INTERNATIONAL STANDARD

ISO 14649-1

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Industrial automation systems and integration — Physical device control — Data model for computerized numerical controllers —

Part 1: Overview and fundamental principles

Systèmes d'automatisation industrielle et intégration — Commande des dispositifs physiques — Modèle de données pour les contrôleurs numériques informatisés —

Partie 1: Aperçu et principes fondamentaux

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 14649-1 was prepared by Technical Committee ISO/TC 184, *Industrial automation systems and integration*, Subcommittee SC 1, *Physical device control*.

ISO 14649 consists of the following parts, under the general title *Industrial automation systems and integration — Physical device control — Data model for computerized numerical controllers*:

NOTE Phase numbers below refer to the planned release phases of ISO 14649 which are described in Annex D.

— *Part 1: Overview and fundamental principles* (Phase 1)

— *Part 10: General process data* (Phase 1)

— *Part 11: Process data for milling* (Phase 1)

— *Part 12: Process data for turning* (Phase 2)

— *Part 13: Process data for wire-EDM* (Phase 2)

— *Part 14: Process data for sink-EDM* (Phase 2)

— *Part 111: Tools for milling* (Phase 1)

— *Part 121: Tools for turning* (Phase 2)

Gaps in the numbering were left to allow further additions. ISO 14649-10 is the ISO 10303 Application Reference Model (ARM) for process-independent data. ISO 10303 ARMs for specific technologies are added after part 10.

This part of ISO 14649 has a strong relationship to ISO 10303 AP238, which is a one-to-one 100 % mapping of ISO 14649, where ISO 14649 represents the ARM and AP238 the AIM. This relationship is referenced in this document and in other parts of ISO 14649.

ISO 14649 is harmonized with ISO 10303 in the common field of Product Data over the whole life cycle. Figure D.1 shows the different fields of standardization between ISO 14649, ISO 10303 and CNC manufacturers with respect to implementation and software development.

Introduction

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. This leads to the possibility of using standard data throughout the entire process chain in the manufacturing enterprise. Impediments 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 and M code” language. Programs are typically generated by computer-aided manufacturing (CAM) systems that use computer-aided design (CAD) information. However, ISO 6983 limits program portability for three reasons. First, the language focuses on programming the tool center 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 ISO 6983.

ISO 14649 is a new model of data transfer between CAD/CAM systems and CNC machines. It remedies the shortcomings of ISO 6983 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 ISO 14649 is its use of existing data models from ISO 10303.

ISO/TC 184/SC 1/WG 7 envisions a gradual evolution from ISO 6983 programming to portable feature-based programming. Early adopters of ISO 14649 will certainly support data input of legacy “G and M codes” 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, ISO 14649 does not include legacy program statements, which would otherwise dilute the effectiveness of the standard.

ISO 14649 is harmonized with ISO 10303 in the common field of Product Data by the ISO 10303-238 Application Interpreted Model (AIM) over the whole life cycle.

This document, ISO 14649-1, “Overview and fundamental principles,” has five informative annexes. Annex A shows the use and assignment of features from ISO 10303-224 in ISO 14649, Annex B is the Application Activity Model that explains the environment and the activities of ISO 14649 in the manufacturing process. Annex C shows an overview of the data model structure as an EXPRESS-G diagram. Annex D describes the relationship of ISO 14649 to ISO 10303 (STEP). Annex E is a hypothetical scenario, intended to illustrate the life cycle application of ISO 14649 to a manufacturing enterprise. It is a vision of the future of manufacturing data transfer as intended by this International Standard.

Industrial automation systems and integration — Physical device control — Data model for computerized numerical controllers —

Part 1: Overview and fundamental principles

1 Scope

This part of ISO 14649 provides an introduction and overview of a data model for Computerized Numerical Controllers and explains its advantages and basic principle, based on the concepts of Product Data.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 841:2001, *Industrial automation systems and integration — Numerical control of machines — Coordinate system and motion nomenclature*

ISO 2806:1994, *Industrial automation systems — Numerical control of machines — Vocabulary*

ISO 4342:1985, *Numerical control of machines — NC processor input — Basic part program reference language*

ISO 4343:2000, *Industrial automation systems — Numerical control of machines — NC processor output — Post processor commands*

ISO/TR 6132:1981, *Numerical control of machines — Operational command and data format*

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*

ISO 10303-1:1994, *Industrial automation systems and integration — Product data representation and exchange — Part 1: Overview and fundamental principles*

ISO 10303-11:1994, *Industrial automation systems and integration — Product data representation and exchange — Part 11: Description methods: The EXPRESS language reference manual*

ISO 10303-21:2002, *Industrial automation systems and integration — Product data representation and exchange — Part 21: Implementation methods: Clear text encoding of the exchange structure*

ISO 10303-22:1998, *Industrial automation systems and integration — Product data representation and exchange — Part 22: Implementation methods: Standard data access interface*

ISO 10303-41:2000, *Industrial automation systems and integration — Product data representation and exchange — Part 41: Integrated generic resource: Fundamentals of product description and support*

ISO 10303-42:2000, *Industrial automation systems and integration — Product data representation and exchange — Part 42: Integrated generic resources: Geometric and topological representation*

ISO 10303-43:2000, *Industrial automation systems and integration — Product data representation and exchange — Part 43: Integrated generic resource: Representation structures*

ISO 10303-49:1998, *Industrial automation systems and integration — Product data representation and exchange — Part 49: Integrated generic resources: Process structure and properties*

ISO 10303-203:1994, *Industrial automation systems and integration — Product data representation and exchange — Part 203: Application protocol: Configuration controlled design*

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*

ISO 10303-224:2001, *Industrial automation systems and integration — Product data representation and exchange — Part 224: Application protocol: Mechanical product definition for process planning using machining features*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply, some of which are defined in ISO 10303 and other standards.

3.1 Terms defined in ISO 10303-1

application

application activity model

application interpreted model

application protocol

application reference model

data

data exchange

implementation model

information

information model

interpretation

model

product

product data

3.2 Terms defined in ISO 10303-11

attribute

entity

entity data type

entity instance

EXPRESS language

3.3 Terms defined in ISO 10303-21

physical file format

3.4 Terms defined in ISO 10303-224

fixture

machining features

manufacturing feature

3.5 Terms defined in ISO 2806

numerical control

computerized numerical control

tool path

3.6 New definitions in ISO 14649

3.6.1
workingstep
machining information for one cutting tool acting on a feature

NOTE It contains a Machining Operation.

3.6.2
machining operation
technological data for a Workingstep that details the operation

NOTE It is composed of cutting tool, toolpath strategy, machining function, cutting depth, finishing allowance, cutting speed, feed rate, retract plane, safety plane, approach strategy, and retract strategy.

3.6.3
workplan
collection of Workingsteps with an execution sequence

NOTE It contains a list of Executables.

3.6.4
executable
one of Workingstep, NC Function, or Program Structure

3.6.5
NC function
one of Display Message, Optional Stop, Program Stop, Exchange Pallet, Index Pallet, Index Table, Set Mark, Unload Tool, or Wait for Mark

3.6.6
program structure
one of Workplan, Parallel, If statement, While statement, or Assignment

3.6.7
project
entity which serves as a starting point for program execution

4 Symbols and abbreviated terms

For the purposes of this document, the following abbreviations apply.

AAM Application Activity Model

AIM Application Interpreted Model

AP Application Protocol

ARM Application Reference Model

CNC Computerized Numerical Control

5 Overview of ISO 14649

5.1 Purpose

The purpose of ISO 14649 is to:

— cover the current and expected future needs for data exchange;

— support the direct use of computer-generated product data from ISO 10303;

— create an exchangeable, workpiece-oriented data model for CNC machine tools;

— use standard, modern languages and libraries for the implementation of the data model;

— ensure compatibility of CNC input data.

ISO 14649 is applicable to advanced CNC machine tool and CAM systems.

5.2 The manufacturing cycle

Figure 1 shows the manufacturing life cycle, from design to fabrication, and how ISO 14649 is envisioned to be used within this cycle. The design phase results in CAD data (ISO 10303-203 geometry) and includes the definition of all the part features in ISO 10303-224. The process planning phase generates the resource requirements for part fabrication, using ISO 10303-213, and other results suitable for use in a Manufacturing Execution System (MES). Process planning also splits the ISO 10303-224 manufacturing features into sets suitable for various processes, e.g. milling, turning, electrical discharge machining (EDM), and inspection (which also uses ISO 10303-219). The ISO 10303-224 feature sets are used during the computer-aided manufacturing (CAM) phase. Based on this, ISO 14649 files are generated that are executed by CNC machine tools. At run time, each controller may access ISO 10303 integrated resources via the Standard Data Access Interface (SDAI) or EXPRESS-X queries in extensible markup language (XML), providing tight integration of ISO 10303 data with machining operations.

