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

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 16100-1 was prepared by Technical Committee ISO/TC 184, *Automation systems and integration*, Subcommittee SC 5, *Architecture, communications and integration frameworks*.

This second edition cancels and replaces the first edition (ISO 16100-1:2002), which has been technically revised.

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 services, protocols and capability templates*

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

— *Part 5: Methodology for profile matching using multiple capability class structures*

The following part is planned:

— *Part 6: Interface services and protocols for matching profiles based on multiple capability class structures*

Introduction

The motivation for ISO 16100 stems from the industrial and economic environment noted by ISO/TC 184/SC 5. 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 Modeling 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 mould 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:

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

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

— conformance tests that ensure the integrity of the software integration.

At the time of publication of this edition of this part of ISO 16100, there are five published parts to ISO 16100 and one planned part. This part of ISO 16100 specifies a framework for interoperability of a set of manufacturing software products used in the manufacturing domain and its integration into a manufacturing application. ISO 16100-2 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. ISO 16100-3 specifies the interface protocol and templates for various manufacturing application areas. ISO 16100-4 specifies the concepts and rules for the conformity assessment of the other parts of ISO 16100. ISO 16100-5 specifies a methodology for profile matching using multiple capability class structures. ISO 16100-6 will specify the interface services and protocols for matching profiles based on multiple capability class structures.

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

Part 1: Framework

1 Scope

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

ISO 16100 (all parts), *Industrial automation systems and integration — Manufacturing software capability profiling for interoperability*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

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
bill of materials
BOM
⟨manufacturing⟩ list of parts that are scheduled to be manufactured in the factory

NOTE For each part, a BOM contains part number, description, quantity, description, etc. The manufacturing BOM is the manufacturing version of product structure known as “as-built configuration”.

3.3
CAD/PDM
computer-aided design/product data management
computer systems that are used for product design and modelling, engineering, product data management and process data management

3.4
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 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.

3.5
capability profiling
selection of a set of offered services defined by a particular interface within a software interoperability framework

3.6
CAPP/CAM
computer-aided process planning/computer-aided manufacturing
computer systems that are used for process planning and programming of numerically controlled machines

3.7
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.

3.8
data collection
gathering of information on workpieces, timing, personnel, lots and other critical entities for production management in a timely manner

3.9
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.

3.10
design pattern
knowledge of how to convert specifications (e.g. manufacturing capability) into practical forms (e.g. capability profile template)

3.11
enterprise resource planning
ERP
planning function that includes inventory transaction, cost accounting, order fulfilment and resource tracking

NOTE 1 The planning methodology uses material requirements planning and master production schedule to calculate requirements for materials and to make recommendations to release replenishment orders when due dates and need dates are not in phase.

NOTE 2 An alternative definition of enterprise resources planning can be found in ISO 15531-1.

3.12
machine tool
manufacturing resource of the equipment class, associated with a machine, that enables the capability of machining

3.13
manufacturing application
group of activities (a process or part thereof), within a manufacturing domain of an enterprise, cooperating to realize a definite objective or role

3.14
manufacturing execution system
MES
system for producing the desired products or services, including quality control, document management, plant floor dispatching, work-in-process tracking, detailed product routing and tracking, labour reporting, resource and rework management, production measurement and data collection

NOTE The Object Management Group defines the information part of manufacturing execution systems (MES) as systems that deliver information enabling "the optimization of production activities from order launch to finished goods. Using current and accurate data, MES guides, initiates, responds to, and reports on plant activities as they occur. The resulting rapid response to changing conditions, coupled with a focus on reducing non-value-added activities, drives effective plant operations and processes. MES improves the return on operational assets as well as on-time delivery, inventory turns, gross margin and cash flow performance. MES provides mission-critical information about production activities across the enterprise and supply chain via bi-directional communications."

3.15
manufacturing software interoperability
ability to share and exchange information using common syntax and semantics to meet an application-specific functional relationship across a common interface

3.16
manufacturing software
type of software resource within an automation system that provides value to a manufacturing application 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

NOTE CAD/PDM is an example of a manufacturing application.

3.17
manufacturing software component
class of manufacturing software resource intended to support the execution of a particular manufacturing task

3.18
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 modelled using UML as a software object.

3.19
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

3.20
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 Annex C provides use cases and related scenarios involving manufacturing software capability.

