INTERNATIONAL STANDARD

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Industrial automation systems and integration — Manufacturing software capability profiling for interoperability —

Part 1: **Framework**

Systèmes d'automatisation industrielle et intégration — Profil d'aptitude du logiciel de fabrication pour interopérabilité —

Partie 1: Cadre

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Foreword

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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 16100 was prepared by Technical Committee ISO/TC 184, *Industrial automation systems and integration*, Subcommittee SC 5, *Architecture, communications and integration frameworks.*

ISO 16100 consists of the following parts, under the general title *Industrial automation systems and integration — Manufacturing software capability profiling for interoperability*:

— *Part 1: Framework*

— *Part 2: Profiling methodology*

— *Part 3: Interface protocols and templates*

— *Part 4: Conformance test methods, criteria and reports*

Introduction

The motivation for ISO 16100 stems from the industrial and economic environment noted by ISO/TC 184/SC5. In particular, there is broad recognition by industry that application software and the expertise to apply that software are assets of the enterprise. Industry feedback has noted the need for improvement and continued development of current design and manufacturing standards to enable software interoperability.

ISO 16100 specifies a manufacturing information model that characterizes software-interfacing requirements. With interfacing requirements clearly expressed, standard interfaces can be more easily and quickly developed using the Interface Definition Language (IDL) or an appropriate programming language, such as Java and C++. These standard interfaces are expected to enable the interoperability among manufacturing software tools (modules or systems).

The Unified Modelling Language (UML) is used in this International Standard for modelling these interfaces. Also, the manufacturing information model can be used to develop commonly sharable database schema using languages such as the eXtensible Markup Language (XML).

Sectors of the manufacturing industry — such as automotive, aerospace, machine tool manufacturing, computer peripheral manufacturing, and mold and die manufacturing — that intensively use computer-aided design (CAD), computer-aided manufacturing (CAM), numerical control (NC) programming, computer-aided engineering (CAE), product data management (PDM), and manufacturing execution systems (MES) will directly benefit from ISO 16100. The software interface requirements in ISO 16100 will facilitate the development of:

a) interoperable design and manufacturing software tools leading to shortened product development time;

b) new software tools that can be easily integrated with current technologies leading to more choices in the market;

c) new application software leading to reduced capital expenditures to replace legacy systems;

d) programming interfaces and database schema leading to cost savings by not having to develop proprietary interfaces for point-to-point software integration.

The end result will be a reduction in product and manufacturing information management cost and lower product costs.

ISO 16100 enables manufacturing software integration by providing the following :

a) standard interface specifications that allow information exchange among software units in industrial automation systems developed by different vendors;

b) software capability profiling, using a standardized method to enable users to select software units that meet their functional requirements;

c) conformance tests that ensure the integrity of the software integration.

ISO 16100 consists of four parts. Part 1 specifies a framework for interoperability of a set of manufacturing software products used in the manufacturing domain and its integration into a manufacturing application. Part 2 specifies a methodology for constructing profiles of manufacturing software capabilities, and includes a methodology for creating manufacturing software capability profiles as well as for using these profiles at the developing stage of manufacturing applications. Part 3 specifies the interface protocol and templates for various manufacturing application areas. Part 4 specifies the concepts and rules for the conformity assessment of the other parts of ISO 16100.

Industrial automation systems and integration — Manufacturing software capability profiling for interoperability —

Part 1:
Framework

1 Scope

Part 1 of ISO 16100 specifies a framework for the interoperability of a set of software products used in the manufacturing domain and to facilitate its integration into a manufacturing application (see Annex A for a discussion of a manufacturing application). This framework addresses information exchange models, software object models, interfaces, services, protocols, capability profiles, and conformance test methods.

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 15704, *Industrial automation systems — Requirements for enterprise-reference architectures and methodologies*

ISO 15745-1, *Industrial automation systems and integration — Open systems application integration framework — Part 1: Generic reference description*

ISO/IEC 19501-1, *Information technology — Unified Modelling Language (UML) — Part 1: Specification*

IEC 62264-1, *Enterprise-Control System Integration — Part 1: Models and Terminology*

IEEE 1320.1-1998, *Standard for Functional Modelling Language — Syntax and Semantics for IDEF0*

W3C Recommendation Feb 1998, *Extensible Markup Language (XML) 1.0*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply. Other relevant terms are defined in Annex D.

3.1
advanced planning
production planning over time horizons of months or years using constraint models that treat both materials and capacity

NOTE In some cases, the planning system includes master production scheduling, material requirements planning, or capacity planning.

3.2
CAD/PDM
computer systems that are used for product design and modelling, engineering, product data management, and process data management

3.3
capability
<software> set of functions and services with a set of criteria for evaluating the performance of a capability provider

NOTE This definition differs from that given in ISO 15531-1 and ISO/DIS 19439, where capability is defined as the quality of being able to perform a given activity. See IEC 62264-1 for a general definition of capability.

3.4
capability profiling
selection of a set of offered services defined by a particular interface within a software interoperability framework

3.5
CAPP/CAM
computer systems that are used for process planning and programming of numerically controlled machines

3.6
controller
<digital systems> hybrid hardware/software systems that are used for controlling machines

EXAMPLES Distributed control systems (DCS), programmable logic controllers (PLC), numerical controller (NC), and supervisory control and data acquisition (SCADA) systems.

3.7
data collection
gathering of information on workpieces, timing, personnel, lots, and other critical entities for production management in a timely manner

3.8
design knowledge
rules and logic that a human designer brings to bear on design problems, including design and implementation techniques

NOTE Many different types of design knowledge are used in different design activities, such as decomposition knowledge, assignment knowledge, consolidation knowledge, and optimization knowledge.

3.9
design pattern
medium-scale patterns, smaller in scale than architectural patterns, but are at a higher level than the programming language-specific idioms[1)]

NOTE The application of a design pattern has no effect on the fundamental structure of a software system, but may have a strong influence on the architecture of a subsystem.

3.10
manufacturing software
type of software resource within an automation system that provides value to a manufacturing application (e.g. CAD/PDM) by enabling the flow of control and information among the automation system components involved in the manufacturing processes, between these components and other enterprise resources, and between enterprises in a supply chain or demand chain

3.11
manufacturing software component
class of manufacturing software resource intended to support the execution of a particular manufacturing task

1) Taken from *Pattern-oriented Software Architecture*, John Wiley & Sons, June 2000.

3.12
manufacturing software unit
class of software resource, consisting of one or more manufacturing software components, performing a definite function or role within a manufacturing activity while supporting a common information exchange mechanism with other units

NOTE A software unit can be modeled using UML as a software object.

3.13
manufacturing system
system coordinated by a particular information model to support the execution and control of manufacturing processes involving the flow of information, material, and energy in a manufacturing plant

3.14
manufacturing software capability
set of manufacturing software functions and services against a set of criteria for evaluating performance under a given set of manufacturing conditions

NOTE See Annex C for use cases and related scenarios involving manufacturing software capability.

3.15
manufacturing software capability profile
concise representation of a manufacturing software capability to meet a requirement of a manufacturing application

3.16
software architecture
fundamental organization of a software system embodied in its components, their relationships to each other and to the environment, and the principles guiding its design and evolution

[IEEE 1471-2000]

3.17
software environment
other manufacturing resources within the computing system that affect the operational aspects of the manufacturing software unit

NOTE The software environment can include other systems that interact with the system of interest, either directly via interfaces or indirectly in other ways. The environment determines the boundaries that define the scope of the system of interest relative to other systems.

3.18
supply chain planning
usage of information technology to address planning and logistics problems at different levels and granularities of detail using models for a product line, a production plant, or a full chain of multiple demand sources, suppliers, production plants, and distribution means

NOTE Supply chain planning can be used to synchronize production, balancing constraints based on goals including on-time delivery, minimal inventory, and maximum profit.

4 Abbreviations

AGV Automatic Guided Vehicle

APT Automated Programmed Tool

BOM Bill of Materials

CAD Computer Aided Design

CAM Computer Aided Manufacturing

CAPP Computer Aided Process Planning

ERP Enterprise Resource Planning

MES Manufacturing Execution System

NC Numerical Control

PDM Product Data Management

SCM Supply Chain Management

SCADA Supervisory Control and Data Acquisition

SQC Statistical Quality control

XML eXtensible Markup Language

UML Unified Modelling Language

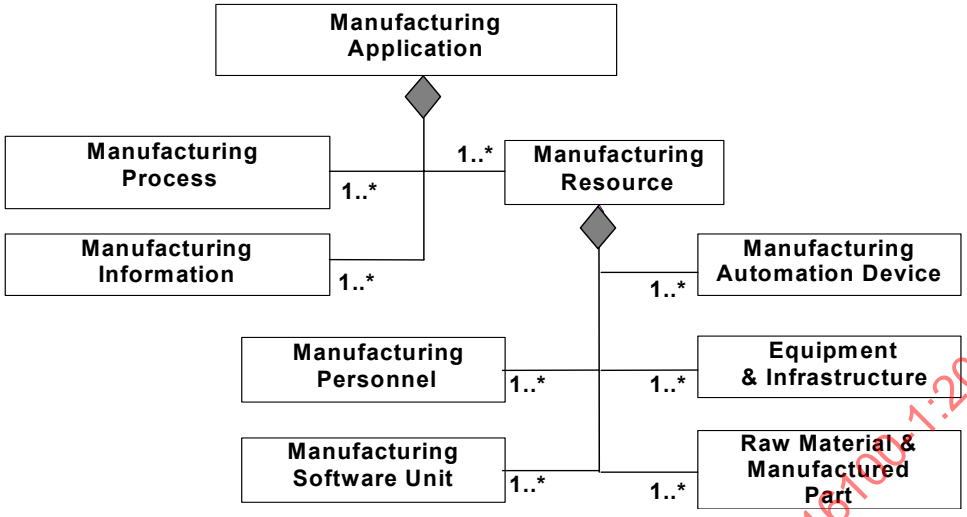
5 Manufacturing application

5.1 Reference application framework

The interoperability framework for manufacturing software is based upon a more general interoperability framework for manufacturing applications. Such an application interoperability framework, which is explained in further detail in ISO 15745-1, provides a basis for integrating an automation and control system architecture within a manufacturing application architecture.

An integrated manufacturing application shall be modeled as a combination of a set of manufacturing resources and a set of information units whose data structure, semantics, and behaviour can be shared and exchanged among the manufacturing resources, as shown in Figure 1. Manufacturing resources are communication networks, devices, software, equipment, material, and personnel necessary to support the processes and information exchanges required by the application.

In this application integration model, the various elements of the model have shared interfaces and exchange material, energy, and information in a cooperative and coordinated manner. The manufacturing processes can cooperate with each other if the functions performed by the various elements of the model can interoperate with each other. When software units perform some of these functions, it is necessary for the software units to be interoperable with the other elements, as well as with each other.



NOTE Boxes represent classes of objects (things). Lines connecting boxes represent associations between objects (things). An association has two roles (one in each direction). A role may optionally be named by a label. A role from A to B is closest to B, and vice versa. Roles are one-to-one unless otherwise noted. A role can have a multiplicity, e.g. a role marked with "1..*" is used to denote *many* as in a one-to-many or many-to-many association. A diamond at the end of an association line denotes a *part-of* relationship. A black diamond at the end of an association line denotes a *composition aggregation* relationship. For example, Manufacturing Application owns (is comprised of) Manufacturing Process, Manufacturing Information, and Manufacturing Resources. This notation is taken from ISO/IEC 19501-1.

Figure 1 — Class diagram of a partial model of a manufacturing application

5.2 Manufacturing domain

The manufacturing domain that includes discrete, batch, and continuous control encompasses many types of industries. The automotive industry is an example of an industry employing discrete control; the pharmaceutical industry is an example of an industry employing batch control; the petrochemical industry is an example of an industry employing continuous control. For manufacturing software, the interface between plant management systems and floor control systems is described by the same method regardless of whether control systems are discrete, batch, or continuous. Similarly, the control flow inside a control system is also described by the same method regardless of whether the system is discrete, batch, or continuous.

Even as the manufacturing domain applies to many industries, the relationship between firms in these industries is changing rapidly due to recent developments in IT infrastructure, as is the case in supply chain management systems. Therefore, ISO 16100 sets a target manufacturing domain to include the manufacturing operation and control activity, the discrete control activity, the batch control activity, the continuous control activity, and the manufacturing process design activity, as shown in Figure 2.

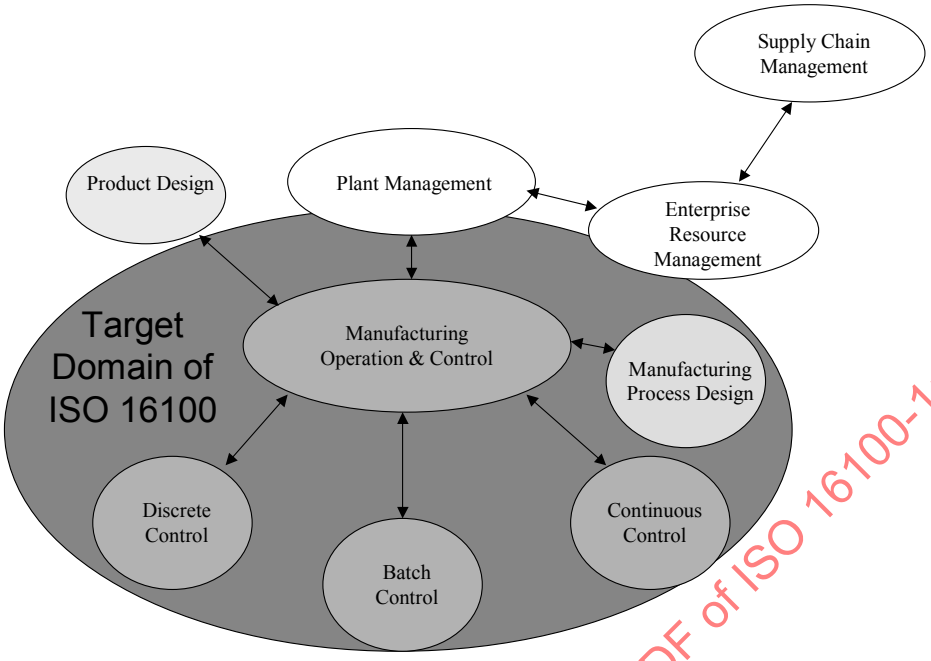


Figure 2 — Target domain of ISO 16100

5.3 Manufacturing processes

A manufacturing process shall be modeled as a set of activities that follow a specific sequence. Each activity shall be associated with a set of functions performed according to a time schedule or triggered by a set of events.

The functions associated with a manufacturing process shall be viewed as being implemented through a set of manufacturing resources. The manufacturing resources shall be considered to be selected and configured to support the material, information, and energy flows required by the specified sequence of manufacturing activities associated with a process.

When a manufacturing process must cooperate and coordinate with another process, the respective functions of these interacting processes are considered to be able to cooperate and coordinate with each other. Such a situation requires that the cooperating and coordinating functions meet a common set of criteria and a set of conditions for interoperability. The software units that implement these functions shall meet a related set of criteria and conditions for interoperability.