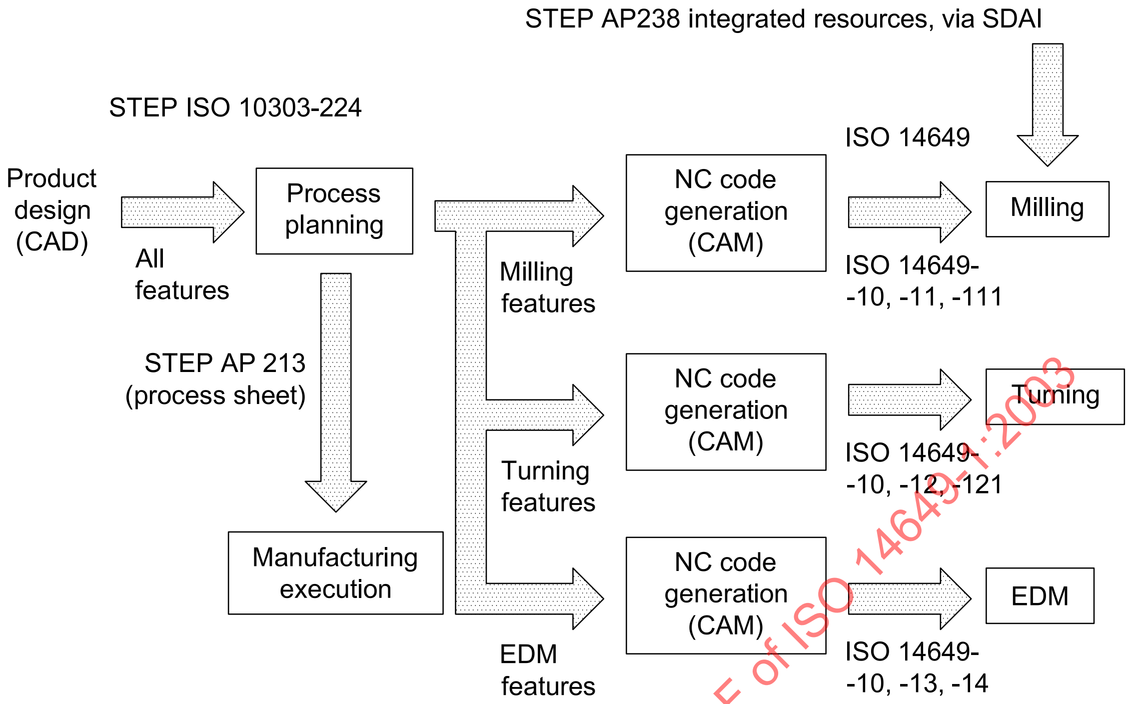


Figure 1 — The manufacturing cycle, from design to fabrication, and how ISO 14649 is envisioned to be used within this cycle

The fundamental principle of the data model is the object-oriented view of programming in terms of manufacturing features, instead of direct coding of sequences of axis motions and tool functions. The objects in this case are manufacturing features and their associated process data. This does not mean that the programming language is object-oriented, in the sense that it provides classes, methods, or inheritance. Rather, the language is a procedural way to link together a sequence of feature objects.

The data model is composed of basic units called *entities*. Entities and the relationships between them are defined in the ISO 10303 EXPRESS data modelling language. Data in a particular ISO 14649 program consists of *instances* of these entities.

The data model contains geometry data, manufacturing feature data, and manufacturing process data. Geometry data typically originates from CAD, and is described in ISO 10303 AP 203. It includes all the information necessary to define the finished geometry of the workpiece. Manufacturing feature data typically originates from CAM. ISO 14649 defines manufacturing features that differ from, but are harmonized with, ISO 10303-224. Manufacturing process data also originates from CAM, and defines the technological parameters to be used during the cutting process such as tool feed and spindle speed, and descriptions of the tooling required for each of the machining operations. Manufacturing process data also includes the definitions of Workingsteps, one for each association of feature, of associated tool and its technological parameters, and the sequence of these Workingsteps. An overall Workplan lists this information. This is shown in Figure 2.

The division of information means that changing the sequence of Workingsteps or optimising tool paths can be done with minimal impact on the rest of the data. Graphical user interfaces are expected to be an excellent help.

Geometry, feature definitions, and process data are described in ISO 14649-10. Milling-specific data is described in ISO 14649-11 and ISO 14649-111. Data models for other technologies, such as turning and EDM, will be described in successive parts as they are completed.

Programming in legacy languages such as ISO 6983 is not part of the data model. CNCs should be able to handle legacy programs in a separate subsystem.

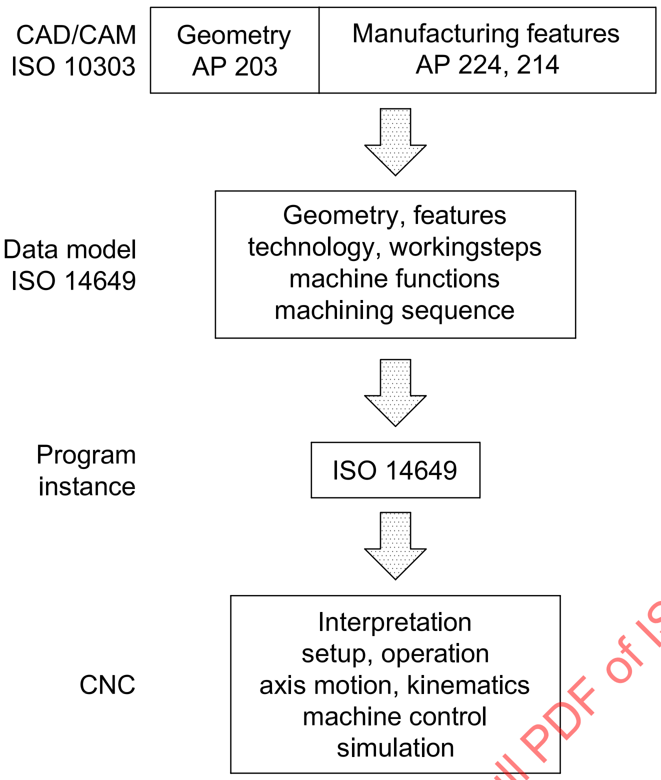


Figure 2 — General description of the data model

5.3 Program organization

A part program is described in a Physical File Format according to ISO 10303-21. The first section of the part program is the header section marked by the keyword “HEADER”. In this header, some general information and comments concerning the part program are given, such as filename, author, date, organization, etc.

The second and main section of the program file is the data section marked by the keyword “DATA”. This section contains all information about geometry, features, and manufacturing tasks. The content of the data section is divided into three significant parts: Workplan and executables with its technology description, Manufacturing features and Geometry description. A Project entity serves as an explicit reference for the starting point of the manufacturing tasks. Figure 3 shows the relationship between these significant parts of an ISO 14649 data set. The structure and the purpose of the date sets that define features and process data are described in the following sections. (See ISO 14649-10 for more detailed definitions.)

5.4 Project description

The project entity in the DATA section serves as a starting point for executing the part program. This instance should contain a main workplan that contains sequenced subsets of executables (executable manufacturing tasks or commands) and may also include information of workpieces to be machined.

5.5 Executables and the Workplan

Executables initiate actions on a machine and are ordered by the workplan. There are three types of executables: Workingstep, program structure, and NC function. Workingsteps represent the essential building blocks of manufacturing tasks. Each workingstep describes a single manufacturing operation using one cutting tool. An example of a Workingstep is the roughing operation of a pocket or the finishing operation of a region of a freeform surface. The detailed information of workingstep is referenced from the technology description.

A program structure is either a workplan or execution flow statements such as “parallel”, “if”, and “while”. A workplan combines several executables in a sequential or parallel order, or depending on given conditions if conditional controls are used.

The order of execution of manufacturing operations is given by the order of executables. In order to change the sequence of operations, only this part of the program file has to be changed. The remaining definitions of geometry and technology are untouched. Intelligent controls may be able to optimise execution ordering, and generate approach and lift movements while guaranteeing a collision-free operation.

Besides Workingsteps, other NC function statements may be included in the sequence of the part program. These include the setting of a workpiece coordinate system or security plane, and auxiliary commands such as program stop, optional stop, or pallet indexing. Workingsteps and NC-functions may appear with conditional statements so that they may depend on run-time conditions. The possible NC function statements are defined in ISO 14649-10.