3.21
manufacturing software capability profile
concise representation of a manufacturing software capability to meet a requirement of a manufacturing application

3.22
product data management
PDM
management of a single, centralized data repository that enables authorized users throughout the company to access and update current product information

NOTE The Object Management Group defines a product data management (PDM) system as a software tool that manages engineering information, supports management of product configurations, and supports management of the product engineering process. The engineering information includes both database objects and "document" objects – sets of information stored in files that are opaque to the PDM system. This information may be associated with specific products or specific product designs, or more generally with product families, production processes or the engineering process itself. The engineering process support usually includes workflow management and concepts of engineering change and notification. In many manufacturing organizations, the PDM is the central engineering information repository for product development activities.

3.23
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]

3.24
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.

3.25
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 Abbreviated terms

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 Modeling Language

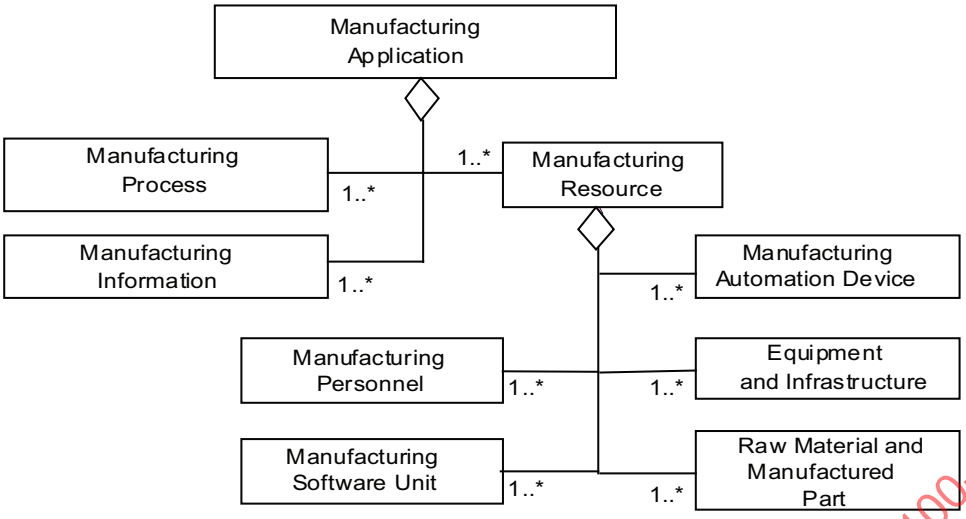
5 Manufacturing application

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 modelled 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.



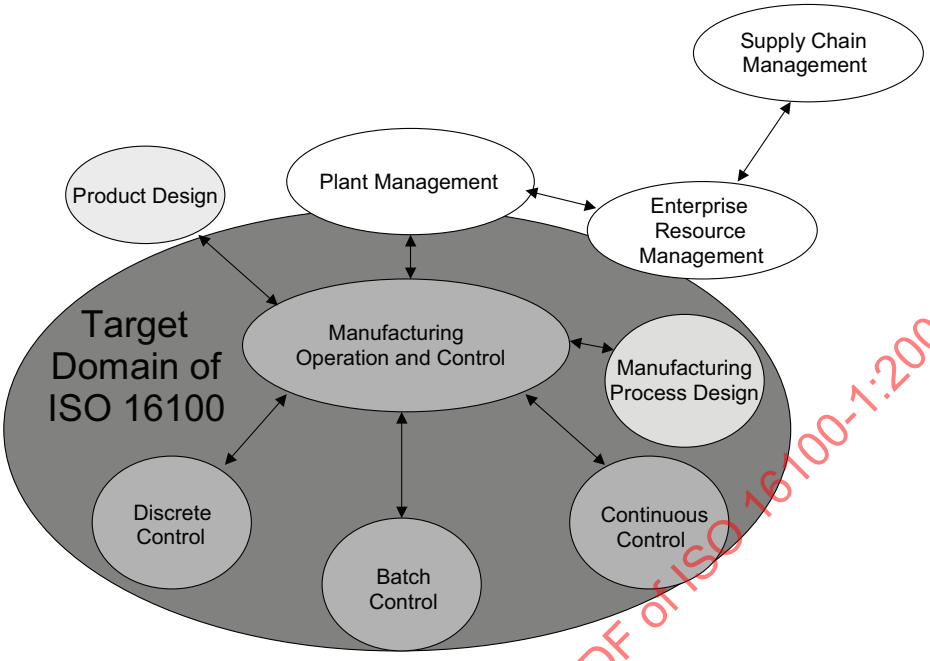
NOTE Boxes represent classes of objects (things). Lines connecting boxes represent associations between objects (things). An association has two roles (one in each direction). A role may optionally be named by a label. A role from A to B is closest to B, and vice versa. Roles are one-to-one unless otherwise 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 shaded diamond at the end of an association line denotes a composition aggregation relationship. The absence of at least one type of aggregated element deletes the object instance of the composition aggregation class. An unshaded diamond denotes a collection aggregation relationship. An object instance of a collection aggregation class can be formed even if some of the types of aggregated elements are not present. For example, Manufacturing Application owns (is comprised of) Manufacturing Process, Manufacturing Information and Manufacturing Resources. This notation is taken from ISO/IEC 19501.