5.4 Manufacturing resources

The manufacturing resources required by a manufacturing application shall be organized in terms of the type of flow being managed and supported among the manufacturing processes — material, control, information, or energy flow. The set of integrated flows can be used to represent an integrated manufacturing application or manufacturing system architecture.

The set of integrated manufacturing resources shall form a manufacturing system architecture that fulfills a set of manufacturing application requirements. These manufacturing resources, including the manufacturing software units, shall provide the functions associated with the manufacturing processes.

The combined capabilities of the various software units, in an appropriate operating environment, provides the required functionality to control and monitor the manufacturing processes according to the production plan and the allocated resources.

An operating environment shall be distinguished by the manufacturing resources needed by the associated set of software units. These manufacturing resources include the processing, storage, user interface, communications, and peripheral devices, as well as other system software required for executing the software units.

5.5 Manufacturing information

A set of information structures shall provide the knowledge infrastructure to manage the various types of flows within a manufacturing application. These information sets shall include data pertaining to the product, the process, and the equipment.

The manufacturing software units shall be the primary means for handling, transforming, and maintaining these information structures.

6 Manufacturing software interoperability framework

6.1 Manufacturing software unit interoperability

Within a context of a manufacturing application, a manufacturing software unit is considered to be capable of performing a specific set of functions defined by a manufacturing system architecture. In performing these sets of functions, the manufacturing software unit is cooperating and conducting transactions with other manufacturing software units.

The functions performed by each software unit shall be those as described by the manufacturing application architecture. The information exchanged between these software units shall enable the coordinated execution of these manufacturing functions.

The software interoperability of a set of manufacturing activities shall be described in terms of the interoperability of the set of software units associated with each manufacturing activity.

A software interoperability framework consists of a set of elements and rules for describing the capability of software units to support the requirements of a manufacturing application. The capability to support the requirements shall cover the ability of the software unit to execute and to exchange data with other software units operating in the same manufacturing system or in different manufacturing systems used in the application.

A software interoperability framework shall be based on the following aspects:

a) syntax and semantics shared between manufacturing software units;

b) functional relationships between the manufacturing software units;

c) services, interfaces, and protocols offered by the manufacturing software units;

d) ability to provide manufacturing software unit capability profiling.

The framework elements shall consist of the roles, the activities, and the artifacts associated with the software entities when dealing with the manufacturing process, information, and resources. The framework rules shall address the relationships, templates, and conformance statements needed to construct a capability class (see ISO 16100-2), a profile class (see ISO 16100-2), and a component class (see ISO 16100-3).

The organization, relationships, and tasks pertaining to the software unit and its manufacturing software components shall be expressed in terms of the framework elements and rules in ISO 16100-3.

Figure 3 shows the relationships between the aspects of the software interoperability framework and the derivation of this framework from a generic application interoperability framework.

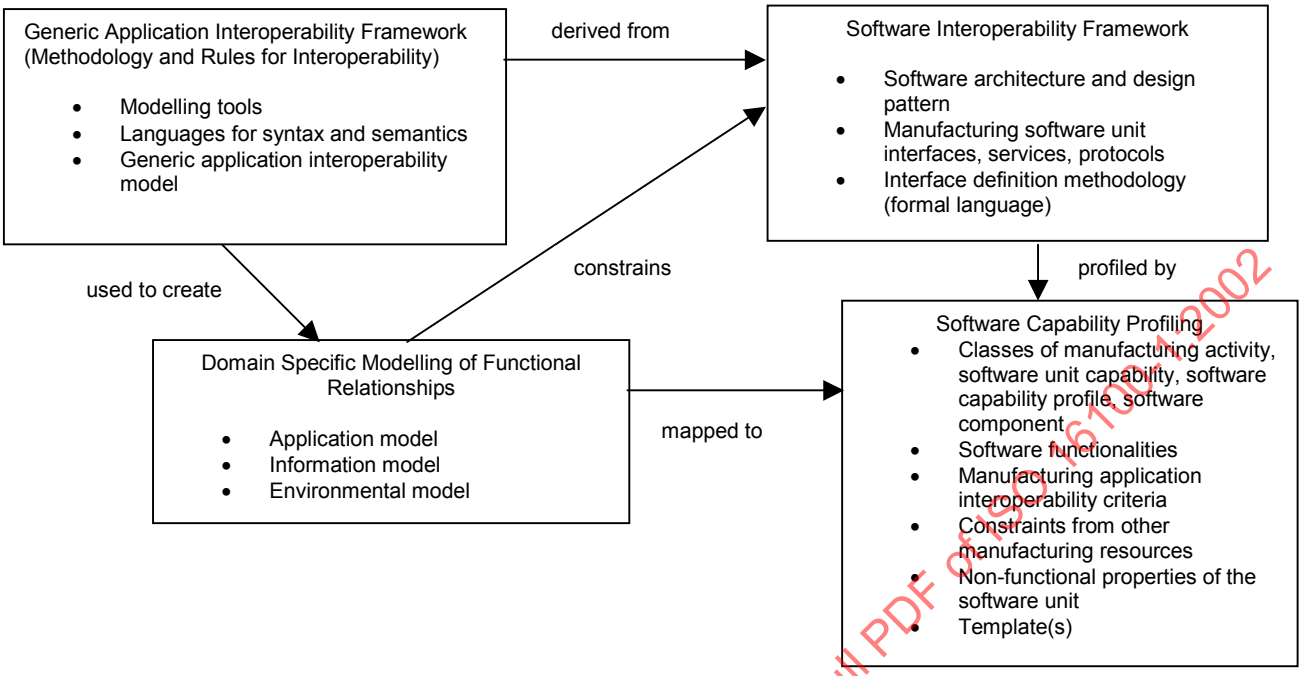


Figure 3 — Relationships of software interoperability aspects

6.2 Functional relationships between the manufacturing software units

Within the manufacturing domain shown in Figure 2, there can be one or more operational software units that cooperate through a specific interface/protocol to perform a single manufacturing function required in that domain. This is realized in the software environment of a specific computing system as one of the components of the manufacturing resources, enabled by a specific software design pattern performing a specific role. Conversely, a single software unit can perform one or more manufacturing functions. One or more manufacturing functions can interoperate with each other to execute, control, monitor, or manage a particular manufacturing activity. A series of activities can be conducted in a particular sequence to complete a manufacturing process. Figure 4 depicts the classes of a software unit and its surroundings and associations.

In this framework, the sequence and schedule of functions performed is determined by the sequence and schedule of the activities that comprise a particular process. The manufacturing software units deployed to perform the functions are considered to execute according to the required sequence and schedule of their associated functions.

The interoperability of the manufacturing processes shall be viewed in terms of the interoperability of the functions, which in turn shall be viewed in terms of the interoperability of the manufacturing resources, including the manufacturing software units. Examples of information flow among design, manufacturing planning, and execution activities are provided in Annex B.

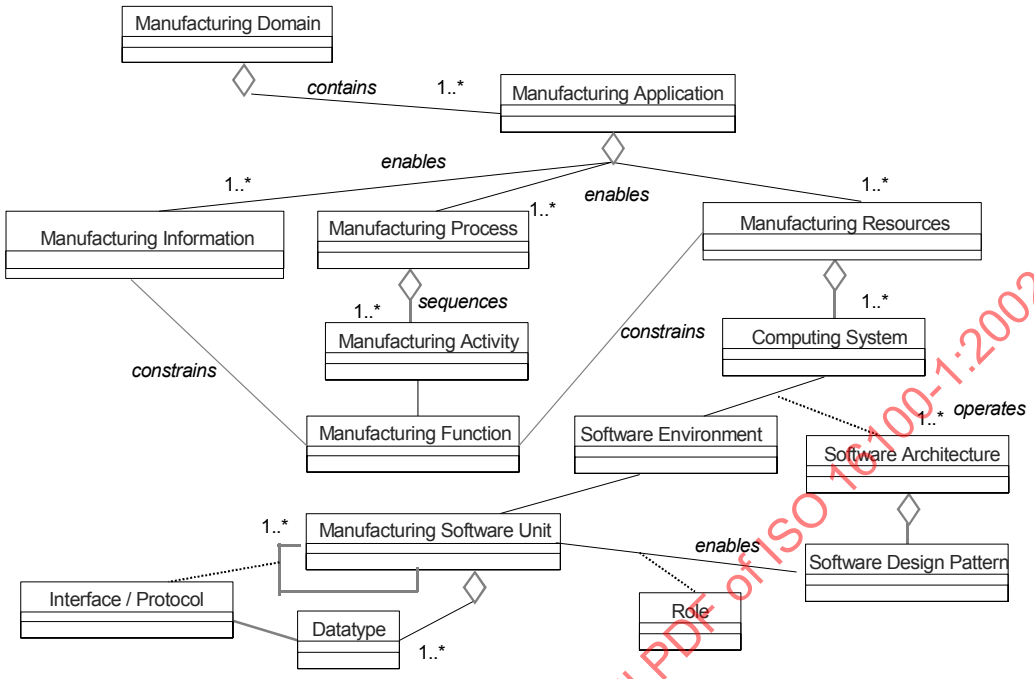


Figure 4 — Class diagram of a software unit and its surroundings and associations within a manufacturing application

A software unit shall be modeled as a set of software components that have been linked to perform a definite manufacturing function. Each software unit shall be represented as a UML object.

A manufacturing software unit shall provide a service interface for use in its configuration, execution, and maintenance.

The capability of a software unit to perform a manufacturing function shall include a description of the set of services available at its service interface. The capability of a manufacturing software unit shall be concisely stated in a capability profile described in XML.

The sequence and timing of the manufacturing activities determines the specified criteria for the interoperability of the associated set of manufacturing software units.

Information structures included or referenced in a capability profile are defined in ISO 16100-2.

6.3 Services, interfaces, and protocols

A manufacturing software unit shall be modeled as a set of manufacturing software components that have been linked to perform a definite manufacturing function.

Manufacturing software units shall interoperate with one another, in support of a manufacturing activity, when the services requested by the former can be provided by the latter, using the same operating environment.

The services, interfaces, and protocols are defined in ISO 16100-3.

6.4 Manufacturing software unit capability profiling

A concise statement of the capability of a manufacturing software unit shall be expressed using a capability profile. The capability profile shall include class of manufacturing activity, the software function performed, the manufacturing application criteria, resource conditions or configurations (software enablers), measurement units, name of the manufacturing software unit, data exchanged, the service interface and the associated operating conditions.

EXAMPLE Class of Manufacturing Activity: Production Control
Software Functions: Scheduling, operation, monitoring, reporting, alarming
Manufacturing application criteria: completeness, timeliness, accuracy
Resource conditions or configurations: operating system peripherals, networks, drivers, performance monitors
Measurement units: Mean Time Between Failure, Mean Time To Repair, Number Of People To Repair (per skill type)
Name of manufacturing software unit: RSI Enterprise Batch

The profile shall provide a minimum level of information and be organized in a format that is XML-based to address the use cases enumerated in Annex C.

The structure, syntax, and taxonomy of manufacturing software capability profiles are defined in ISO 16100-3.

7 Conformance

The concepts and rules for conformity assessment of capability profiles are defined in ISO 16100-4.

Annex A
(informative)

Manufacturing application reference model

A.1 Model of a manufacturing enterprise

A.1.1 Activity domains

The processes within a manufacturing enterprise can be represented as a set of activities (see Figure A.1). The number of domains and the names may differ from one enterprise model to another. In this International Standard, the domain classes defined in the manufacturing enterprise reference architecture noted in Annex B.3 of ISO 15704 will be referenced.

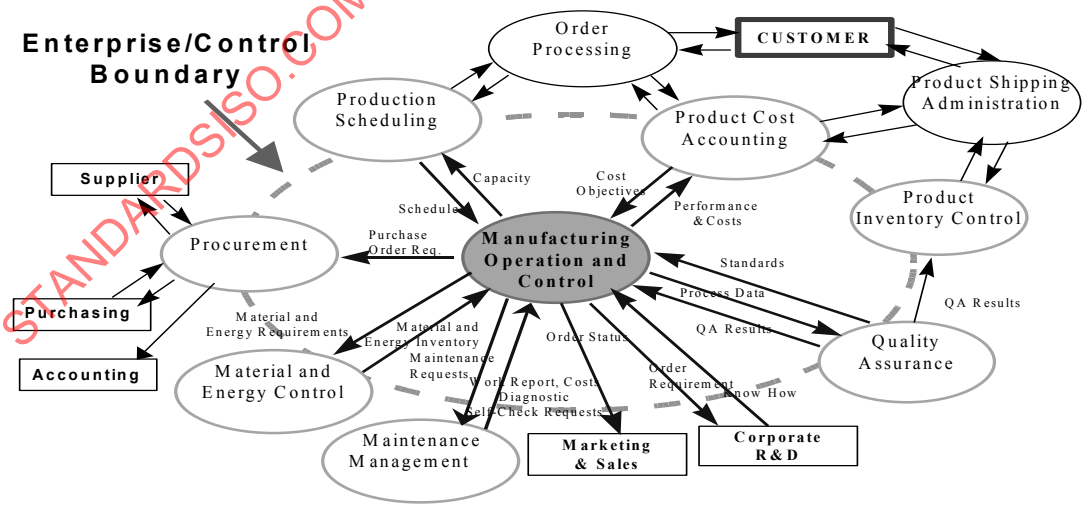
These activity domains can be organized in a hierarchical fashion, wherein the *Production Control* activity domain and its sub-domains can be placed at Level 3 and below, while all the other enterprise activity domains can be positioned at Level 4 and higher. The hierarchical arrangement of the domains will allow more detailed treatment of the manufacturing process requirements (see Figure A.2). Hierarchical arrangement of enterprise domains. A different grouping may result if the target domain were some activity other than *Production Control*.

The classes of functions to be used in distinguishing a manufacturing software capability can be defined in terms of the following characteristics:

a) generic activity type;

b) domain category as noted in the principal domains described in this clause and the sub-domains of the *Production Control* domain;

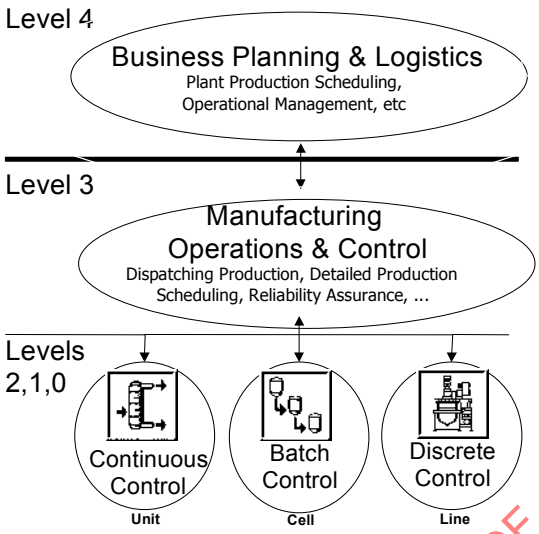
c) flow type supported by the associated manufacturing process.