5.6 Workingstep and machining operation

This part contains a detailed and complete definition of all Workingsteps used in the workplan. The technological description includes tool data, machine functions, machining strategies and other process data. Included in this description are a definition of the workpiece and all features of the finished part. The association between features and Workingsteps is given, i.e. which Workingsteps belong to which feature. A complete technology description includes but is not limited to cutting width and depth, spindle speed, feed, finishing allowance, and tool used.

The description of the tools includes the tool dimensions, tool type, and other data used to identify the usage and conditions of the tool. All tool data for milling is specified in ISO 14649-111.

The technology description will be fairly large for many applications, and is intended to be manipulated by computers. If a human operator intends to manipulate such data, he should be guided through a graphic user interface.

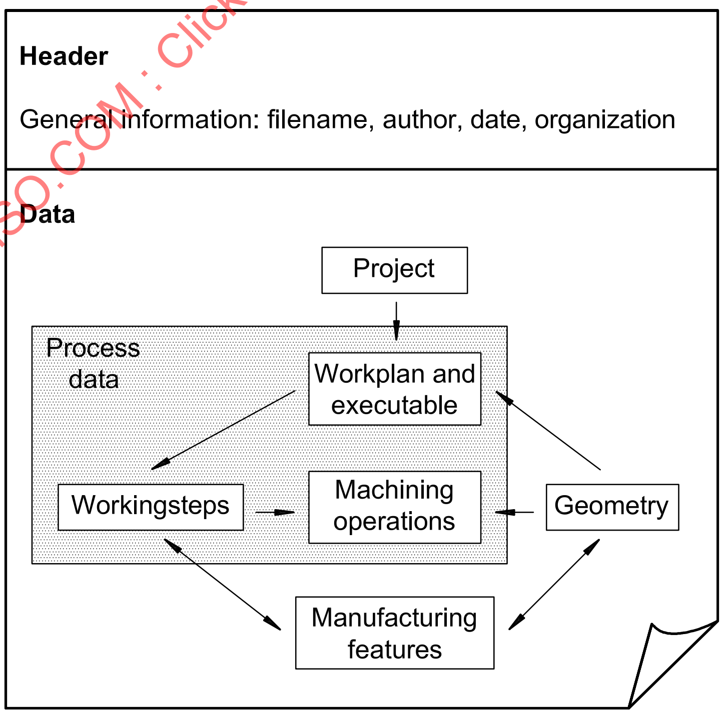


Figure 3 — Data structure of ISO 14649

5.7 Geometric description

CAD systems and CAM systems have standardized their exchange of product data, especially the geometry description, with ISO 10303 data (ISO 10303-21, -42, and -43). All geometrical data for workpieces and manufacturing features are described using this ISO 10303 data format. This data should also be used directly by the CNC to avoid conversions between different data formats that may result in reduced accuracy. To enable an understanding of the part program based on ISO 14649 data model, examples are given in Annex E of ISO 14649-11:2002.

5.8 Manufacturing feature description

ISO 10303-224 (and ISO 10303-214) defines manufacturing features that aid the development of a machining process plan, but which are not necessarily incorporated into the process plan that results. ISO 14649 takes this one step further and defines features that are referenced within the process plan. ISO 14649 features are mapped from those in ISO 10303-224 when features are assigned to the machine tool that will produce them. The relationship is determined between the placement of the manufacturing feature and the axis and tool spindle configuration of the machine.

Annex A shows in more detail and examples how features are used and their relationship.

5.9 Implementation of the program data file

There are two methods for implementing an ISO 14649 program data file. The first is the direct use of the program data in ISO 10303 Part 21 physical file format. With this method, CNC machines must be able to handle the ISO 14649 ARM (Application Reference Model) directly, that is, the EXPRESS models defined in ISO 14649-10, -11, and ISO 14649-111. The second method is to implement the program file using the ISO 10303 AP238 AIM (Application Interpreted Model), which is a mapping of the ARM into the ISO 10303 Integrated Resources. Using this method, data transfers between design, process planning, and CNC can be accomplished using ISO 10303 SDAI (Standard Data Access Interface) or EXPRESS-X queries with data formatted in XML according to ISO 10303-28.

Annex A
(informative)

Use and assignment of design features for machining geometry

In ISO 14649, features are used to describe the volumes to be removed by machining, to get the final form of the workpiece described by the design features in ISO 10303-224 and ISO 10303-214. This features are recognized by the CAD or 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 or 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. This is shown in Figures A.1 and A.2.

Figure A.3 shows how machining features or volume removal features may be generated nominally, derived from design features, or created temporarily. Temporary features may arise from relationships between design features and part dimensions, as conveniences to streamline machining. CAM features may also depend on the setups.

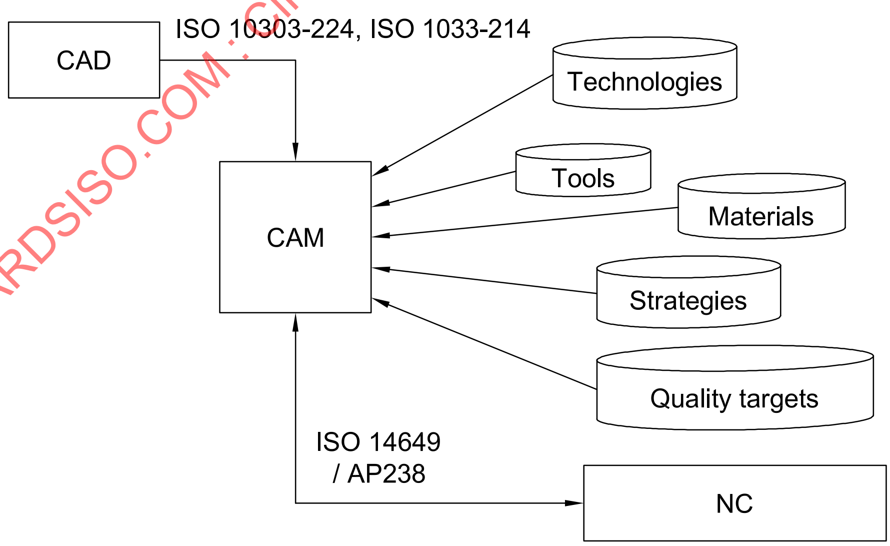


Figure A.1 — Design and process dataflow and associated standards

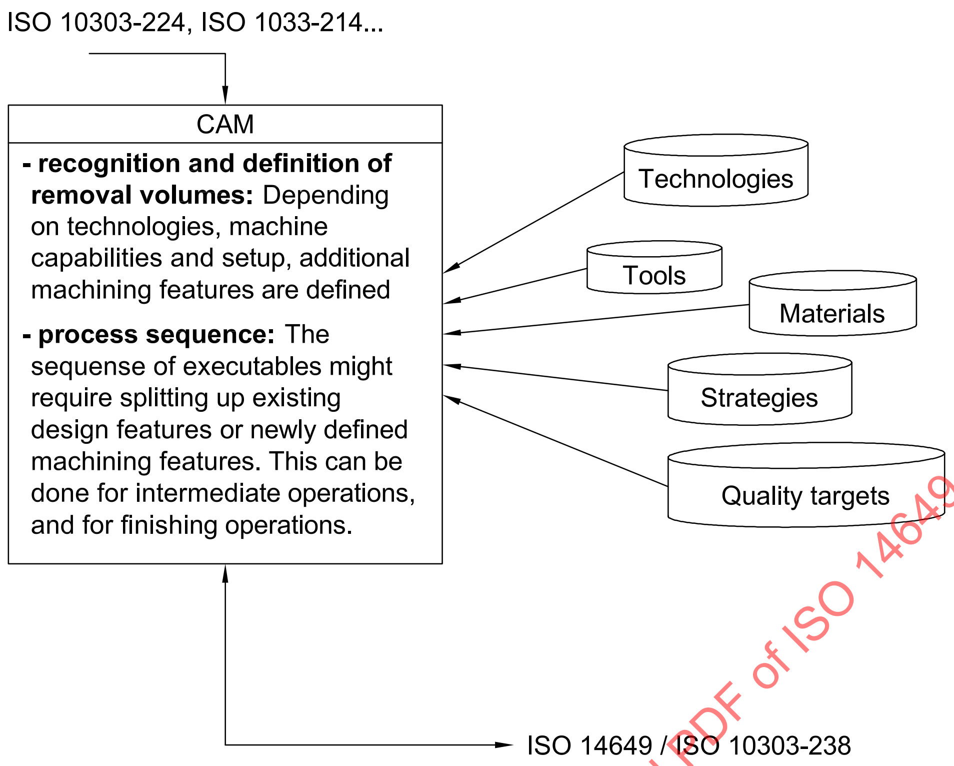
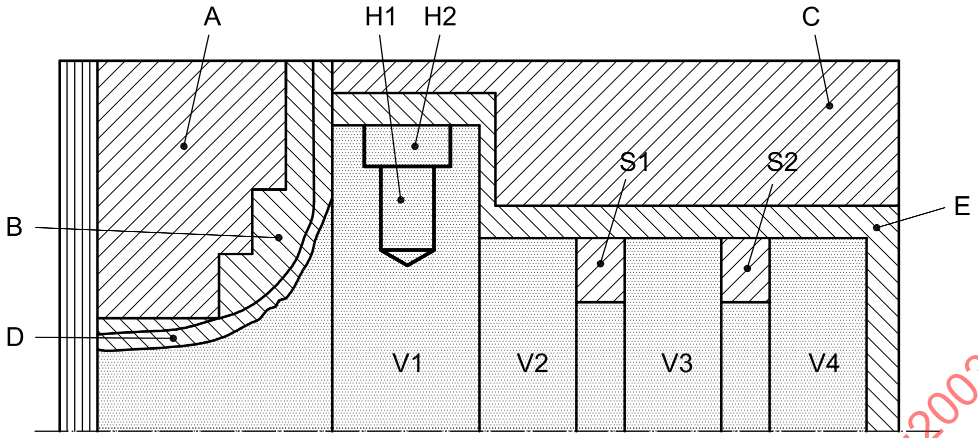