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.



NOTE The dark grey shaded area delimits the scope of a manufacturing domain in ISO 16100.

Figure 2 — Target domain of ISO 16100

5.3 Manufacturing processes

A manufacturing process shall be modelled 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 fulfils 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, provide 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 artefacts 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). Framework elements for multiple capability class structures are covered in ISO 16100-5 and ISO 16100-6.

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

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.

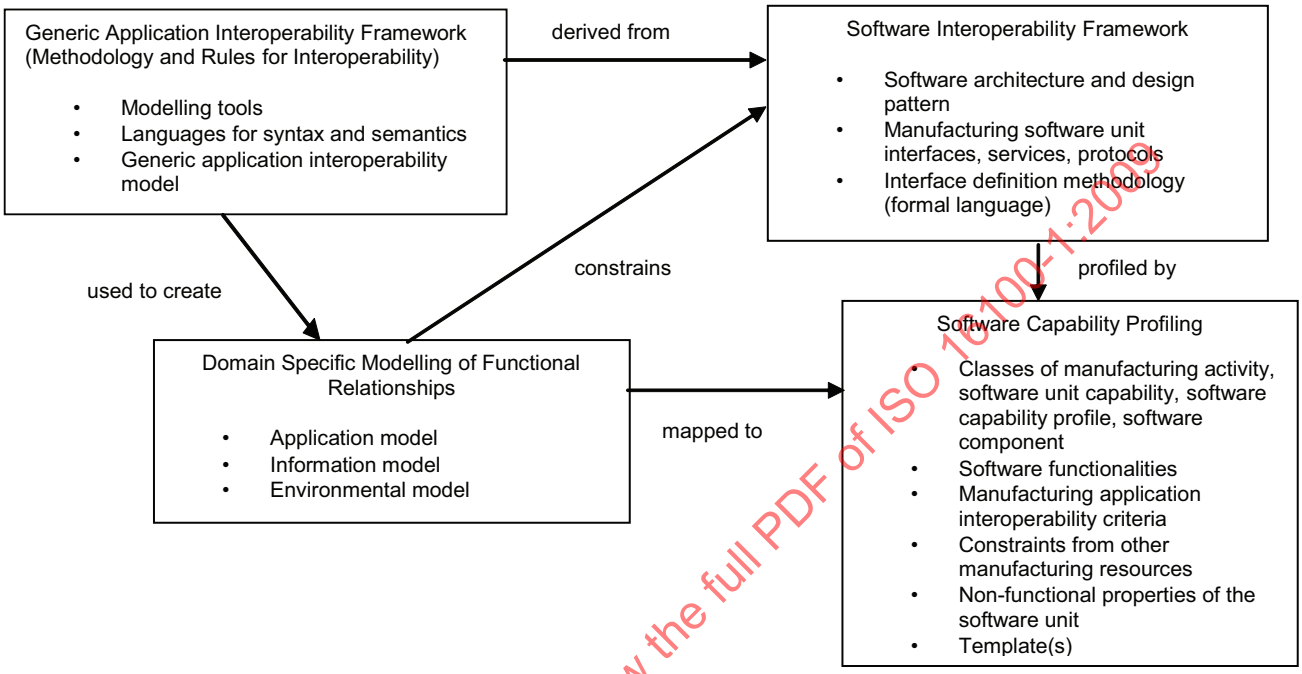


Figure 3 — Relationships of software interoperability aspects

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 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 shows various classes including those used to represent a software unit and its surrounding elements and associations within an environment of a manufacturing application.

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.