NOTE Figure adapted from IEC 62264-1.

Figure A.1 — Activity diagram of a partial model of a manufacturing application

Although different enterprises use different names for the functions in these activity domains and these domains may have varying functional boundaries, these functions can be distinguished by their input, output, and processing operations. The functions within each sub-domain can be enumerated and these functions are referenced to distinguish the manufacturing software capability descriptions.



NOTE Figure adapted from IEC 62264-1.

Figure A.2 — Hierarchical arrangement of enterprise domains

A.1.2 Business planning and logistics level

The activity domains within the business planning and logistics level can be grouped as follows:

a) Purchasing, procurement, and product cost accounting;

b) Production scheduling, product inventory control, and quality assurance;

c) Material and energy flow control and management;

d) Marketing and sales, order processing, product shipping management;

e) Corporate services such as accounting, human resources, research and development, information technology support, legal, standardization, and trade.

A.1.3 Customer relationship management

The Customer Relationship Management activity domain includes functions, such as marketing, sales, partnering, integrator support, order processing, and other coordination functions.

The Integrated e-Commerce activity sub-domain involves functions such as electronic data interchange, web ordering, business-to-business electronic storefront, and business-to-consumer electronic storefront.

A.2 Corporate services

The Accounting activity sub-domain involve the functions, such as general ledger, bank book, accounts receivables, accounts payable, currency management, assets depreciation, and other financial transaction support.

The Quoting and Estimating sub-domain involve functions, such as standard product routing, labor performance, and shop floor cost control.

The Human Resource Management activity domain includes functions such as payroll, human resources support, time and attendance, organizational chart maintenance, applicant handling, and employee training and retention.

A.3 Material and energy management

In the Material and Energy Planning and Control activity sub-domain involve functions, such as bill of material, production order processing, master scheduling, and material requirements planning.

The Advanced Materials Management sub-domain involves functions, such as returned material authorization, advanced distribution, serial lot management, shipping, RF data collection for distribution, and request for quotation.

The Capacity Requirements Planning sub-domain involves functions, such as manufacturing cost accounting and standard product costing.

The Distribution activity sub-domain involves functions such as inventory management, order entry, purchase order and receiving, traffic and transportation, and packaging and labeling for distribution.

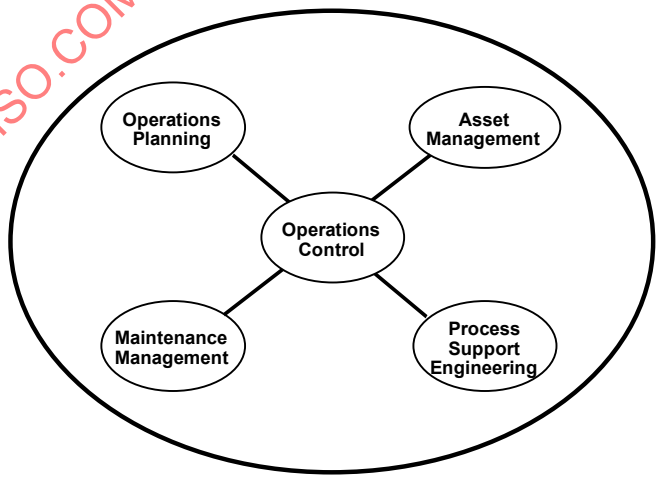
A.4 Engineering support

The Engineering Support activity domain involves functions of product design, process design engineering, installation, and support, such as engineering change management, facility environmental management and monitoring.

A.5 Manufacturing operations and control level

The Production Control domain at the manufacturing operations and control level can be further decomposed as a set of activity sub-domains. These sub-domains may be organized differently according to the mission of the manufacturing environment — make to stock, make to order, assemble to order and mixed — mode operations.

The specific activity sub-domains are Operations control, Operations planning, Asset management, Maintenance management, and Process Support engineering. These are shown in Figure A.3.



NOTE Figure adapted from IEC 62264-1.

Figure A.3 — Composition of the *Production Control* domain

A.6 Production control domain reference model

This clause defines a reference model for the set of functional activities in a manufacturing enterprise that will be addressed by this interoperability framework. Other manufacturing enterprise reference models may have a different functional decomposition; however, the reference set of functions defined in this International Standard can be mapped to other functional decompositions.

The set of manufacturing activities that can be found in a *Production Control* domain include

a) Design product,

b) Engineer process,

c) Plan enterprise resources,

d) Acquire resources,

e) Execute manufacturing orders,

f) Control equipment and process,

g) Perform production steps.

These activities, except for (g), are identified in Annex B in terms of activity diagrams. The diagrams show the functions performed within an activity and the sequence of performance. Annex B provides details for activities (a) through (e). Details for activities (f) and (g) can be constructed using the same conventions for activity diagramming (see B.1). Activity (g) will require feedback to activities (a) through (f).

Annex B
(informative)

Examples of the manufacturing activity reference model

B.1 Activity diagram convention

The figures in this annex partially conform to the IDEF0 modelling methodology specified in IEEE 1320.1-1998. The IEEE 1320.1 standard describes the modelling language that supports the IDEF0 method for developing graphical representations of a system or subject area. The physical construction of IDEF0 models represents functions (i.e. activities), functional relationships, and the physical and data objects required by relationships. An IDEF0 model is composed of a hierarchical series of diagrams with associated explanatory material that gradually introduce increasing levels of detail to describe functions and their interfaces within the context of a system

The basic components of the IDEF0 language are boxes and arrow segments. A box models an activity that can be decomposed into a set of sub-activities. An activity typically takes inputs and, by means of some mechanism and subject to certain controls, transforms the input into output. An activity is named by an active verb or verb phrase and has a number starting with the letter "A" placed in the bottom right corner of the box. An arrow attached to the left side of a box represents input data, i.e. what will be transformed or consumed by the activity. An arrow attached to the top represents control data, i.e. conditions that must be met before the activity can produce correct output. An arrow attached from the bottom represents mechanism data, i.e. the means necessary to carry out the activity. An arrow attached to the right represents the output data, i.e. what is produced by the activity.

B.2 *Develop Products* activity

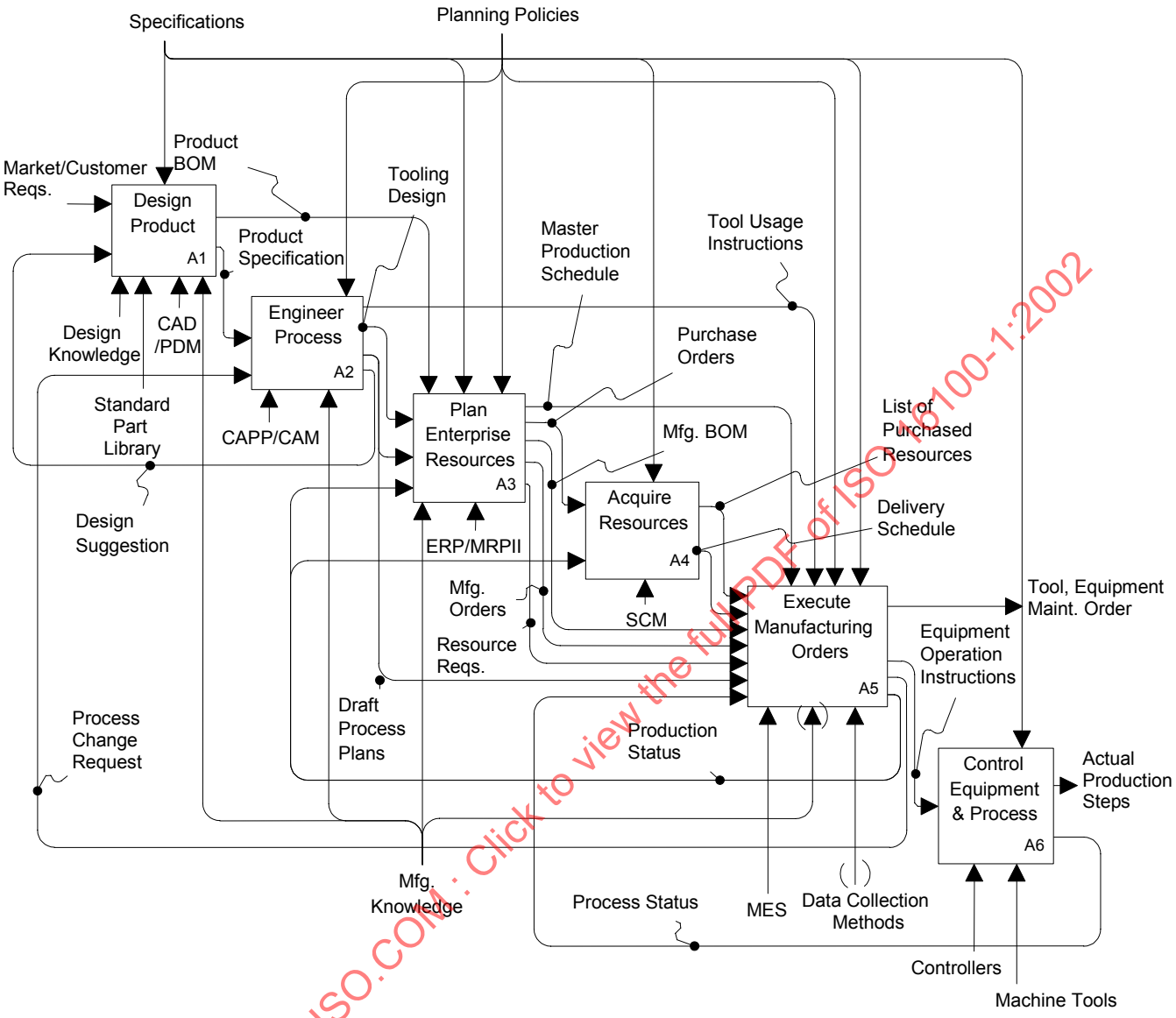


Figure B.1 — Develop Products

Design Product (A1):

The product design engineering includes functional requirements, conceptual design, embodiment design, detailed design, design analysis, and the specification of Bill of Material.

Engineer Process (A2):

Generate a manufacturing process plan and alternative plans. The manufacturing process engineering includes process selection, operation planning, work piece routing, and equipment/device control program generation. This activity provides design and processing information for the downstream resource planning and manufacturing execution.

Plan Enterprise Resources (A3):
Analyze parts and perform make/buy decisions for all the parts. Develop business plan and schedule to acquire necessary resources and/or to produce products for the market. The enterprise resources include material, finished parts, equipment, and labor skills. The enterprise resource planning function includes financial and order management, production and material planning, master production scheduling, capacity requirement planning, and job definition. It also includes business process planning and resource requirement specification.

Acquire Resources (A4):
Based on resource requirement plan, purchase resources from suppliers to meet the production schedule. This activity is supported by supply chain management, which includes distribution, logistics, transportation management, and advanced planning.

Execute Manufacturing Orders (A5):
Based on the production plan and master schedule, carry out manufacturing orders in a production facility to produce finished goods. This activity includes initiate, manage, and report on production activities.

Control Equipment and Process (A6):
Using pre-programmed instructions, control and monitor equipment motions and processes in real time. This activity usually involves distributed numerical control, programmable logic control, and factory-floor data collection.

Actual Production Steps:
An actual production step is a detailed instruction to equipment or workers to execute production activity, such as load tools to a machine, start a milling cycle, drill a hole, check the actual dimension of a feature, etc.

ERP/MRPII:
Enterprise Resource Planning (ERP) and Manufacturing Resource Planning (MRP) II are the systems that provide financial, order management, productions and materials planning and related functions. The Modern systems focus on global planning, business processes and execution across the whole enterprise (intra-enterprise systems), with an accrued recent importance of aspects like supply chain planning and the whole supply chain management aspects and extending to include the whole inter-enterprise supply chain.

Equipment Operation Instructions:
Specific operation steps or recipes that used to control machine movement, such as machining, welding, assembly, material movement, etc.

List of Purchased Resources:
A list of resources that are purchased from suppliers. For each resource item, the list contains resource number, description, purchased date, quantity, cost, and other related-information that is company specifiA.

Manufacturing Execution System (MES):
A production activity management system that initiates, guides, responds to, and reports on production activities on-line and in real time to production management people. The system aids the Execute Manufacturing Orders activity.

Manufacturing Knowledge:
The information (rules, logic, examples) that a manufacturing engineer brings to bear on manufacturing engineering problems, including production techniques and implementation techniques. Many different types of manufacturing knowledge are used in different manufacturing activities, such as decomposition knowledge, assignment knowledge, consolidation knowledge, and optimization knowledge which are used in process planning, resource planning, production planning, and scheduling.

Manufacturing Orders:
Instructions that are sent to factories to start jobs to fulfil customer orders. The starting dates are specified in the manufacturing order according to the production plan and the master production schedule.

Market/Customer Requirements:
A list of customer needs based on market studies, detailed evaluation of the competition, and review of all available literature. It includes the description on product performance, appearance, delivery time, target price, volume, safety, and environment.

Planning Policies:
Rules, regulations, strategies to plan business, engineering, and production activities.

Process Change Request:
Feedback from factory-floor production requesting changes to process plan when some problems in the process plan were found. Changes can be process parameter changes, tool changes, setup changes, etc.

Draft Process Plan:
They are the plans created by processes and their sequences for machining parts. The specifications are subject to validation and approval. There is only one primary process sequence and can be several alternative process sequences.

Process Status:
A report on the conditions of a process that is being monitored. The report includes alarms, process changes or shifts, workpiece throughput, etc.

Product Specification:
Specify product information such as product structure, material, dimension, tolerance, and surface finish etc.

Product Bill of Material:
An index to illustrate the structure and detailed information of product, component and part, known as "as-designed configuration" or "Engineering BOM- EBOM". It includes the item number of letter, the part number, the quantity needed in the assembly, the name or description of the component, the material from which the component is made, and the source of the component.

Production Status:
A report on the state of all scheduled operations and production units. This also includes the information on resources, process setup, job schedule, and material routing.

Purchase Orders:
A purchase order is an instruction to buy certain resources (such as material, parts, components, tools, and machines) from a supplier.

Resource Requirements:
A list of resources required supporting production jobs.

Specifications:
Sets of description of standard engineering, manufacturing, and business practices that guide and control the product development process.

Standard Part Library:
An information library or database that contains standard parts. A standard part is a member of a class of parts that has a generic function and is manufactured routinely without reference to its use in any particular product. Examples of standard parts are screws, bolts, rivets, jar tops, buttons, most beams, gears, springs, and washers.

Supply Chain Management (SCM):
SCM is a mechanism that aids users to manage the supply of resources, including forecasting, distribution and logistics, transportation management, electronic commerce, and advanced planning.

Tool, Equipment Maintenance Order:
An instruction indicating specific tools, machines, or devices that need maintenance before performing any production activities.

Tooling Design:
Specification of the form, function, and material of a tool (e.g., cutter, fixture, and probe). There are two major subtype of tooling design: (1) tool assembly design that specifies the assembly of a tool or fixture from standard components, and (2) special tool design, which must be fabricated.