Figure A.2 — The role of the CAM- System in defining features and sequencing their machining



CAM-features depend on the setup

— Left set-up features “**A**”, “**B**”; “**D**”

— Right set-up features “**C**”, “**E**”, “**H1**”, “**H2**”, “**S1**”, “**S2**”

CAM-Features depend on the volume to be removed

— New roughing shape **A** defined in CAM.

— New roughing shape **C** defined in CAM.

— Roughing of **B** can be based on the underlying design feature**.**

— For Finishing **D,** the equivalent design feature can be used.

— Instead of using four single elements for finishing the right setup, based on V1 to V4, only one element “**E**” is used for finishing. For this in CAM the additional element **E** is defined.

CAM-features depend on the design-features

— To realize the features H1, H2, and S1, S2, their equivalent design-features are directly referenced.

Figure A.3 — Example to show the combination and relation of features used for machining

Annex B
(informative)

Application Activity Model (AAM)

The ISO 14649 Application Activity Model (AAM) describes the relationships between the design, programming, and manufacturing activities in which the standard plays a part. The AAM is informative, not normative. It represents the typical activities assumed by ISO 14649 and shows how this ISO 14649 fits within these typical activities, but does not prescribe these activities.

The AAM uses IDEF-0 nomenclature to represent these activities. A legend for reading IDEF-0 figures is shown in Figure B.1.

