables systems integration.

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