Tool Usage Instructions
Instructions that guide users to properly use tools in production.

B.3 *Design Products* activity

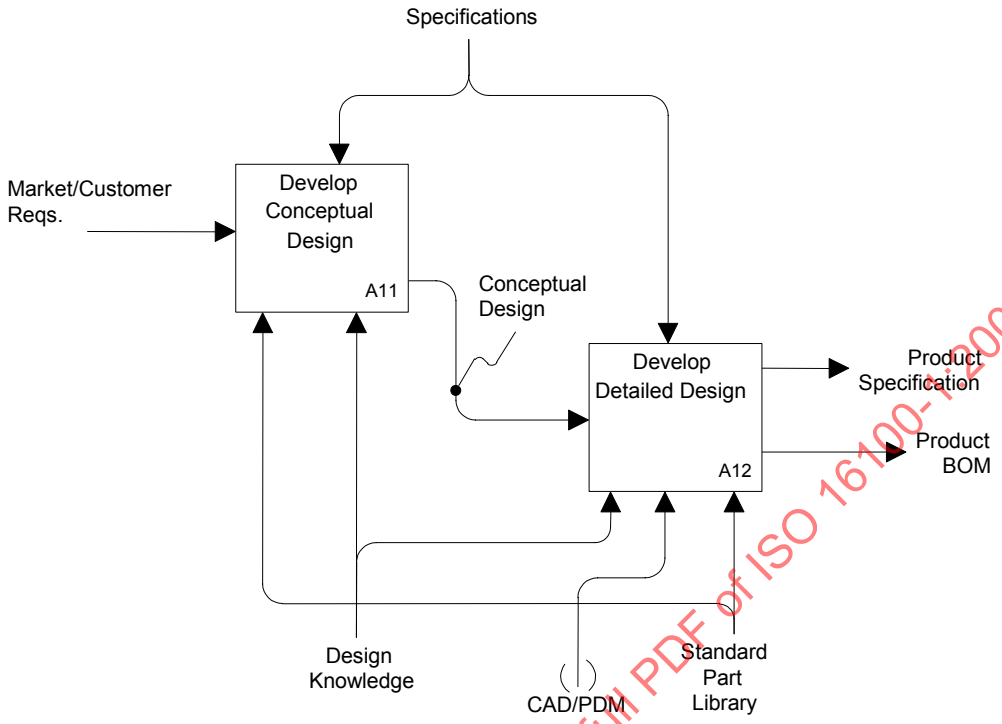


Figure B.2 — Design Product

Develop Conceptual Design (A11):

A decision-making process that generates product concepts. A product concept includes product requirements, functions, behaviours, form, possible materials, structure, and constraints.

Develop Detailed Design (A12):

A decision-making process that generates detailed geometry, topology, dimensions, tolerances, surface finishes, surface hardness, and material specification of a product.

Conceptual Design:

The product concept that includes product functions, behaviours, form, kinds of materials, structures, constraints, and engineering requirements.

B.4 *Develop Conceptual Design* activity

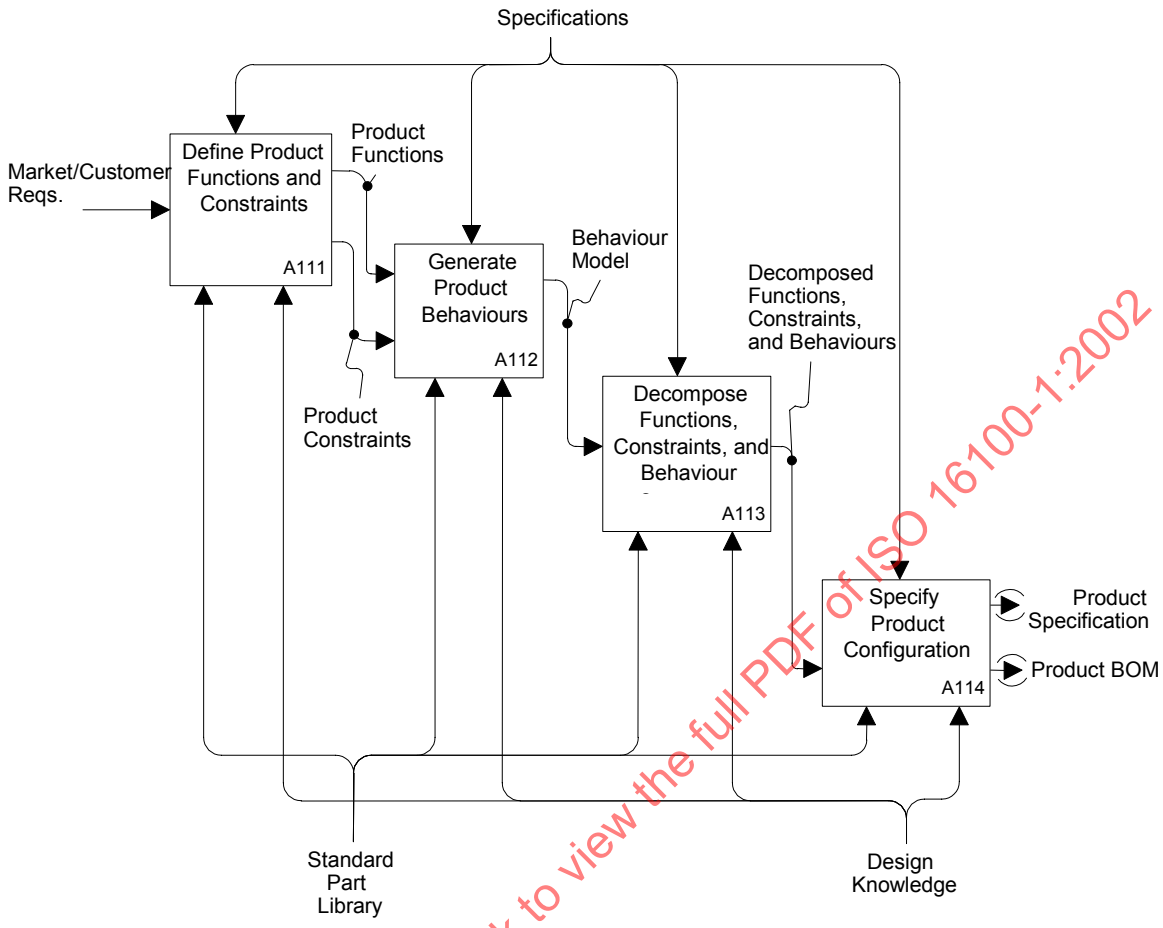


Figure B.3 — Develop Conceptual Design

Define Product Functions and Constraints (A111):
The activity is to define product functions and constraints based on engineering requirements.

Generate Product Behaviours (A112):
The activity is to generate product behaviours based on product functions and constraints.

Decompose Functions, Constraints, and Behaviours (A113):
The activity is to decompose the functions into sub-functions, the constraints into sub-constraints, and the behaviours into sub-behaviours, so that each part, subassembly, and assembly of a product has its own functions, constraints, and behaviours.

Specify Product Configuration (A114):
The activity is to specify product form and structure based on the decomposed functions, constraints, and behaviours. Product configuration includes its components and the relationships among these components.

Product Functions:
Product functions are the intended use or purpose of device, Function represents the transformation relationship between input and output of, in general, energy, material, and information flow.

Product Constraints:
Constraints on product, subsystem and component designs imposed by corporate policy, such as design styles, composition, technology used, ergonomics, and product family similarity. These may imply both layout constraints and component constraints.

Behaviour Model:

Behaviour model is a mathematical model of how an artifact behaves based on physical principles. It is described by input and output variables and the relationship between them.

Product behaviours are the physical actions of the artifact in a specified environment.

Decomposed Functions, Constraints, and Behaviours:

Product Functions, Constraints, and Behaviours are decomposed into sub-functions, sub-constraints, and sub-behaviours based on physical principles.

B.5 *Develop Detailed Design* activity

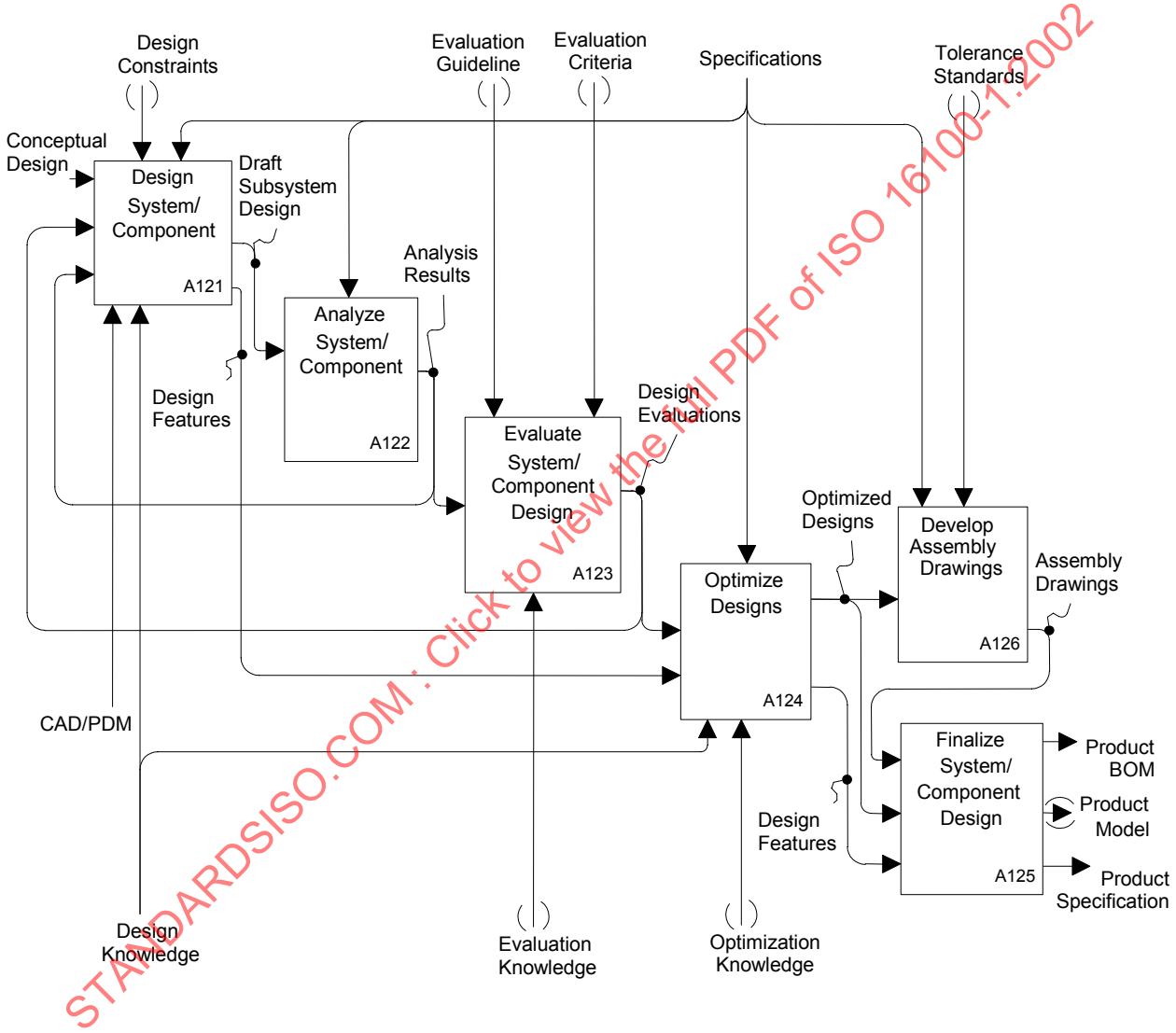


Figure B.4 — Develop Detailed design

Design System/Component (A121):

Each component (or device) is detailed in geometry and materials (with all the tolerance information) so that the product can be manufactured. In some cases, this involves identification of the group technology — the features of the component that are used to perform a design classification — so that similar designs can be identified in the firm's knowledge base of previous designs. This is an iterative process, modified by the results of analysis and evaluation, layout and interface changes, and changes requests from the manufacturing engineering activities.

Analyze System/Component (A122):
Perform engineering analysis of the characteristics and behaviour of components and subsystems. Determine and quantity the response of the designed system to both external and internal signals (e.g., forces). Both mathematical and visual simulations may be used.

Evaluate System/Component Design (A123):
Determine whether and how well the design meets functional and performance specifications and satisfies other qualitative constraints, including cost. Rapid prototypes may be developed in order to perform mechanical and aesthetic evaluations. Downstream producibility feedback becomes a part of this evaluation.

Optimize Designs (A124):
Create a rigorous mathematical model of the system and optimize interrelated design parameters using various mathematical and engineering techniques.

Finalize System/Component Design (A125):
Create and approve for release a product version consisting of a detailed set of design drawings and component specifications such as function, geometry, material, finish, processing notes, assemblies, and assembly notes. Note that as change requests are processed, alterations to the design occur in many places, and the finalization produces a successor version. What is important here is that an engineering management process intervenes in the technical design process to define a consistent archival design document set for release to manufacturing engineering, production, or maintenance.

Develop Assembly Drawings (A126):
Develop the set of drawings showing how the components are assembled into subassemblies and the subassemblies are assembled and connected to create the final product. In some cases, this is a detailed enhancement of the layout drawings; in other cases, it is an entirely different set of views of the product components.

Analysis Result:
Results of engineering analysis (such as structural behaviour, thermal behaviour, electrical behaviour, effects of vibration, performance of specific functions) of the draft component or subsystem design:.

Assembly Drawings:
The set of drawings showing how the components fit together into assemblies and specifying the characteristics of each fit and connection. In some cases, this is a detailed enhancement of the layout drawings; in other cases, it is an entirely different set of views of the product components.

Design Feature:
Identification of features of a product or component, which are important to the designer in making design decisions and identifying similarities with previous designs. This may includes some kind of group technology coding scheme for automated identification of similarities.

Design features and codes are distinguished from manufacturing features and codes in that the latter are intended to support manufacturing process decisions and may therefore emphasize different aspects of the part. For example, two parts which have very similar shape and materials but different tolerances may share common design features but have significantly different processing requirements, and therefore different manufacturing features.

Design Evaluations:
Interpretations of the engineering analysis and other evaluations to determine how well the design meets functional specifications, performance specifications, standards, and other criteria.

Draft Subsystem Design:
All the elements of the product model for a system or component that are needed to perform various engineering analyses and evaluations: typically materials (or components) and geometry for all analyses, and topology, tolerances, surface finish, and mating specifications for some analyses.

Evaluation Criteria:
Criteria and metrics developed for estimation of design quality during product planning, as a means of determining the probability of successful market for the design.

Evaluation Guideline:
Design for availability, reliability, maintainability, disposability, and usability (quality concerns). This may also include producibility and ease of assembly, to the extent that process knowledge is incorporated directly in the design function. (Process constraints may also be reflected in feedback from manufacturing engineering functions.)