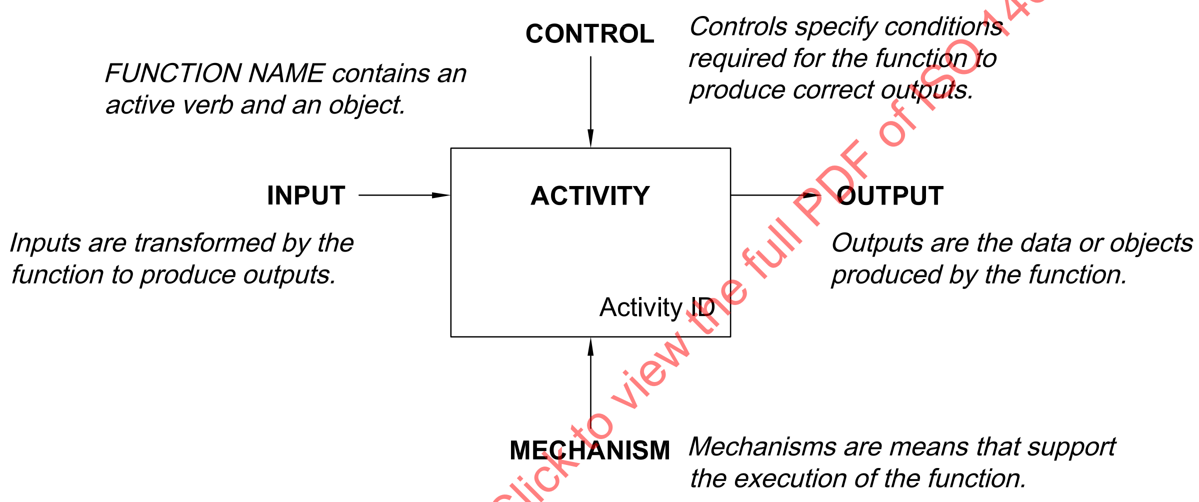


Figure B.1 — IDEF-0 Functional blocks

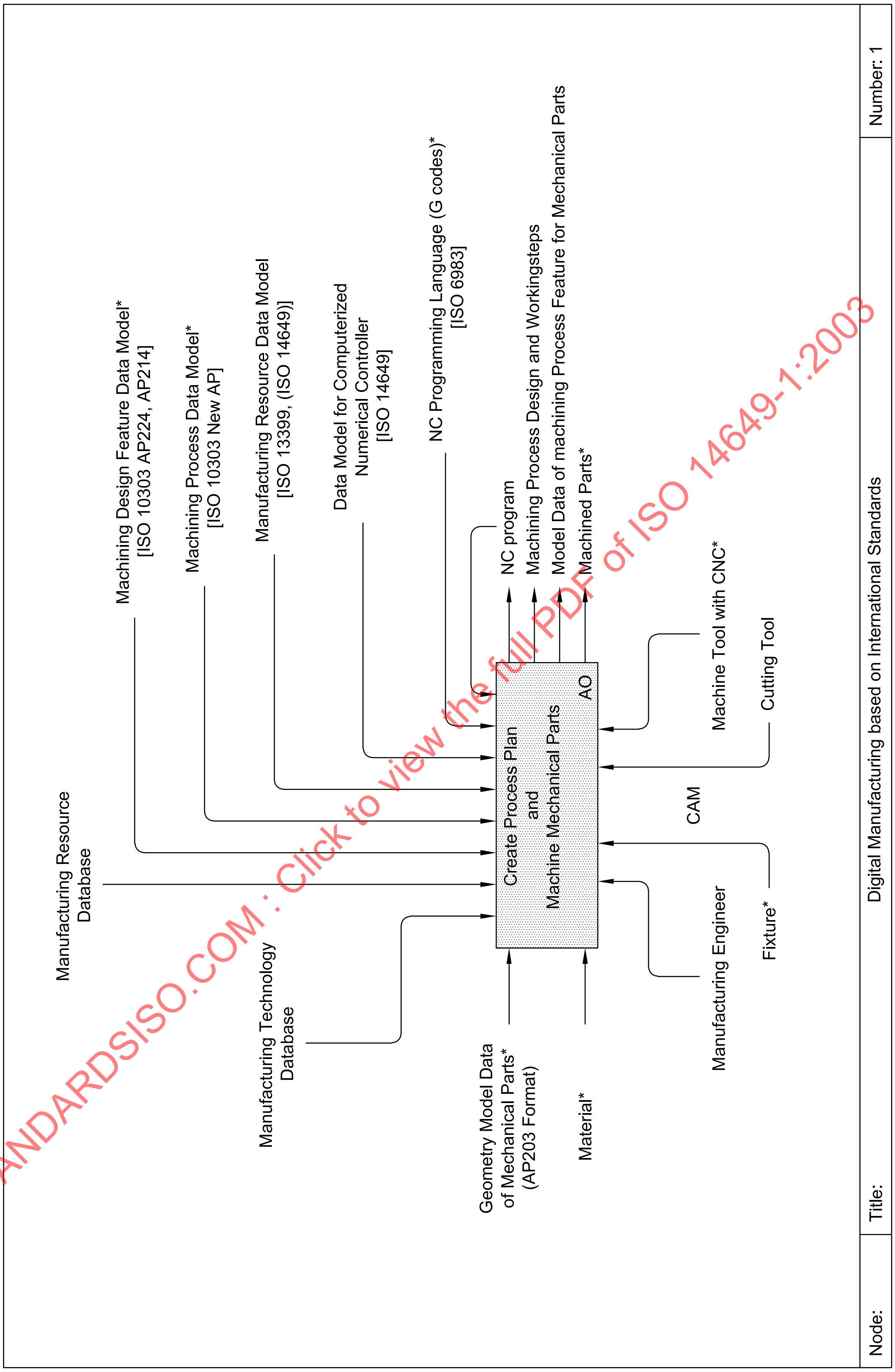


Figure B.2 — Application Activity — Model Overview

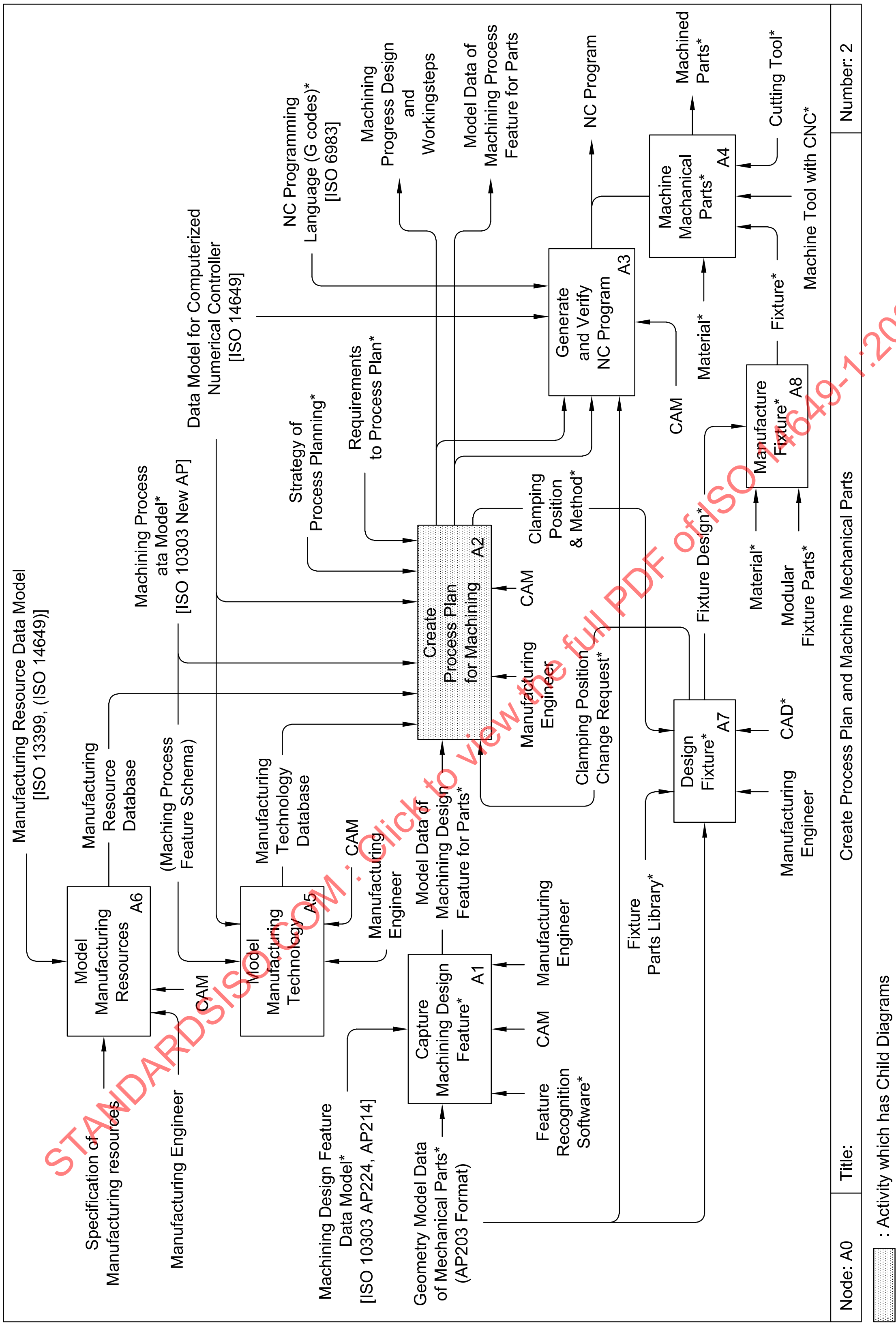


Figure B.3 — Design Process Planning

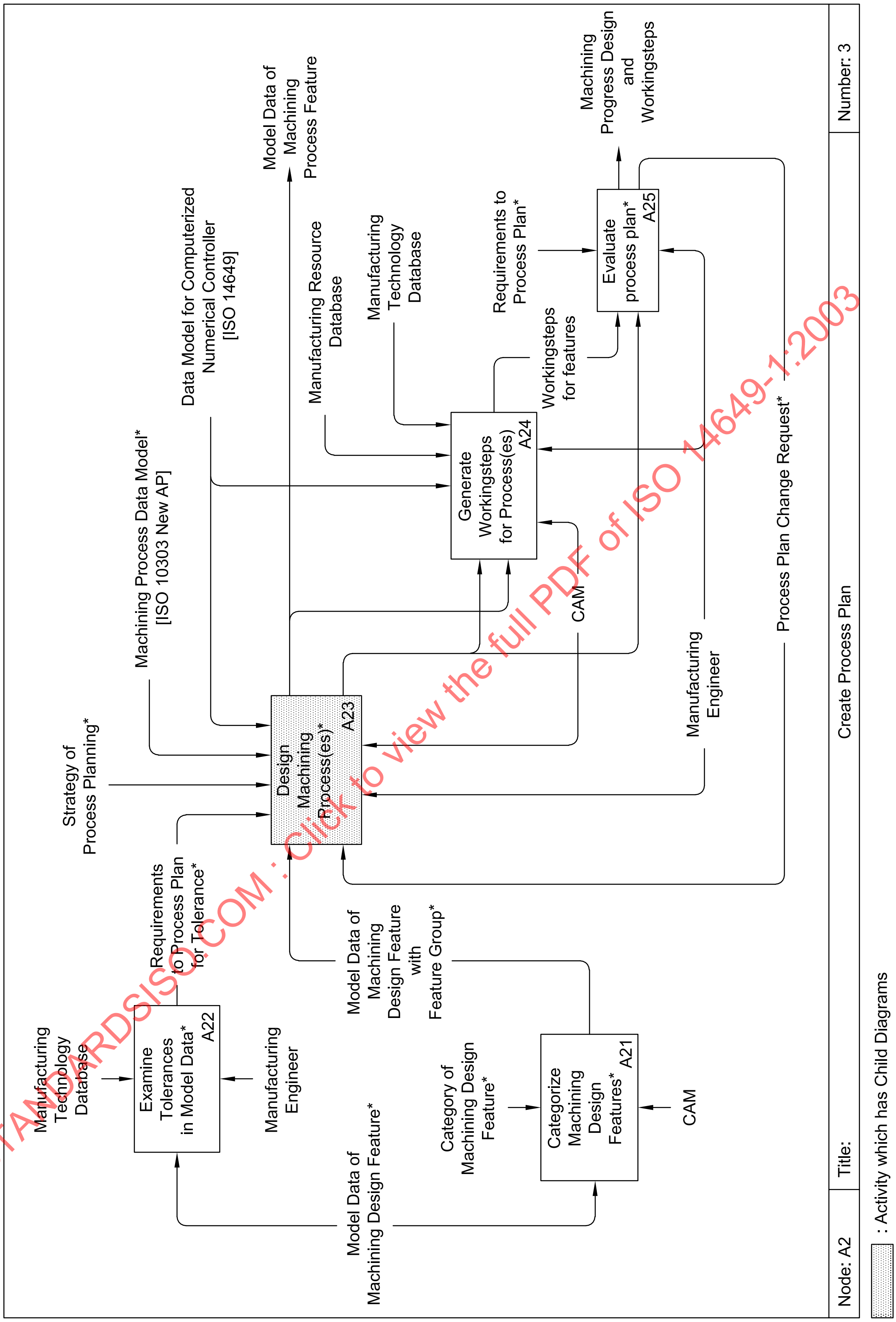


Figure B.4 — Plan Machining Processes