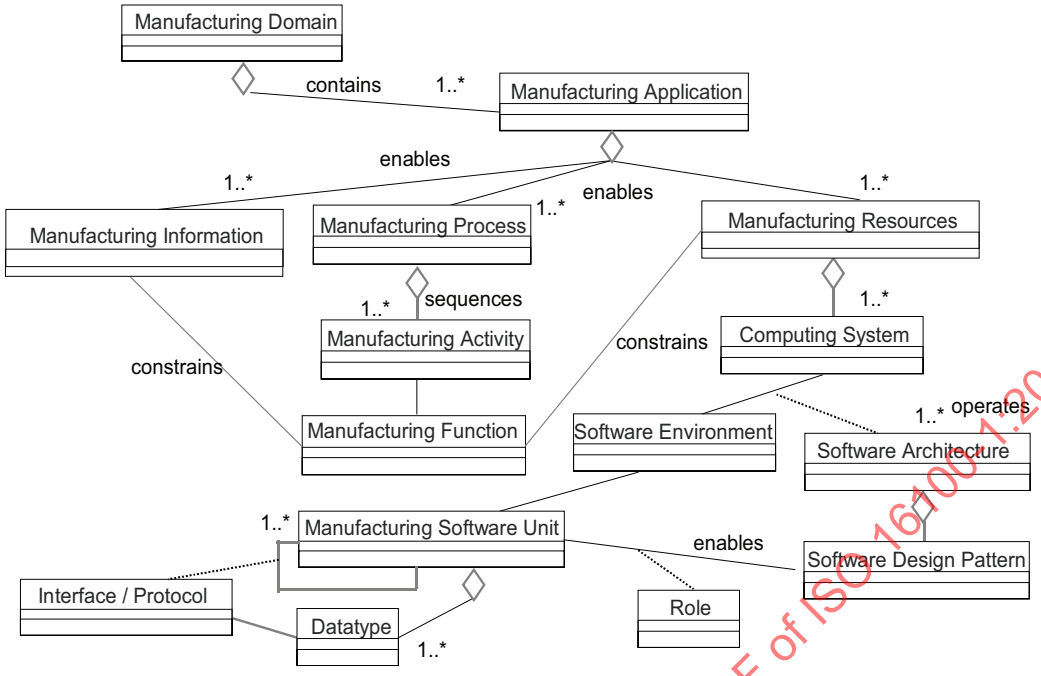


Figure 4 — Class diagram of a software unit and its surroundings and associations within a manufacturing application

A software unit shall be modelled 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 modelled 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.

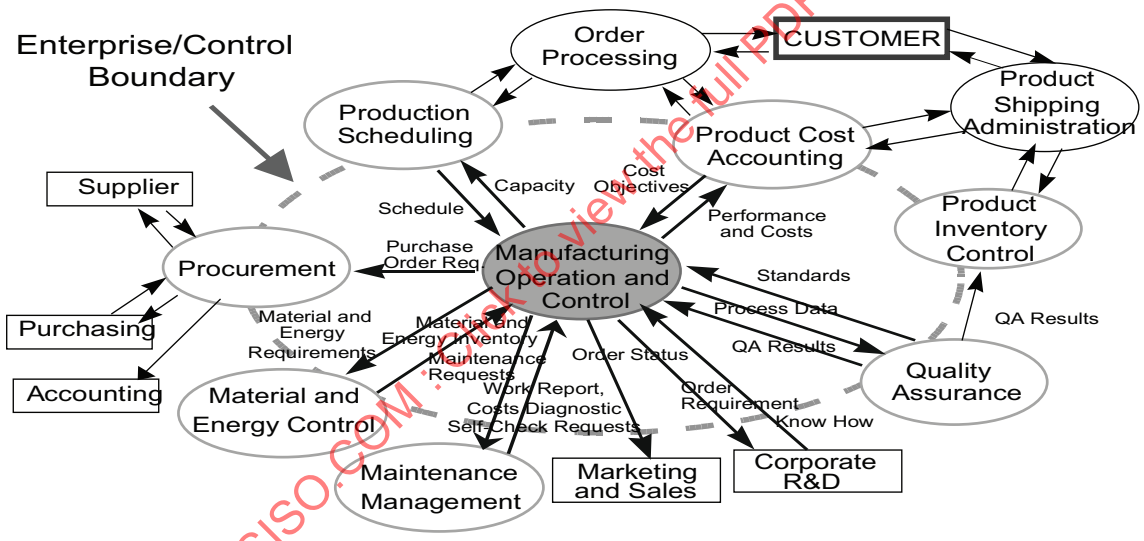
Annex A
(informative)

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 part of ISO 16100, the domain classes defined in the manufacturing enterprise reference architecture noted in ISO 15704:2000, Clause B.3, will be referenced.



NOTE Figure adapted from IEC 62264-1.

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

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). A different grouping may result if the target domain were some activity other than Production Control.