Evaluation Knowledge:
Knowledge of how to judge design quality: judgement techniques, valuations and confidence factors in the conformance of a design to various desirable goals. This also includes prioritization of the goals themselves.

Optimized Designs:
Designs are optimized based on optimized objectives and constraints.

Optimization Knowledge (Design Knowledge):
Knowledge of how to refactor a design based on functional decomposition in order to improve implementation, by recognizing and improving inter-functional and non-functional relationships.

Product model:
A computer-interpretable representation of the product and subassembly layouts, and all the specifications for each component, including

a) for parts to be fabricated:

1) Material of which the component is made (may be either composition or stick material);

2) Component dimensions, geometry and topology;

3) Surface finish (roughness, hardness, coating);

4) Notes on special processing procedures;

b) for sub-assemblies:

1) The (partial) bill of materials: the list of component parts;

2) The assembly configuration: how the components fit together;

3) Fit specifications: tightness requirements for fits, bindings and seals;

c) and in general:

1) Quantitative quality controls: tolerances, datum's, limits and fits;

2) Design features: features of the part, which are important to the designer in making decisions and identifying similarities. Features may be codified based on some classification system designed to determine similar parts (group technology codes for product design);

3) Design intent: statements of the relationships between specific design choices and specific constraints, specifications and guidelines, which govern the product or design process. Also statements of the interrelationships of the design choices themselves, including the use of off-the-shelf components;

4) Notes on special handling procedures;

5) Notes on special quality control procedures.

B.6 *Engineer Process* activity

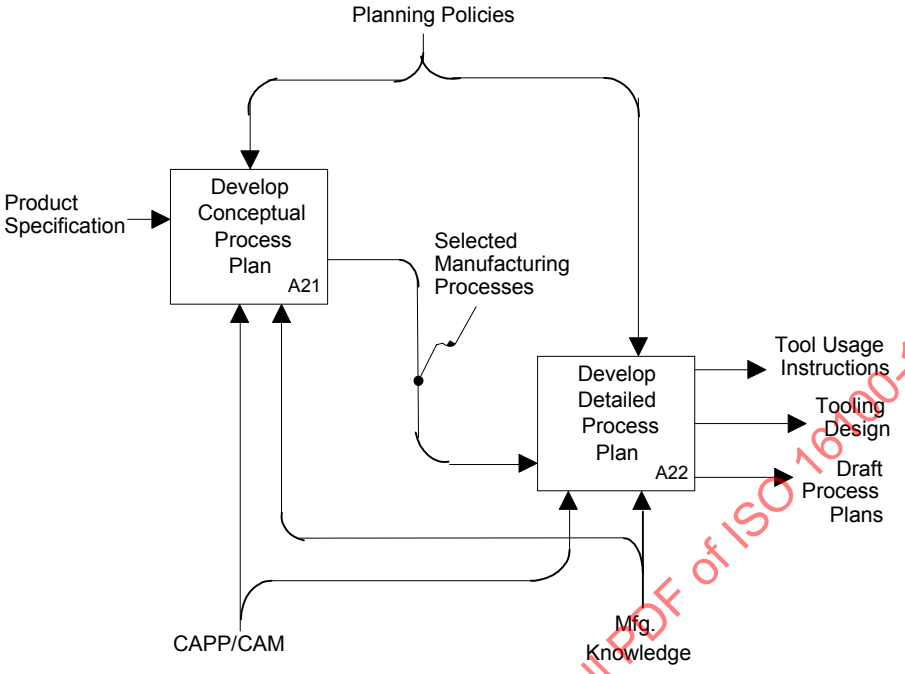


Figure B.5 — Engineer Process

Conceptual process planning (A21):

Conceptual Process Planning is an activity to select manufacturing processes and resources, and to estimate manufacturing cost and time in the early design stage.

Detailed Process Planning (A22):

Detail process planning is an activity to specify operations, determine operation sequences, select machines and tools, depict setups, define process parameters, and estimate process time and manufacturing cost based on a detailed design.

Selected Manufacturing Processes:

The manufacturing processes that are selected based on conceptual process plan.

Draft Process Plans:

They are the plans created by process planners based on design specifications and available resources. The plans are subject to validation and approval.

B.7 *Conceptual Process Planning* activity

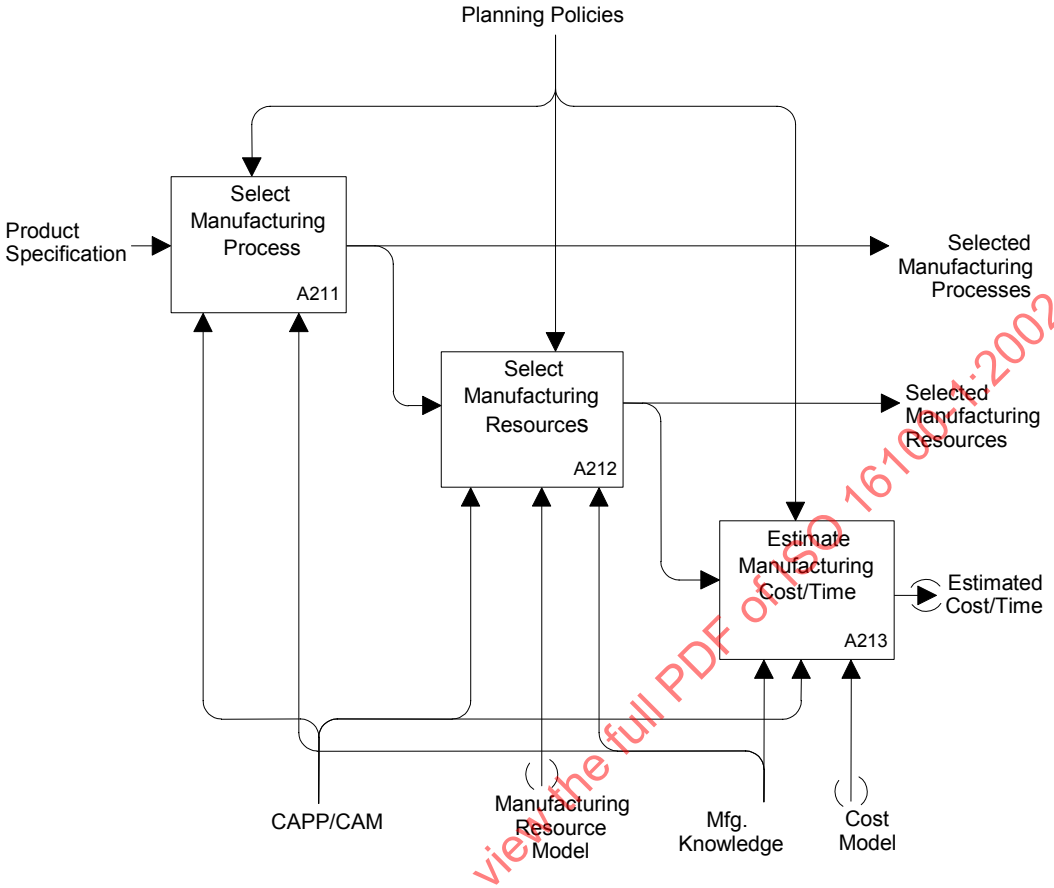


Figure B.6 — Conceptual Process Planning

Select Manufacturing Processes (A211):
Select primary manufacturing processes, such as casting, forging, molding, and machining, based on conceptual design.

Select Manufacturing Resources (A212):
Choose appropriate manufacturing resources including both physical resources and human resources. Physical resources include machines, tools, fixtures, and gages. Human resources include labor skills.

Estimate Manufacturing Cost/Time (A213):
Estimate cost/time based on selected manufacturing processes and resources. Manufacturing cost covers material, purchased parts, labor, tooling, machine usage, and overhead.

Selected Manufacturing Resources:
Selected Manufacturing resources include both physical resources and human resources. Physical resources include machines, tools, fixtures, and gages. Human resources include labor skills.

Manufacturing Resources Model:
Manufacturing Resources Model represents the type, attributes, and capability of manufacturing resource. The model is used for selecting manufacturing resources.

Cost Model:
Cost model is a model to represent manufacturing cost structure of product based on manufacturing activity.

Estimated Cost/Time:
Estimated Cost/Time is the manufacturing cost and time of product to be estimated based on manufacturing activities.

B.8 *Select Manufacturing Resources* activity

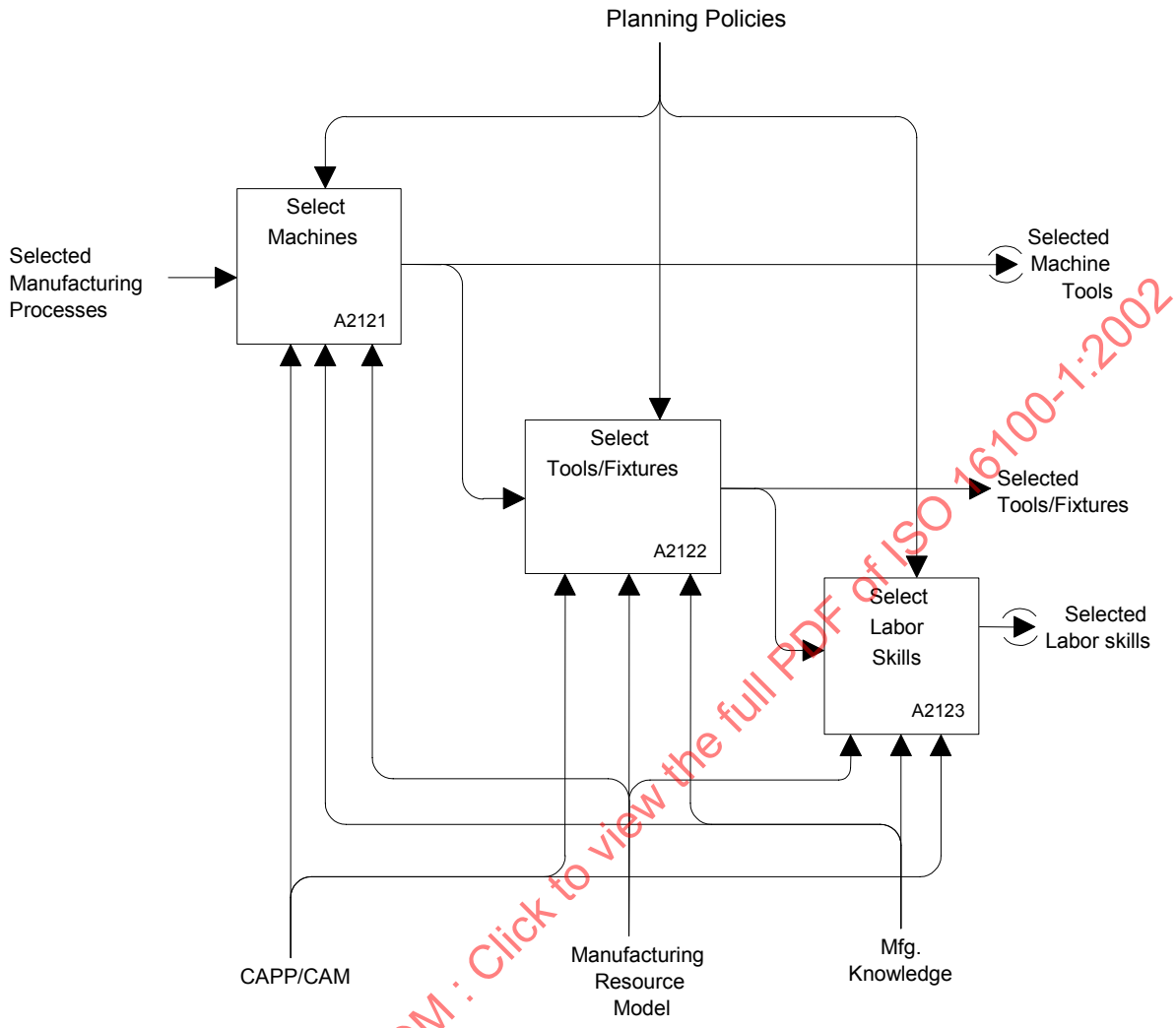


Figure B.7 — Select Manufacturing Resources

Select Machines (A2121):
Select Machines is an activity to select manufacturing machine or equipment based on manufacturing process, product information.

Select Tools/Fixtures (A2122):
Select Tools/Fixture is an activity to select manufacturing tools/fixtures based on manufacturing processes, product information, and selected machines.

Select Labor Skills (A2123):
Select Labor Skills is an activity to select proper labor skills based on manufacturing processes.

Selected Machine Tools:
Selected Machine Tools are the machine tools to be used in manufacturing activities.

Selected Tools/Fixtures:
Selected Tools/Fixtures are the tools/fixtures to be used in manufacturing activities.

Selected Labor skills:
Selected Labor is the labor to be selected to be selected based on selected machining processes, and labor skills.

B.9 *Develop Detailed Process Plan* activity

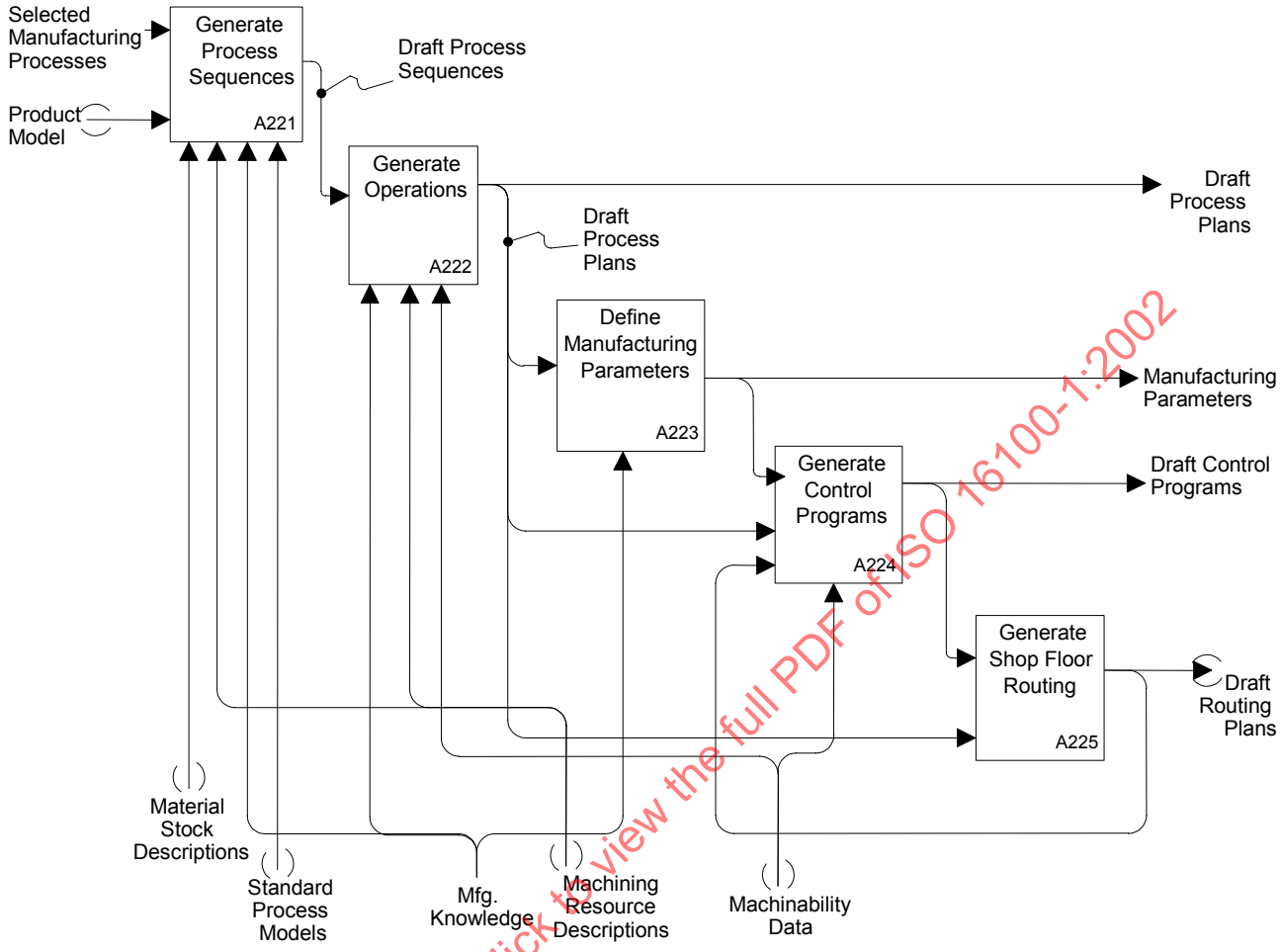


Figure B.8 — Develop Detailed Process Plan

Generate Process Sequences (A221):
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.