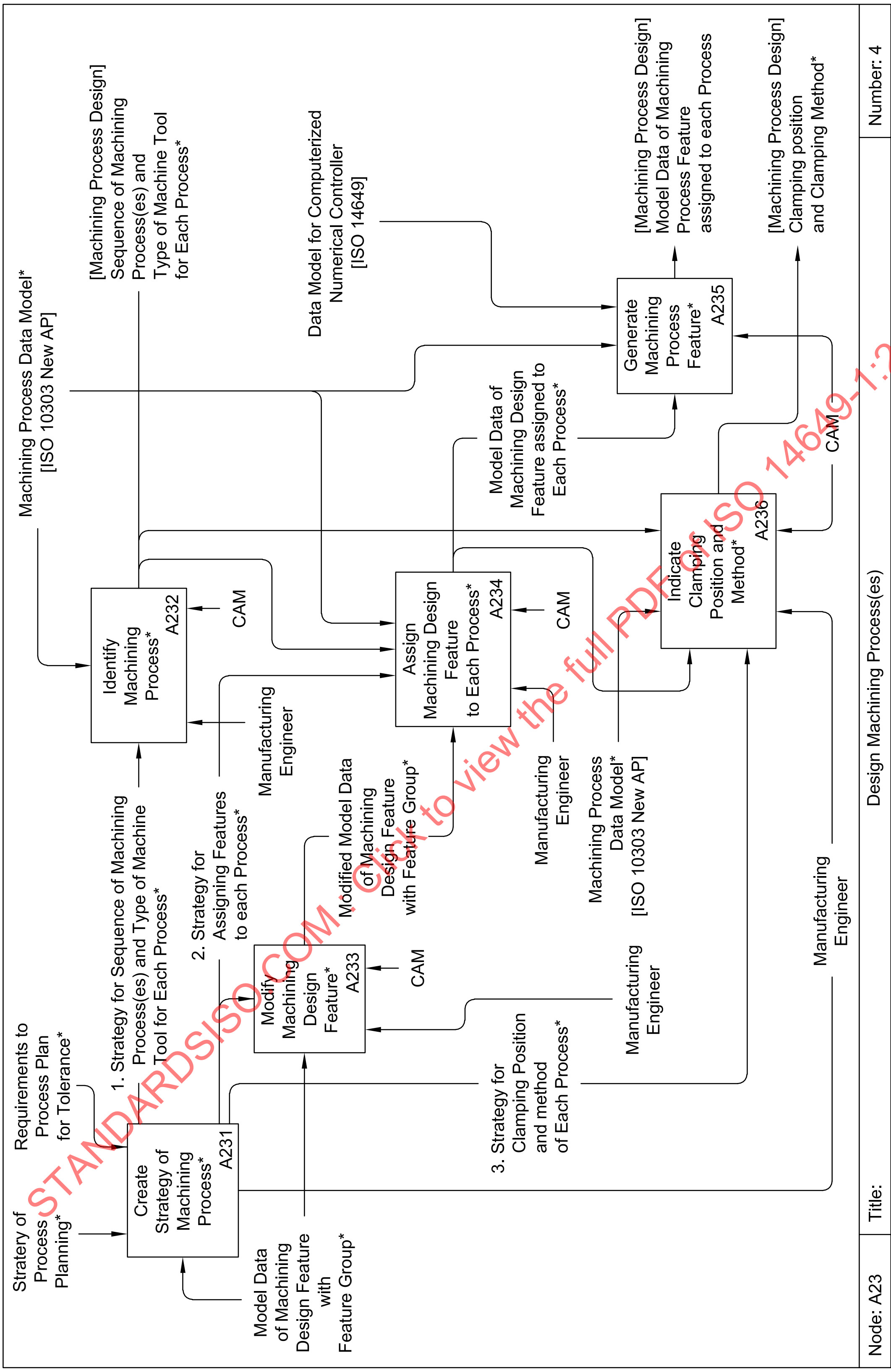


Figure B.5 — Design Machining Operations

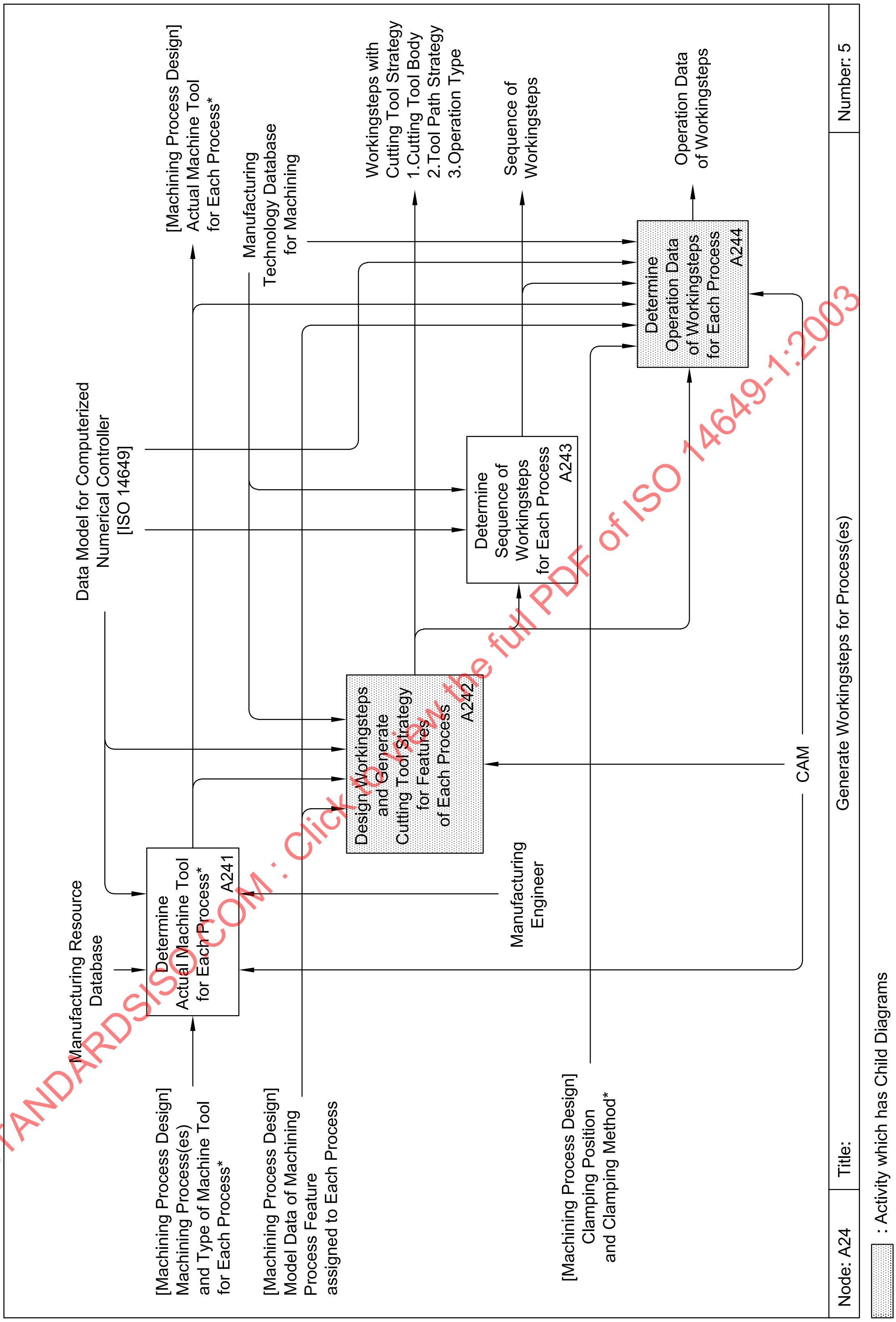


Figure B.6 — Generation of Workingsteps

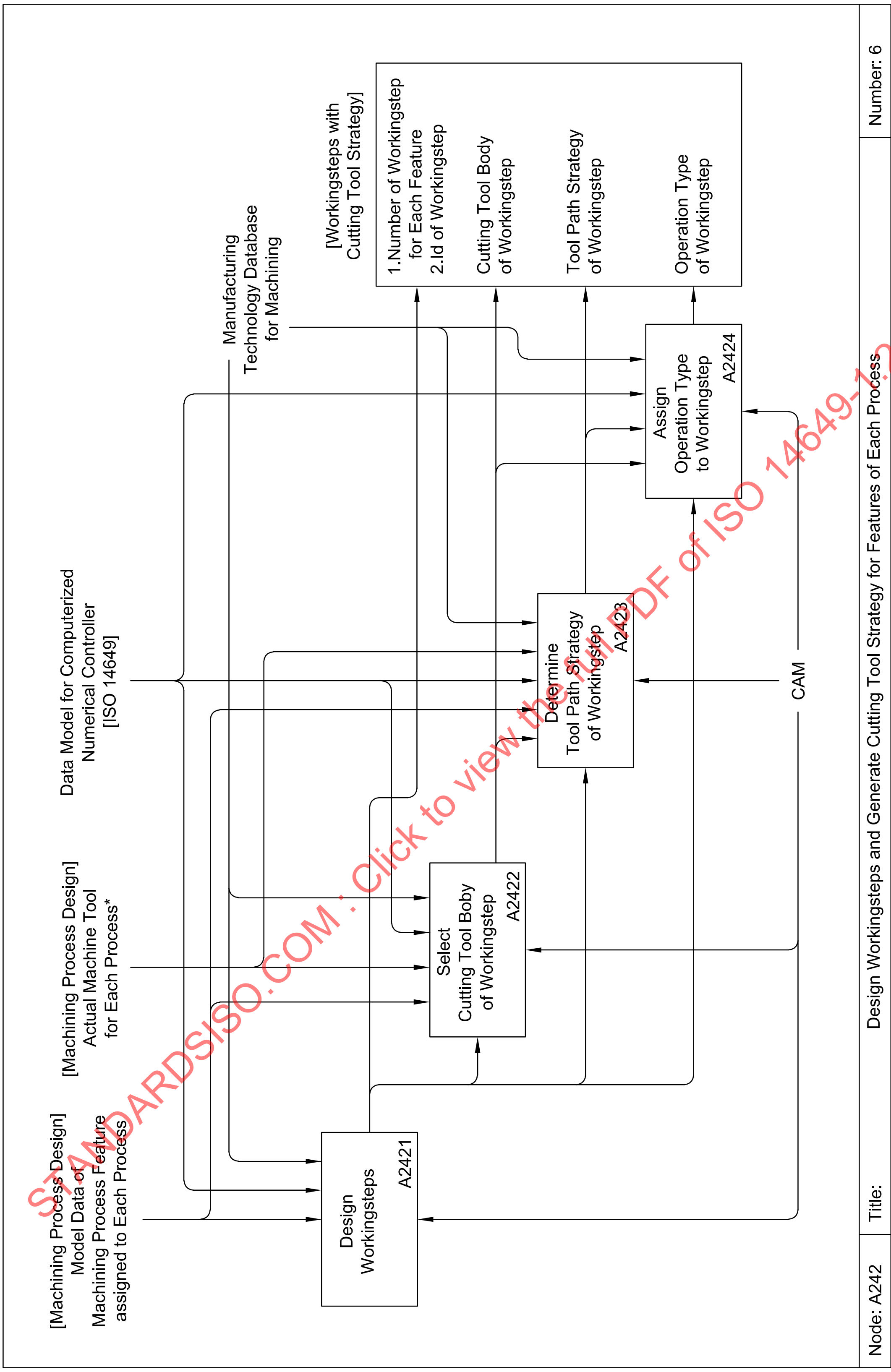


Figure B.7 — Design of Strategies

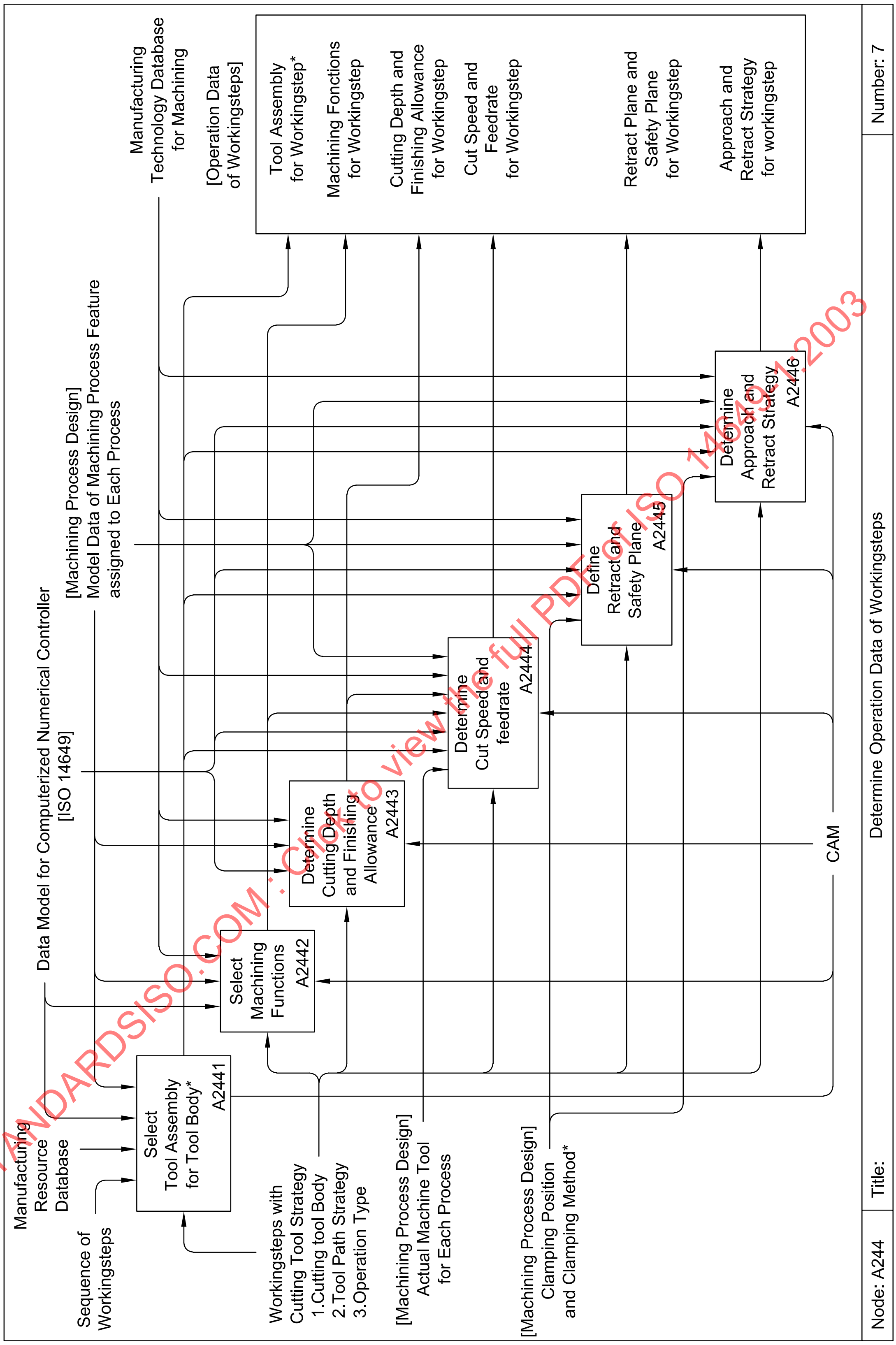


Figure B.8 — Detail Planning of Machining Operations

Annex C
(informative)

Structure of ISO 14649 data model

An overview of the ISO 14649 data model structure is shown in Figure C.1. This diagram is a summary of the exact EXPRESS_G diagram.

ISO 14649 allows also the direct control of axis motions using a Toolpath, which is an attribute of Machining_operation.