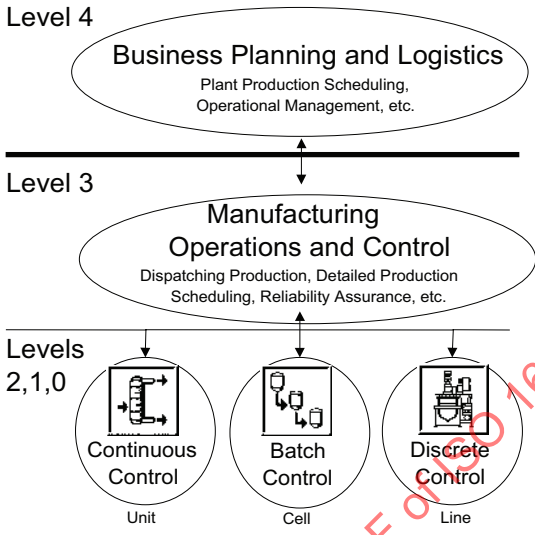
The classes of functions to be used in distinguishing a manufacturing software capability can be defined in terms of the following characteristics:

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.

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 involves functions such as general ledger, bank book, accounts receivable, accounts payable, currency management, assets depreciation and other financial transaction support.

The Quoting and Estimating sub-domain involves functions such as standard product routing, labour 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

The Material and Energy Planning and Control activity sub-domain involves 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 labelling 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 part of ISO 16100 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) to e). Details for activities f) and g) can be constructed using the same conventions for activity diagramming as those described at the start of Annex B. Activity g) will require feedback to activities a) to f).

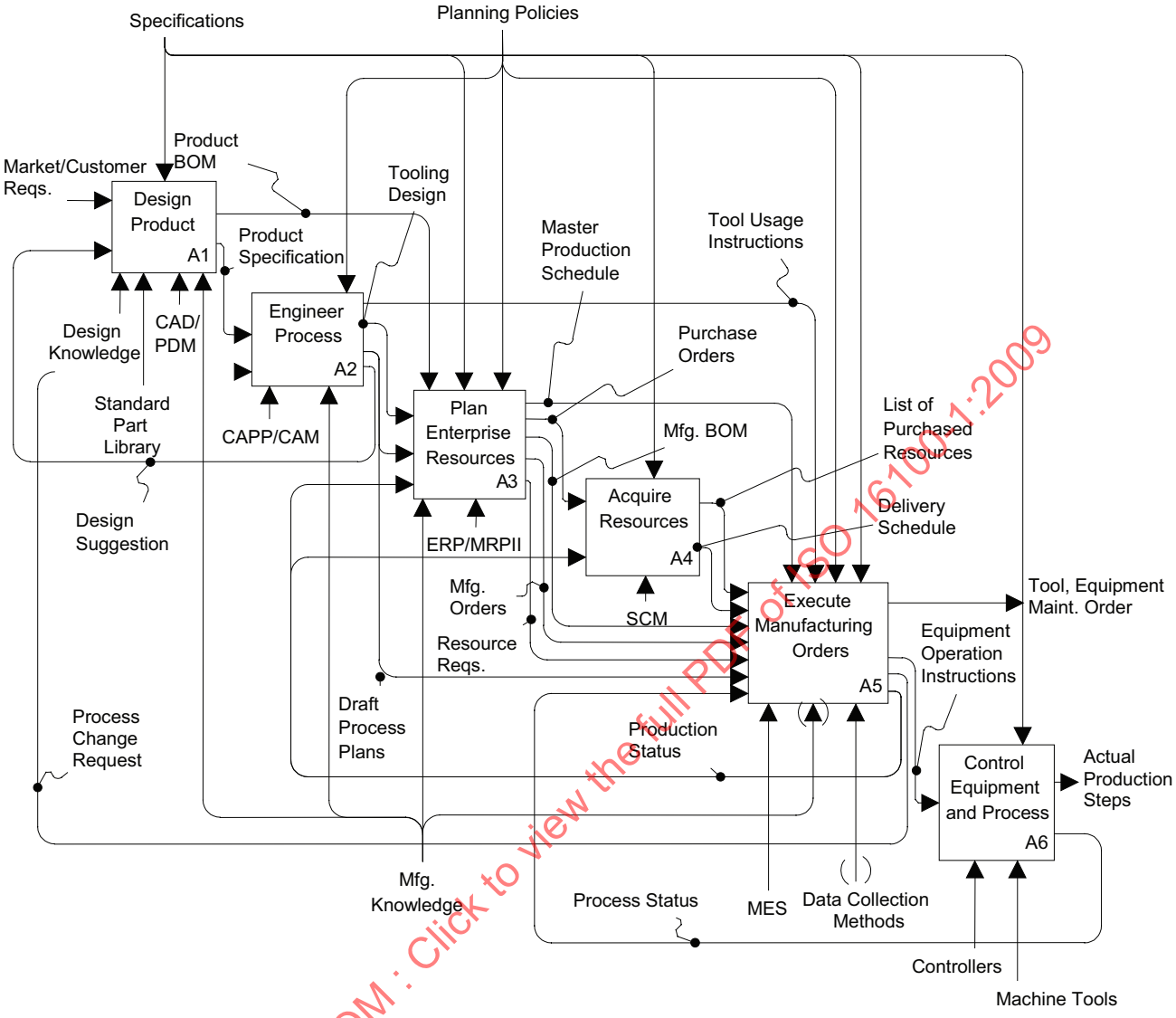
Annex B
(informative)