Generate Operations (A222):
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.

Define Manufacturing Parameters (A223):
The Activity is to define and select manufacturing parameters for each operation in the process routing. Manufacturing parameters includes cutting speed, feed speed, and depth of cutting.

Generate Control Programs (A224):
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 programs such as the numerical control (NC) programs for the machining centres, robot programs, and automatic guided vehicle (AGV) programs.

Generate Shop Floor Routings (A225):
The activity is to determine the shop floor configuration and means of workpiece transportation. Shop floor specifications include work centres in which workpieces are machined and corresponding workpiece travel itineraries.

Draft Control Programs:
The programs created by process planners based on the draft process and routing plans. The programs are subject to validation and approval. See the definition of control programs for detail.

Draft Process Sequences:
The specifications of processes and their sequences for machining parts. The specifications are subject to validation and approval. There is only one primary process sequence and can be several alternative process sequences.

Draft Routing Plans:
The plans created by process planners based on draft process sequences and available resources. The plans are subject to validation and approval. See the definition of routing plans for detail.

Machinability Data:
The reference data that specify machining conditions for using specific cutters and machining centres to machine specific materials. The machinability data are usually found in handbooks or provided by machine tool vendors.

Machining Resource Descriptions:
The form and functional description of available machine and tooling equipment. The form description includes dimensions and the shape of the equipment. The function description includes the capabilities of the equipment, such as dimensional variation distributions of machined features, machine speeds versus powers, work volume, fixture rigidity and versatility, machine controller descriptions, cutter descriptions, and adapter descriptions.

Material Stock Descriptions:
The form and material properties of the stock material available from the market or specially produced in a factory.

Standard Process Models:
A predefined set of operations and related specifications that are used to machine different types of parts.

B.10 *Generate Operations* activity

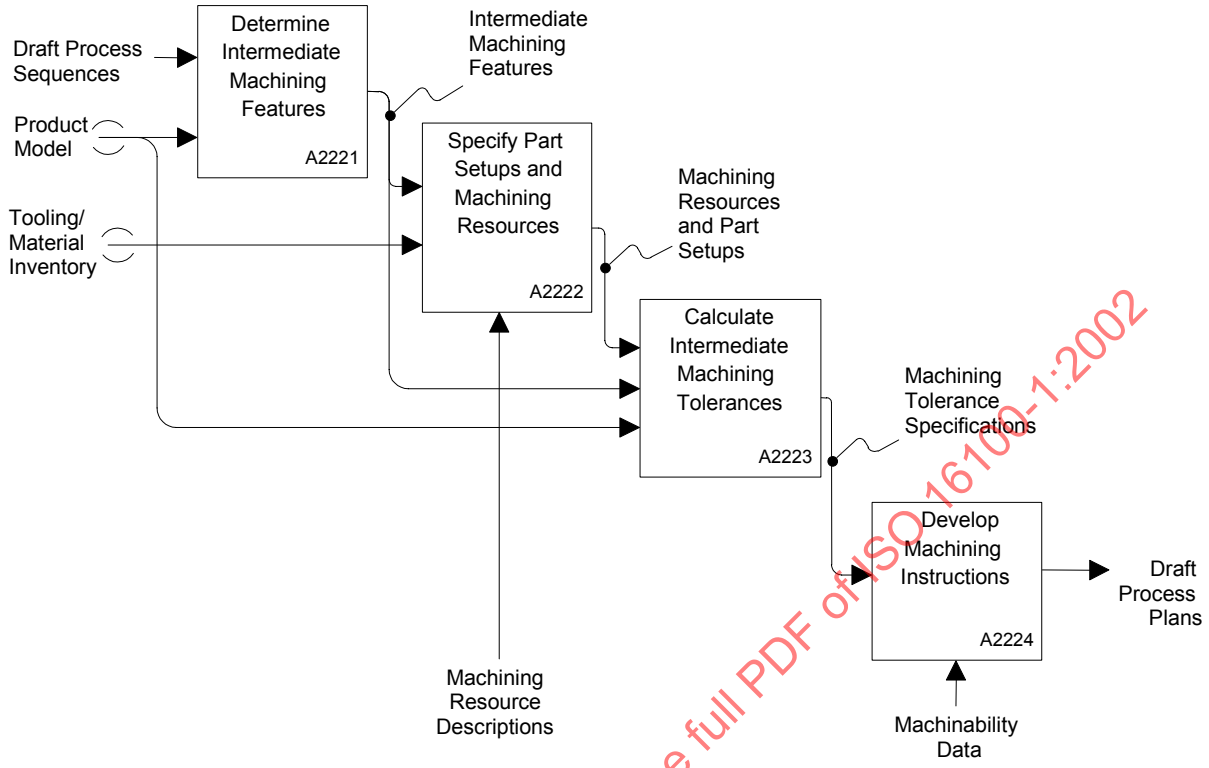


Figure B.9 — Generate Operations

Determine Intermediate Machining Features (A2221):
The activity is to determine intermediate machining surfaces and features in each operation of the generated process sequences.

Specify Part Setups and Machining Resources (A2222):
The activity is to choose the type or a specific machining centre, determine the position and orientation of the stock relative to the machine coordinates, and select appropriate cutters, adapters, types of coolant, jigs and fixtures for one or more of the machining processes from the defined process sequence. The part setup determination and machining resources selection are interrelated and are performed in one activity. The machines, tools, and fixtures can be specified by their capabilities or the identifications of specific machines, tools, and fixtures.

Calculate Machining Tolerances (A2223):
The activity is to compute tolerance allocations for the machining steps in each operation based on process capabilities. The intermediate tolerances should guarantee the realization of the design requirements of the part.

Develop Machining Instructions (A2224):
The activity is to specify step-by-step instructions of machining operations. When necessary, special machine, tooling, and setup requirements are specified in the instructions. A machining operation is the material removal work performed by a machine with a tool on a feature.

Intermediate Machining Features:
The features and geometries that define the intermediate shapes at stages of machining processes.

Machining Resource Descriptions:
The form and functional description of available machine and tooling equipment. The form description includes dimensions and the shape of the equipment. The function description includes the capabilities of the equipment, such as dimensional variation distributions of machined features, machine speeds versus powers, work volume, fixture rigidity and versatility, machine controller descriptions, cutter descriptions, and adapter descriptions.

Machining Resources and Part Setups:
The machining resources include the specifications of all machines, tooling, materials, labor skills, and machining tasks necessary to carry out the plans and execute control programs. Examples are tool lists, machine lists, and labor skill lists. A specification of locations and orientations of the part relative to the machine coordinates and the means of fixing the part on the machine table during the machining process.

Machining Tolerance Specifications:
These are tolerances defined in process planning for the intermediate features. These are derived from target tolerances for the part features by the process planners.

Tooling/Material Inventory:
The data that describe those tools and stock materials that are in the inventory and accessible for parts production. The inventory data include the quantity on-hand and on-order, order status, and types of tools and stock materials. The tools include cutter, adapters, machining centre holders, jigs, clamps, fixtures, indexing tables, and types of coolant.

Select Machining Centres (A22221):
The activity is to choose the most appropriate machine tools for machining parts based on the design requirements and machining features.

Specify Setups (A22222):
The activity, based on the selected machining centres and the derived machining features, determines the orientations and locations of the workpiece on the machine table relative to the machine coordinates.

Specify Tool Assemblies and Fixtures (A22223):
The activity is to select appropriate cutters and adapters with respect to machine holders, group tools and adapters into tool assemblies, and identify machine holders in which the individual tools or the tool assemblies fit. Furthermore, specify the fixture and clamping locations for the machining process. For unavailable fixtures, place orders to acquire them.

Tooling and Fixtures:
Tooling is the cutting tools that us used in manufacturing processes. Fixture is the fixture tools used in manufacturing processes.

Machining Centre:
Identification of the machines, with proper tooling, on which a sequence of machining operations is performed. A machining centre provides a tool magazine with a set of tools, drive mechanisms, a motion controller, and a spindle.

Setups:
A specification of locations and orientations of the part relative to the machine coordinates and the means of fixing the part on the machine table during the machining process.

B.11 *Generate Control Programs* activity

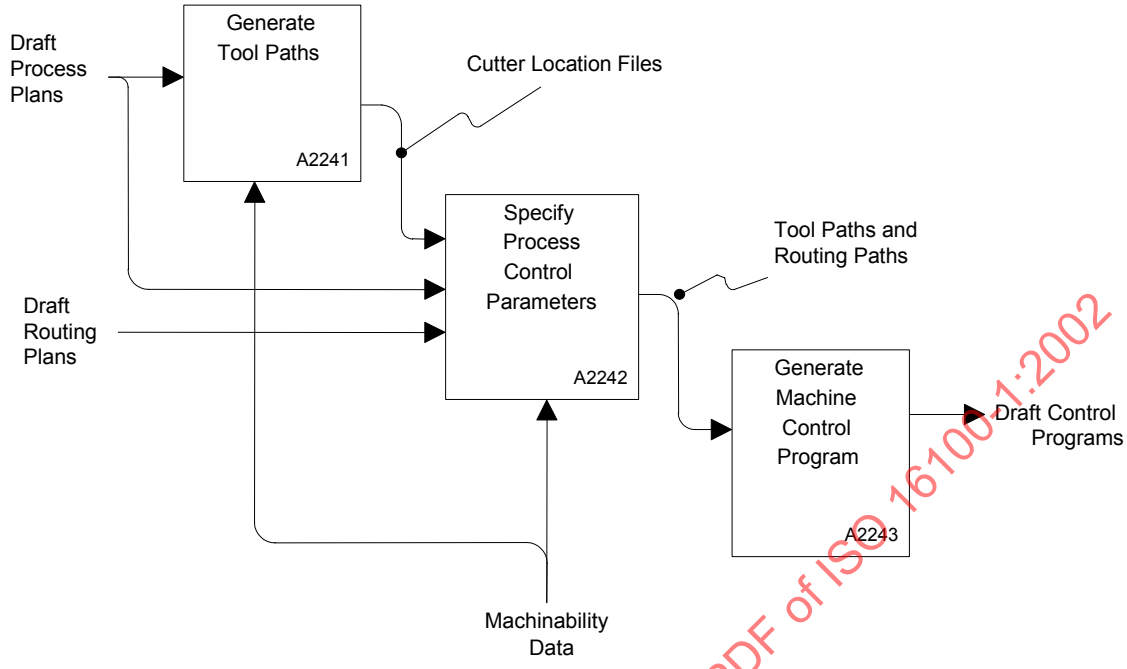


Figure B.10 — Generate Control Programs

Generate Tool Paths (A2241):
The activity is to create cutter routes for machining a part based on the derived machining features, product model, setups, the selected machining centres and tools. Linear interpretations, circular interpretations, or spline interpretations along the routes should also be specified. The cutter path is an input to NC program generation.

Specify Process Control Parameters (A2242):
The activity is to specify parameters that define the machining, routing, and workpiece handling process conditions, such as cutting speeds, feedrates, moving speeds, maximum depths of cut, tool changes, coolant on/off, AGV speed, and robot speed.

Generate Machine Control Program (A2243):
The activity is to develop programs such as NC (numerical control) programs, APT (automated programmed tool) programs, robot programs, and AGV programs for the direct control of machining centres, workpiece handling machines, and workpiece moving machines.

Cutter Location Files:
The files specify cutter paths and machine controls for machining. The files are used to create APT and NC programs.

Tool Paths and Routing paths:
Tool paths are the route that cutters follow during the machining processes. The routing paths are the route that workpieces follow in moving from one workstation to another.

Draft Control Programs:
The programs created by process planners based on the draft process and routing plans. The programs are subject to validation and approval. See the definition of control programs for detail.

B.12 *Generate Shop Floor Routing* activity

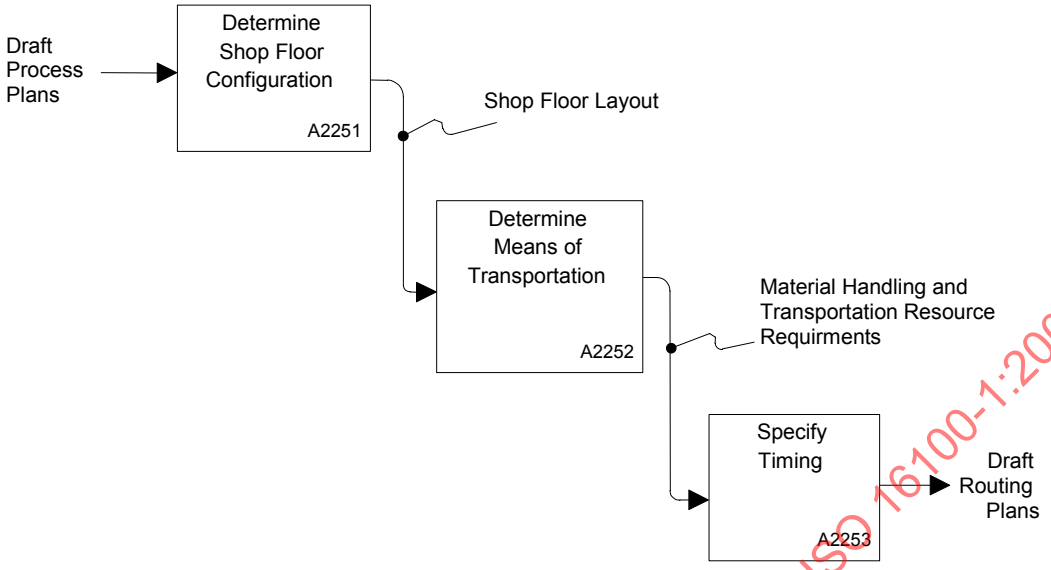


Figure B.11 — Generate Shop Floor Routing

Determine Shop Floor Configuration (A2251):
The activity is to specify the locations of machining centres, workpiece handling machines (e.g. robots), and workpiece transportation machines (e.g. automatically guided vehicles) on the shop floor.