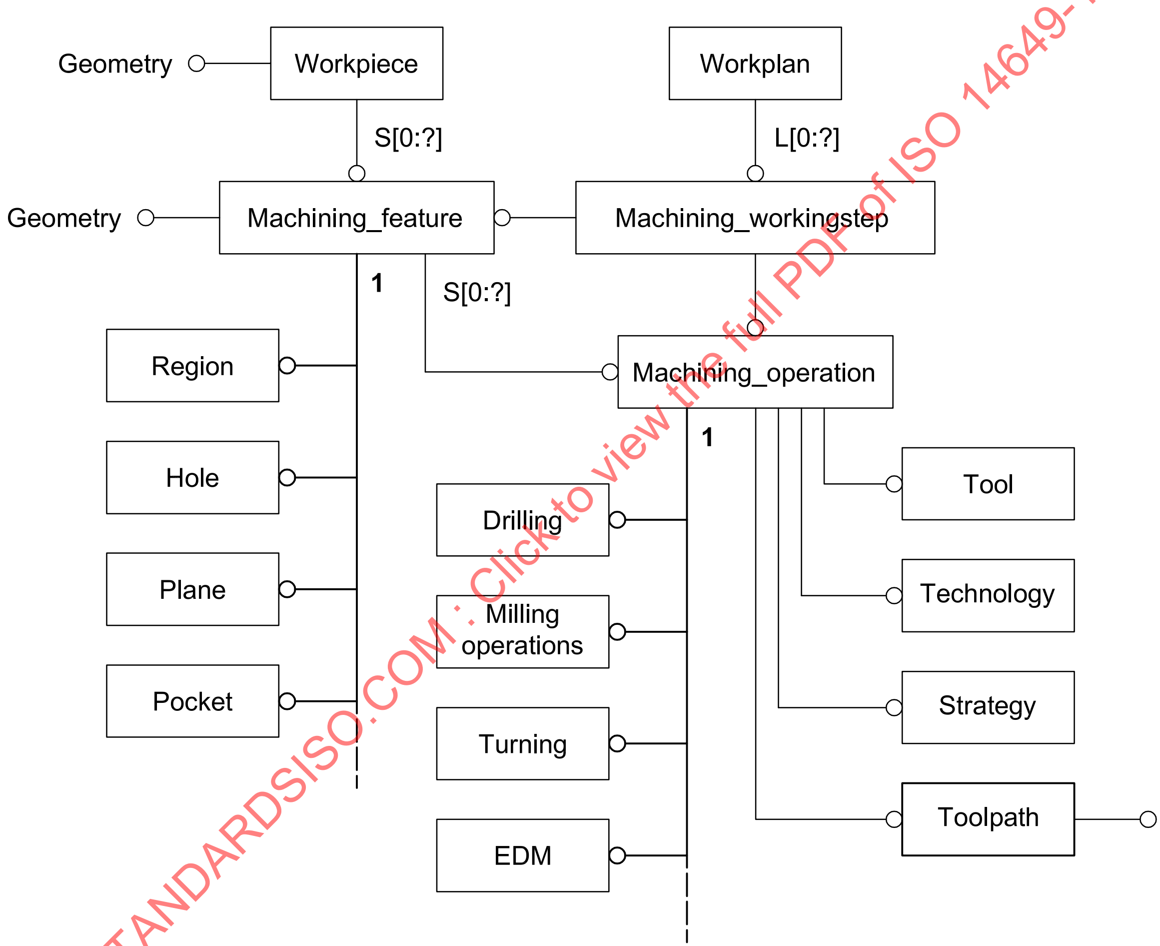


Figure C.1 — Overview of ISO 14649 data model structure

Annex D
(informative)

Relationship between ISO 14649 and ISO 10303 (STEP)

D.1 General

Both the feature description and the model structures in ISO 14649 are harmonized with ISO 10303.These harmonization's will likely result in future revisions to ISO 14649.

Figure D.1 shows the shares of activities and responsibilities between ISO 14649 and ISO 10303 (STEP).

The data models within ISO 14649 are organized into levels

D.2 Levels for activities and responsibilities

Cooperation between SC 1 and SC 4 in ISO/TC 184 is organized into levels that define activities and responsibilities, as shown in Figure 1.

Level A deals with the modeling of the manufacturing technologies in the Application Reference Models (ARMs) with a precise description in EXPRESS schemas. Level A is the responsibility of ISO/TC184/SC 1/WG 7. Each machining technology will be covered by an individual model in a specific part. General process data valid for all technologies are included in the generic ISO 14649-10.

Level B deals with integration and compatibility in a ISO 10303 environment, based on the Application Interpreted Models (AIMs) that map the ARMs to the set of ISO 10303 integrated resources. Level B is the responsibility of ISO/TC 184/SC 4. For each machining technology a specific AP (Application Protocol, final numbering assigned by SC 4) will be developed. Each AP will contain the relevant General Process Data and the conformance testing as ruled by SC 4.

Level B covers also the data exchange and compatibility needs. Based on actual STEP standards, different data formats can be used in the data bases and to transfer exchangeable data to the CNC controllers, such as ISO 10303-21, ISO 10303 SDAI Database and the most actual and advanced ISO 10303 Data Server with EXPRESS-X queries and data formatted in XML (ISO 10303-28).

Level C deals with adoption software, which is the implementation of Level A or B in controllers. CNC manufacturers or third parties are responsible for implementing Level C. Until the execution of workingsteps and their linear or conditional sequencing is supported by the basic resources of ISO 10303, this will be done with individual adoption software in Level C. Implementation depends on the used interchangeable data formats, mentioned under Level B. The direct implementation from Level A, based on EXPRESS Tools is only intended for first prototyping and testing of the model. It will be replaced by one of the methods of level B when this parts of ISO 14649 will be available.

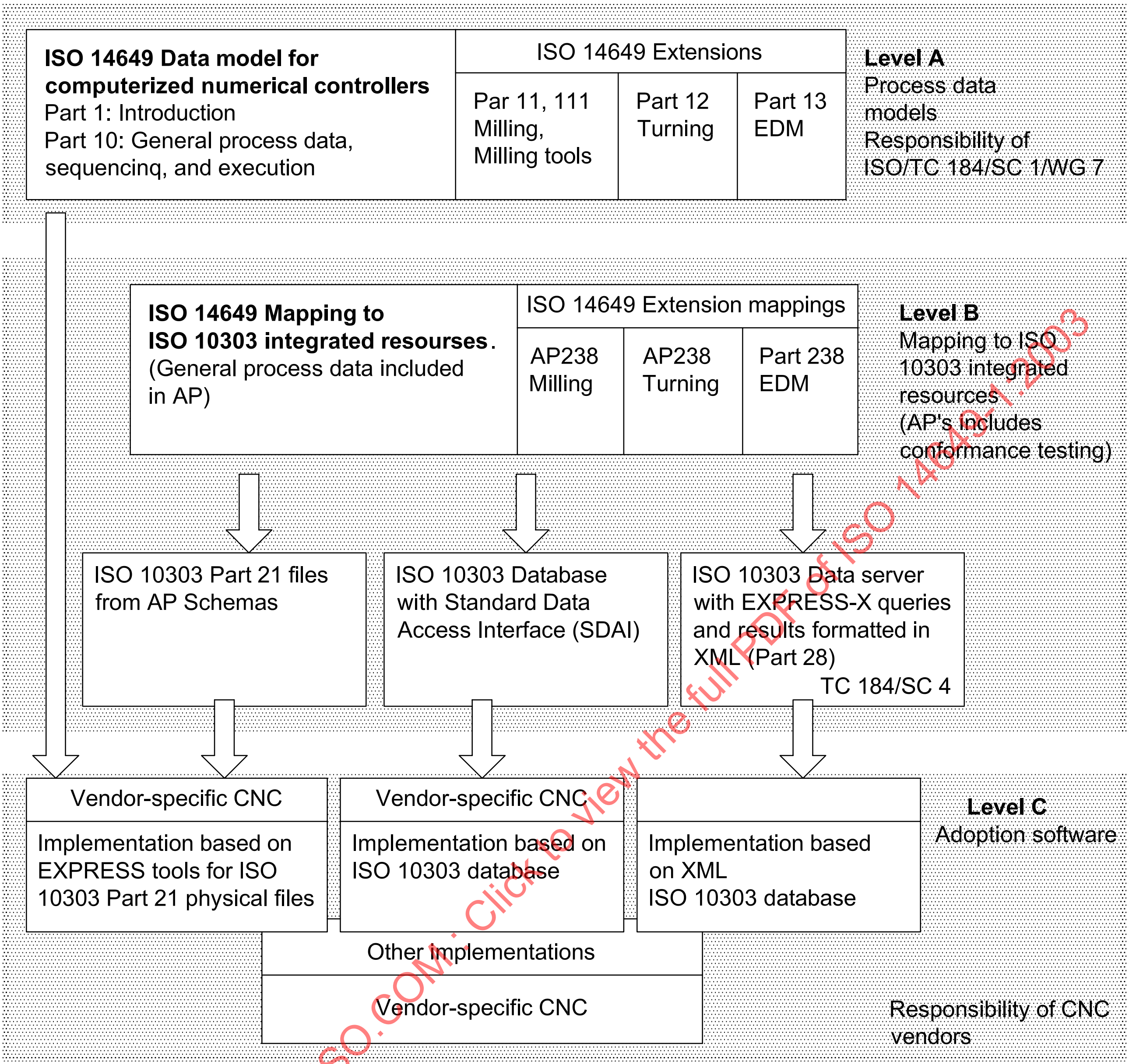


Figure D.1 — Distribution of activities and responsibilities between ISO/TC 184 SC 1 and SC 4

D.3 Publishing phases

The publishing of ISO 14649 will be done in three phases.

Phase 1 includes Part 1, "Overview and fundamental principles," with the Application Activity Model (AAM) and a scenario as informative annexes; ISO 14649-10, "General Process Data," which contains the Application Reference Model (ARM) for process-independent technology data and executables for linear and conditional sequencing; and ISO 14649-11 and ISO 14649-111, "Process Data for Milling," and "Tools for Milling," which contain the ARMs for milling process data and milling tools, with examples as annexes.

Phase 2 includes the AIM schemas corresponding to Parts 10 and 11 and the Application Protocol's for the milling technology.