Determine Means of Transportation (A2252):
The activity is to specify types of machines and the operations to handle workpieces into and out of machining centres and transport the workpieces from one machining centre to another.

Specify Timing (A2253):
The activity is to specify total time that a workpiece is in a machining centre and the time moving from one centre to another. Time in a machining centre includes loading/unloading time, setup time, and machining time.

Shop Floor Layout:
A specification of locations and orientations of all the machines (including robots) and the areas they cover, tool cribs, AGV routes, material storage places, and other facilities needed in the machining processes.

Material Handling and Transportation Resource Requirements:
The specifications of all the needed material handling and transportation machines, as well as fixtures and holders. Material handling machines include, for example, robots and actuators. Transportation machines include, for example, automatic guided vehicles.

B.13 *Execute Manufacturing Orders* activity

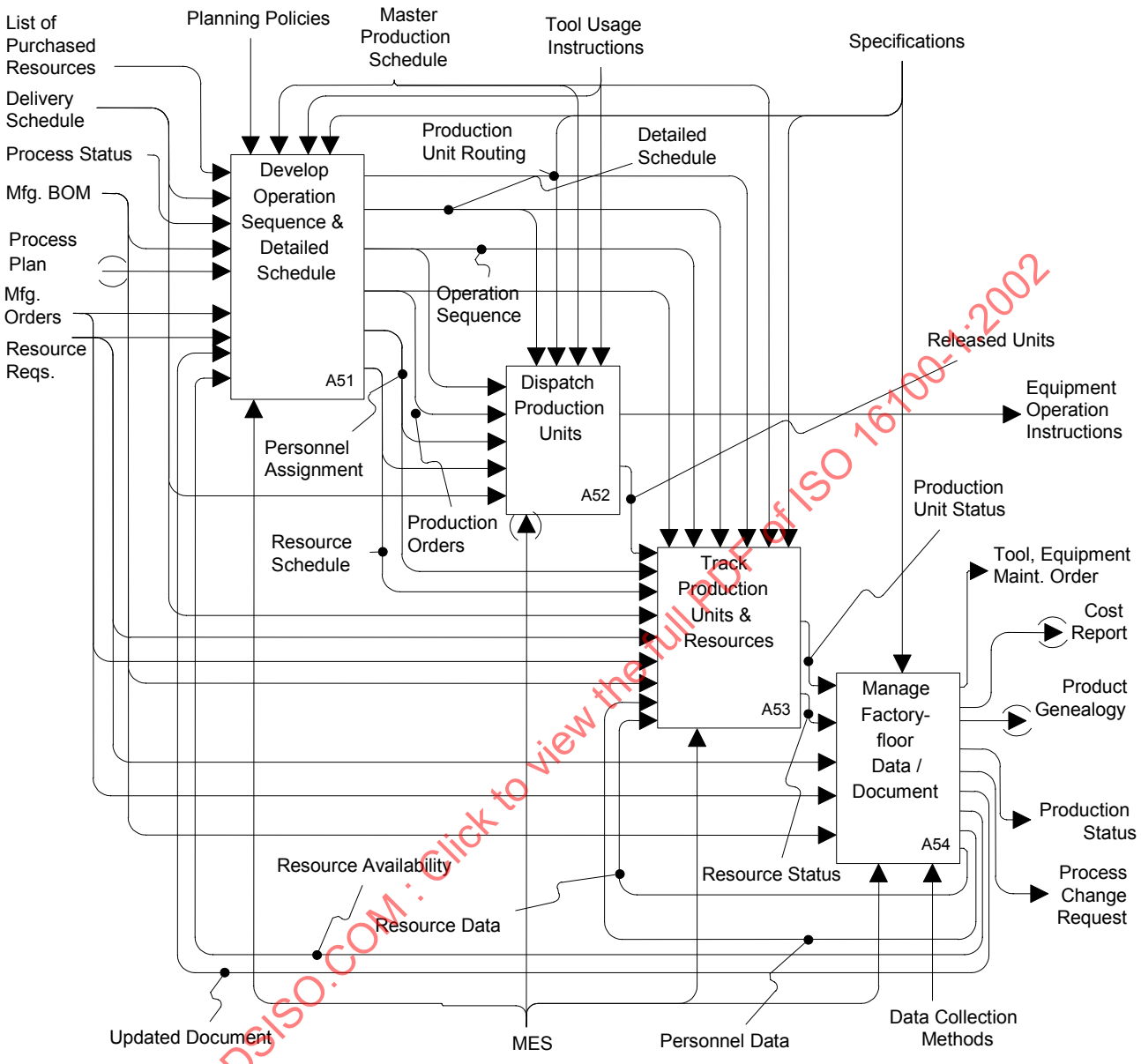


Figure B.12 — Execute Manufacturing Orders

Develop Operation Sequence & Detailed Schedule (A51):

Based on the production plan and the master production schedule, define, sequence, and schedule operations locally on the levels of work cell, workstation, and machine in order to optimize productivity, such as minimize setup time, maximize throughput, minimize idle time, minimize queue time, and adjust shift pattern when new priority is in effect.

Dispatch Production Units (A52):

Determine which production unit in the queue is best processed next. The objective is to minimize the lead time and lateness.

Track Production Units & Resources (A53):
Provide the information on where any production unit is at all times and its disposition. Also provide the product genealogical information, such as who worked on it, current production information, component materials by supplier, lot number, serial number, any rework, measured data, or other exceptions related to the product. In the same time, provide the status information on specified resources, such as tools, devices, machines, and stock materials, at all times.

Manage Factory-floor Data/Document (A54):
Provide hardware/software interface links to obtain mission-critical data pertinent to production activities. Collect the data from the factory and analyze them for multiple purposes, such as product throughput, quality, delivery, and equipment maintenance. Manage documents, such as cost reports, maintenance orders, inventory reports, process change requests, manuals, specifications, and company policies. Control the data collection, access, and distribution. Provide versioning control of documents, such as part programs, operation instructions, manufacturing orders, detailed schedules, part drawings, engineering change notices, production unit records, records of communication from shift to shift, manuals, standards, company policies, and safety regulations.

Cost Report:
A report on manufacturing cost of producing a part. It contains the costs for items such as material, labor, and usage of equipment.

Detailed Schedule:
A plan that specifies starting time and finished time of each production unit in the queue locally to an area in the manufacturing facility, such as a work cell, a workstation, or a machine.

Operation Sequence:
A set of step-by-step instructions that specify how to perform tasks to process a workpiece in an local area, such as a machine, a workstation, a work cell.

Personnel Assignment:
A list of workers who are assigned to perform specific operations in the production plan. Each worker is assigned to perform or monitor one or more operations, usually, with due dates.

Personnel Data:
A record of personnel assigned to perform production activities. It includes data such as work hours, on-station time, skills, and certificates.

Process Change Request:
Feedback from factory-floor production requesting changes to process plan when some problems in the process plan were found. Changes can include process parameter changes, tool changes and setup changes.

Process Plan:
A plan that specifies operation sequences, equipment, and process parameters for manufacturing a product.

Process Status:
A report of the conditions of a process being monitored. The report includes alarms, process changes or shifts, and workpiece throughput.

Product Genealogy:
One of the components in MES system, which provides the visibility to where work is at all times and its disposition. Product genealogy information may include who worked on the product, components materials by supplier, lot, serial number, current production conditions, and any alarms, rework, or other exceptions related to the product. This information provides traceability of each part and component.

Production Orders:
Instructions that are sent to a local area of a factory to start processing a production unit with the starting date and time and the ending date and time.

Production Status:
A report on the state of all scheduled operations and production units. This also includes the information on resources, process setup, job schedule, and material routing.

Production Unit Routing:
A plan that specifies the traveling route of a production unit in a manufacturing facility. The plan also specifies stops for processing and queuing.

Production Unit Status:
A snapshot of a product unit being processed. The status includes the quantity of finished product, scrap rate, rework rate, product measurements analyses, and a check of the status with the master production schedule.

Resource Availability:
A report on whether needed resources are available for production during specified time periods.

Resource Data:
The data that indicate the condition of a resource based on inspection or measurement analysis.

Resource Requirements:
A list of resources required to support production jobs.

Resource Schedule:
A plan of control resource availability and allocation. It specifies a group of resources that each resource is assigned to which operation or transferred from one place to another in a specific time period. Only resources that are used/shared by multiple work cells or workstations are on the resource schedule.

Resource Status:
A snapshot of a resource used in production. The conditions, location, and service time of the resource are reported. If it needs maintenance, replacement, or disposition, the resource is marked accordingly.

Update Document:
Document that is modified to include new information.

B.14 *Develop Operation Sequence and Detailed Schedule* activity

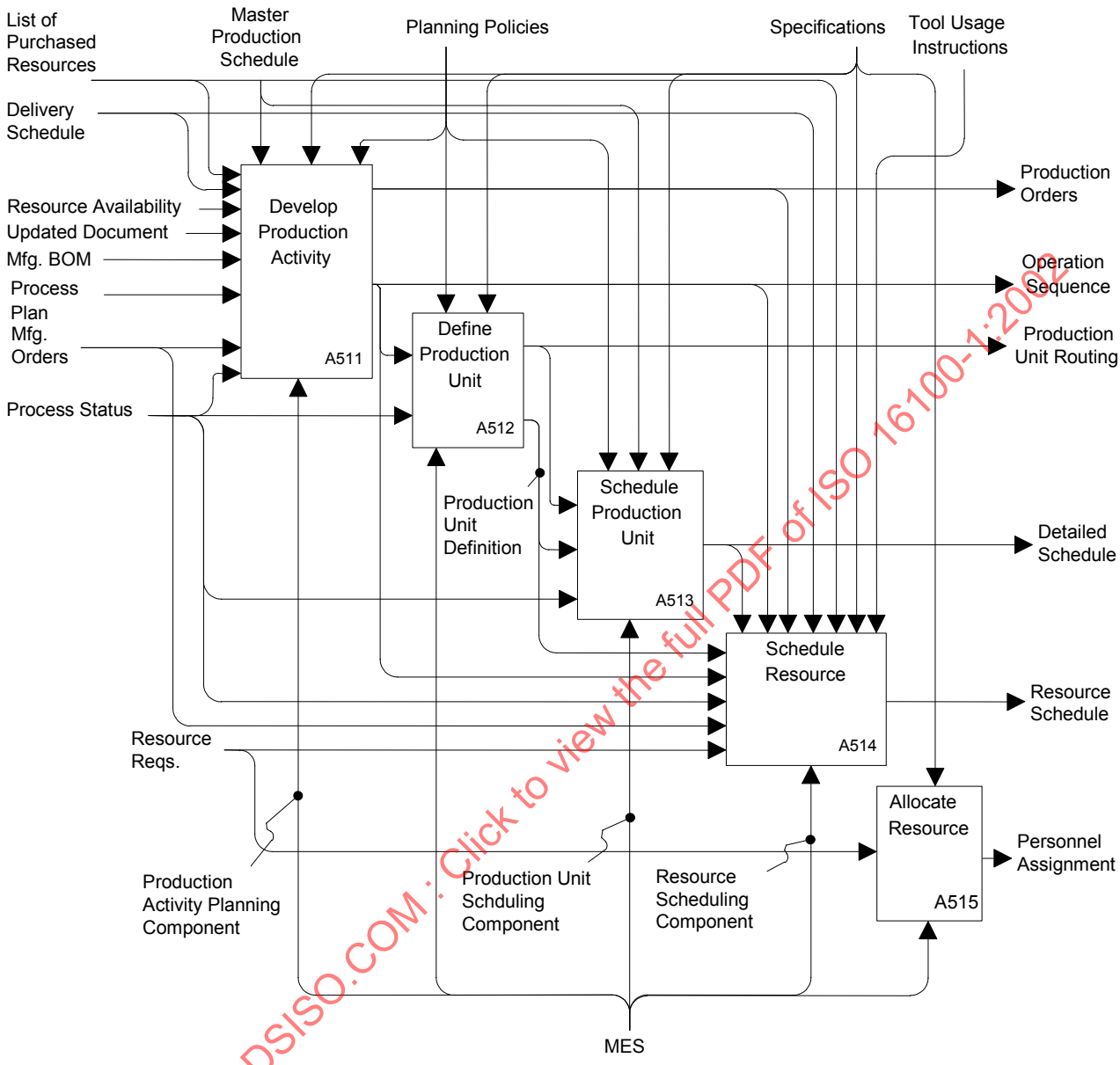


Figure B.13 — Develop Operation Sequence and Detailed Schedule

Develop Production Activity (A511):

Sequence production operations based on priority, characteristics, setup changes/time, master production schedules, etc. Also, generate alternative operation sequences to recognize possible production changes, such as priority changes, machine downtime, etc.

Define Production Unit (A512):

Identify a lot or batch by decomposing or aggregating manufacturing orders. Each lot or batch is scheduled, processed, monitored, and tracked by the system as a unit.

Schedule Production Unit (A513):

Add start and finish time information to a lot or batch dictated by the operation sequences. The goal is to optimize productivity and quality and to conform to the master production schedule.

Schedule Resource (A514):

Add start and finish time information on each resource that is used by operation(s) in the production.

Allocate Resource (A515):
Assign and make resource available to operations that need the resource before they start. Equipment must be properly setup. This activity issues an assignment that associates a type of resource and quantity of it to specific operation(s) that need(s) the resource for a specific time period.

Production Unit Definition:
Definition of a lot or a batch. It includes an ID, number of workpieces, and the descriptions of the workpieces. Each workpiece may have a serial number. In the product record, workpiece ID and production unit ID are associated.

Production Unit Scheduling Component:
A software component in MES that aids users to schedule production unit to be processed locally in a manufacturing facility.

Production Activity Planning Component:
A software component in MES that aids users to plan production activities.

Resource Scheduling Component:
A software component in MES that aids users to schedule the release of resources to work cells, workstations, and/or machines.

B.15 *Dispatch Production Units* activity

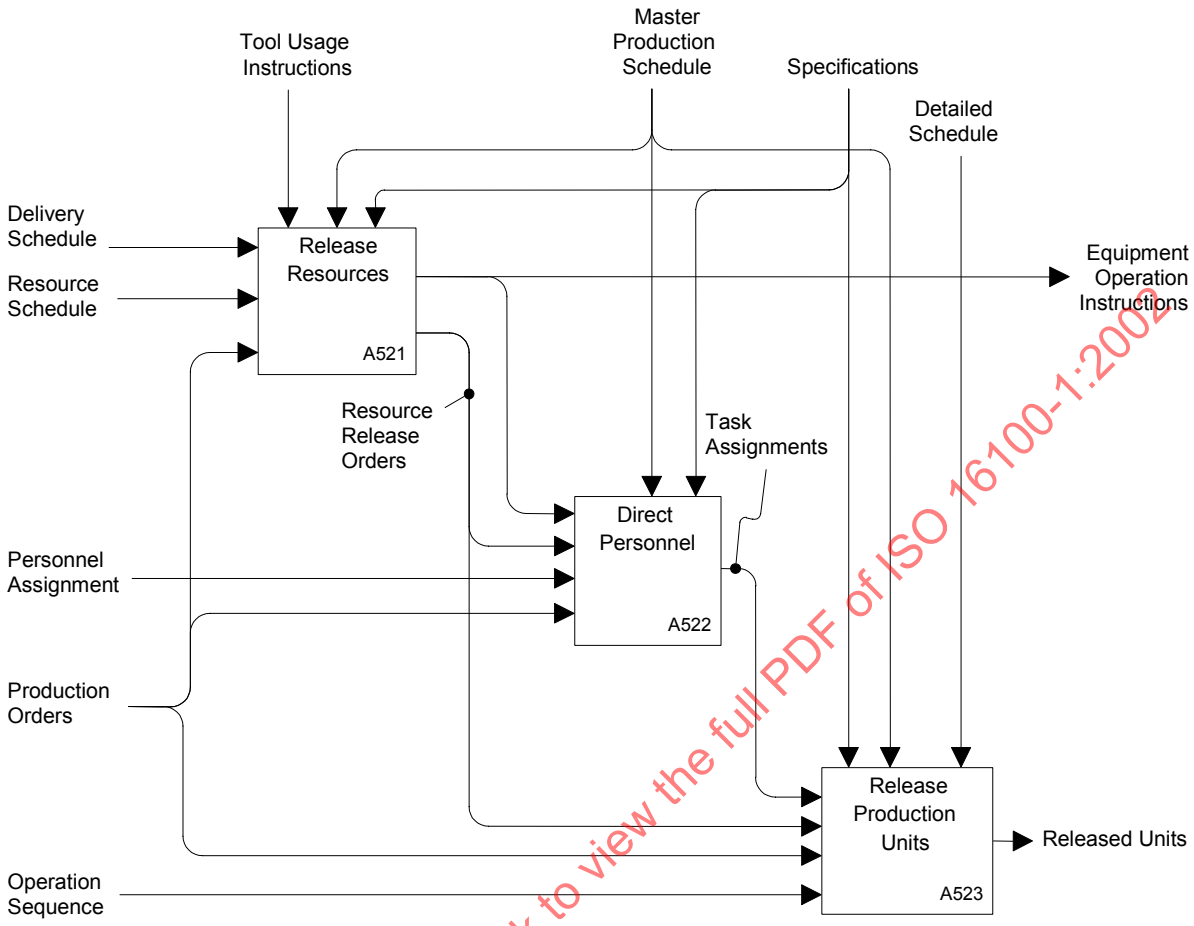


Figure B.14 — Dispatch Production Units

Release Resources (A521):
Based on resource allocation, release resource for the production activity in a timely manner. This activity results in physical materials, tools, etc., being moved from inventory or a storage to production cells or workstations.

Direct Personnel (A522):
Assign workers with adequate skills to perform specific operations according to the detailed schedule.

Release Production Units (A523):
Based on the detailed schedule, release production units to work cells or workstations and initiate processing the production units.

Resource Release Orders:
A resource release order is an instruction that requests to release resources from storage or from current user to a new user.

Task Assignments:
Records of assigning tasks with due dates to workers.

Released Units:
Production units that are released for processing in the manufacturing facility.

B.16 *Track Production Units and Resources* activity

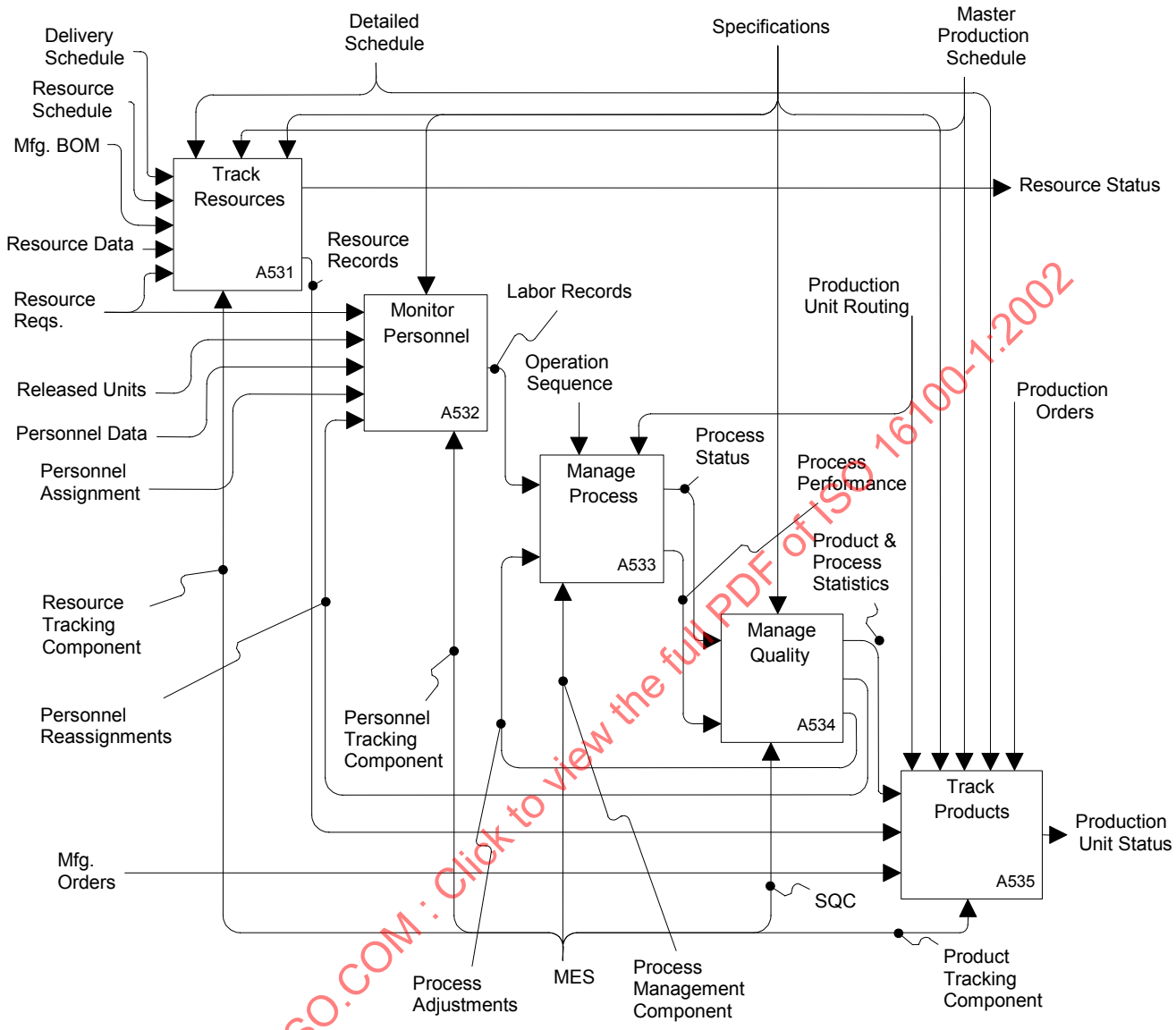


Figure B.15 — Track Production Units and Resources

Track Resources (A531):

Follow up and monitor the status of resources. On-line track resource usability and consumption. Create a record of history of resources that are necessary to be traced.

Monitor Personnel (A532):

Follow up personnel status and report the status. The report includes attendance, labor skill changes, job assignments, time performed on each assignment, and material/tool preparation time.

Manage Process (A533):

Monitor a production process and timely make decisions to adjust detailed schedule and process plan when unexpected situations occur. These activities should be coordinated with the process and equipment control functions. Process management includes alarm management to make sure factory person(s) are aware of process changes that are outside acceptable tolerances. It also includes process setup and tool preparation before production units are dispatched for processing. It maintains a history of past events or problems to aide in diagnosing problems.

Manage Quality (A534):
Provide timely analysis of measurements collected from products and processes to control product quality. Check the current production rate with the detailed production schedule. Identify problems in production requiring attention. Recommend proper actions to correct the problems. Make the statistics and status of products and processes visible to production/business management personnel.

Track Products (A535):
Monitor the progress of production and provide up-to-minute report on the production status, such as the quantity of a product made, scrap rate, rework rate, and the comparison to the production schedule.

Labor Records:
A labor record is a piece of data that records the time, the attendance, tasks performed, tasks assigned, skill level, and certificates of a worker.

Personnel Tracking Component:
A software component in MES that aids users to track workers in a manufacturing facility.

Personnel Reassignments:
Requests to reassign workers to new tasks.

Process Adjustments:
Requests from operators to process planners to modify the process plan or to adjust certain predefined parameters to improve process performance.

Process Management Component:
A software component in MES that aids users to manage processes.

Process Performance:
Measures of how good parts, components, and products are produced by a process. Process performance include production rate, product quality, and process capability.

Product & Process Statistics:
Measurements and statistical analyses of process performance and quantities and the quality of products.

Product Tracking Component:
A software component in MES that aids users to track resources used in a manufacturing facility.

Resource Records:
A resource record is a piece of information that indicates where the resource is located and who is using it for which operations on which production unit for how long. If it is a piece of equipment, the record should also show whether it is functional.

SQC (Statistical Quality Control) :
SQC is a software component in MES that aids users to analyze and control product quality and to monitor process capability and shift.

B.17 *Manage Factory Floor Data and Documents* activity

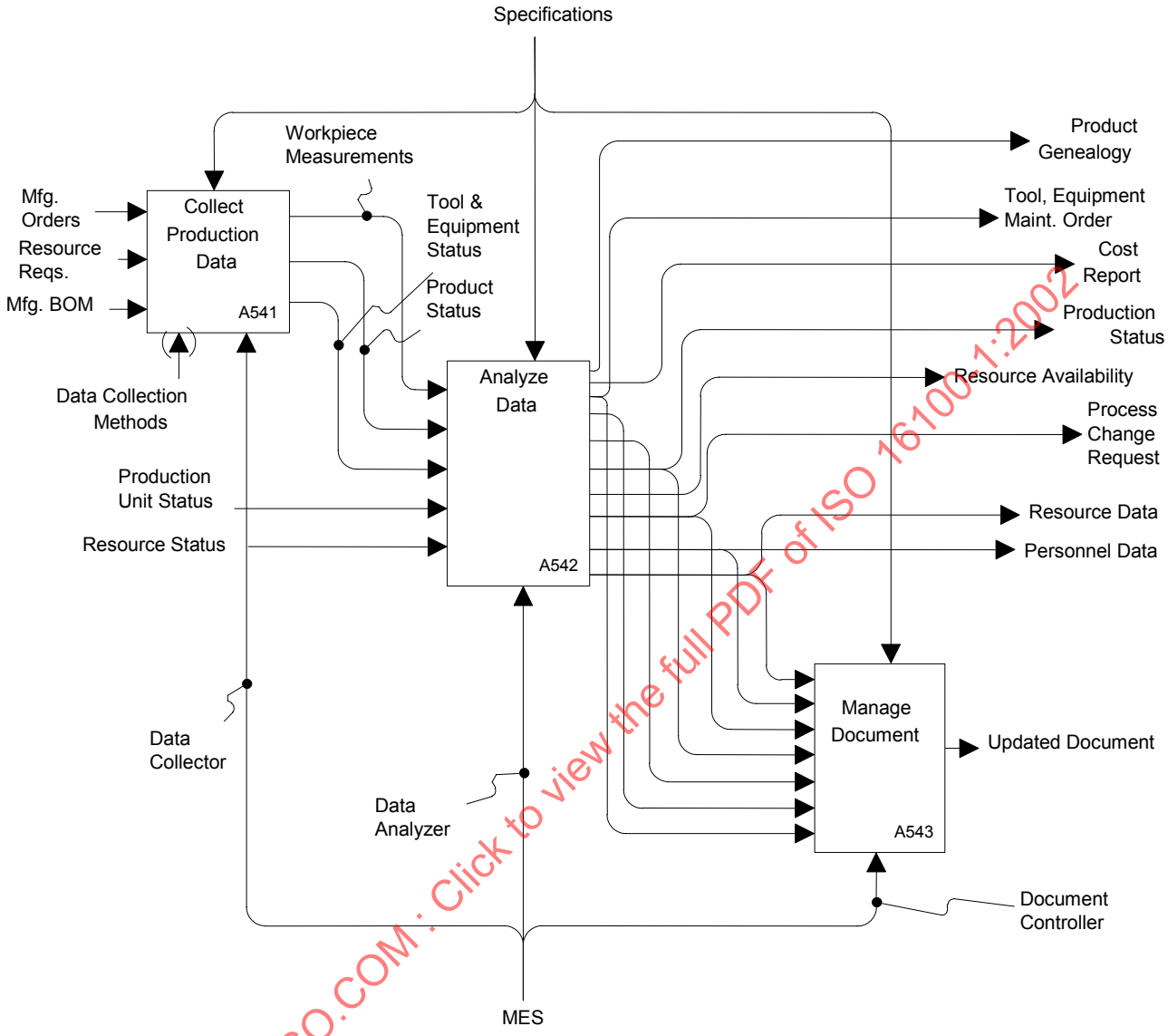


Figure B.16 — Manage Factory-floor Data/Document

Collect Production Data (A541):

Using data collection devices, acquire data by measuring and sampling workpieces, products, and production processes to support the management of product, quality, and process.

Analyze Data (A542):

Using collected data and adequate algorithms, analyze the data and generate record and reports, and make them available for decision making and product tracking.

Manage Document (A543):

Collect (or generate), maintain, and distribute production-related documents and records to support the production, factory-floor decision making, and product traceability.

Data Collector:

A collection of devices with control software that are linked to factory-flow production equipment to gather data either manually or automatically from the manufacturing facility in an up-to-minute time frame.

Data Analyzer:
A software component that provides up-to-minute report of actual manufacturing operations results along with the comparison to past history and business expectations. The results include such measurements as resource utilization, resource availability, product cycle time, conformance to schedule, and performance to standards.

Document Controller:
A mechanism, usually software, that controls records and forms that support product life-cycle activities, such as manuals, drawings, computer models, procedures, recipes, programs, engineering change orders (ECO), shift-to-shift communication records, etc.

Product Status:
Current conditions of a product, including the quantity of the product made, check it against the schedule, measurement and test results, and any exceptional process conditions occurred.

Tool & Equipment Status:
The condition of all tools and equipment. Condition includes the usage load, wear and tear, broken status, and the forecasted life span.

Workpiece Measurements:
The assessment and comparison of workpiece geometry, dimension, tolerance, and functions for the conformance to the design attributes.