Examples of the manufacturing activity reference model

Figures B.1 to B.18 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.

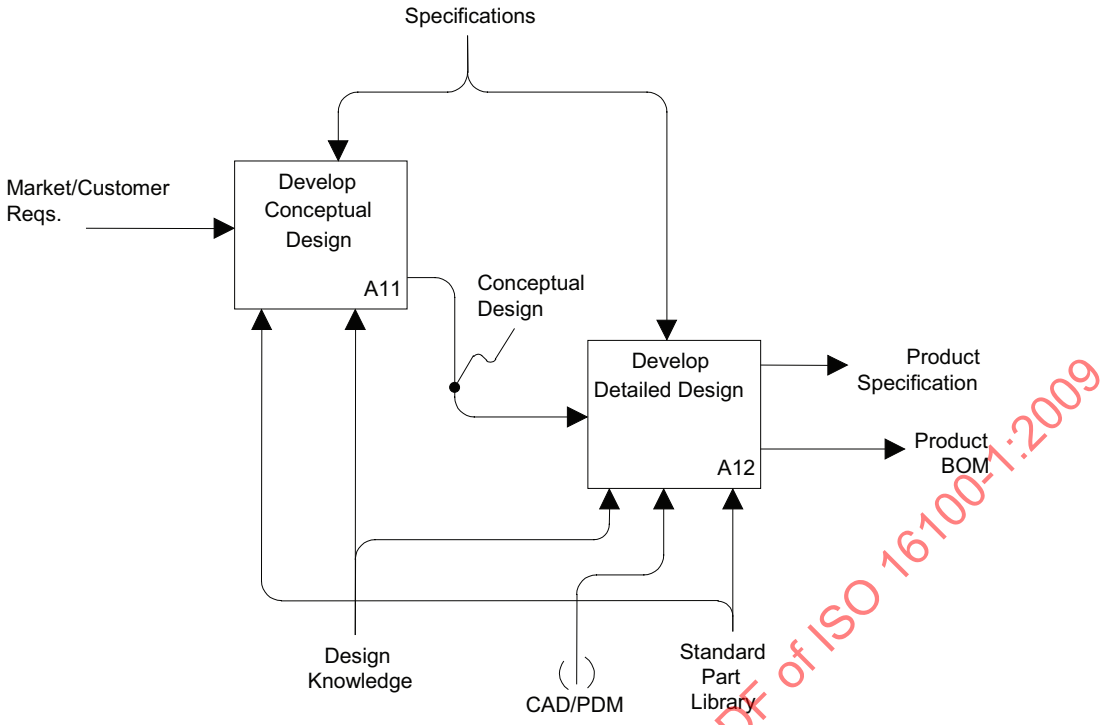
The elements shown in the manufacturing activity reference models in Figures B.1 to B.18 are explained in Table B.1.



No.	Activity	Description
A1	Design Product	The product design engineering includes functional requirements, conceptual design, embodiment design, detailed design, design analysis and the specification of Bill of Material.
A2	Engineer Process	Generate a manufacturing process plan and alternative plans. The manufacturing process engineering includes process selection, operation planning, workpiece routing and equipment/device control program generation. This activity provides design and processing information for downstream resource planning and manufacturing execution.
A3	Plan Enterprise Resources	Analyse 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 labour 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.
A4	Acquire Resources	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.
A5	Execute Manufacturing Orders	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.
A6	Control Equipment and Process	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.

See Table B.1 for explanations of the other elements in this figure.

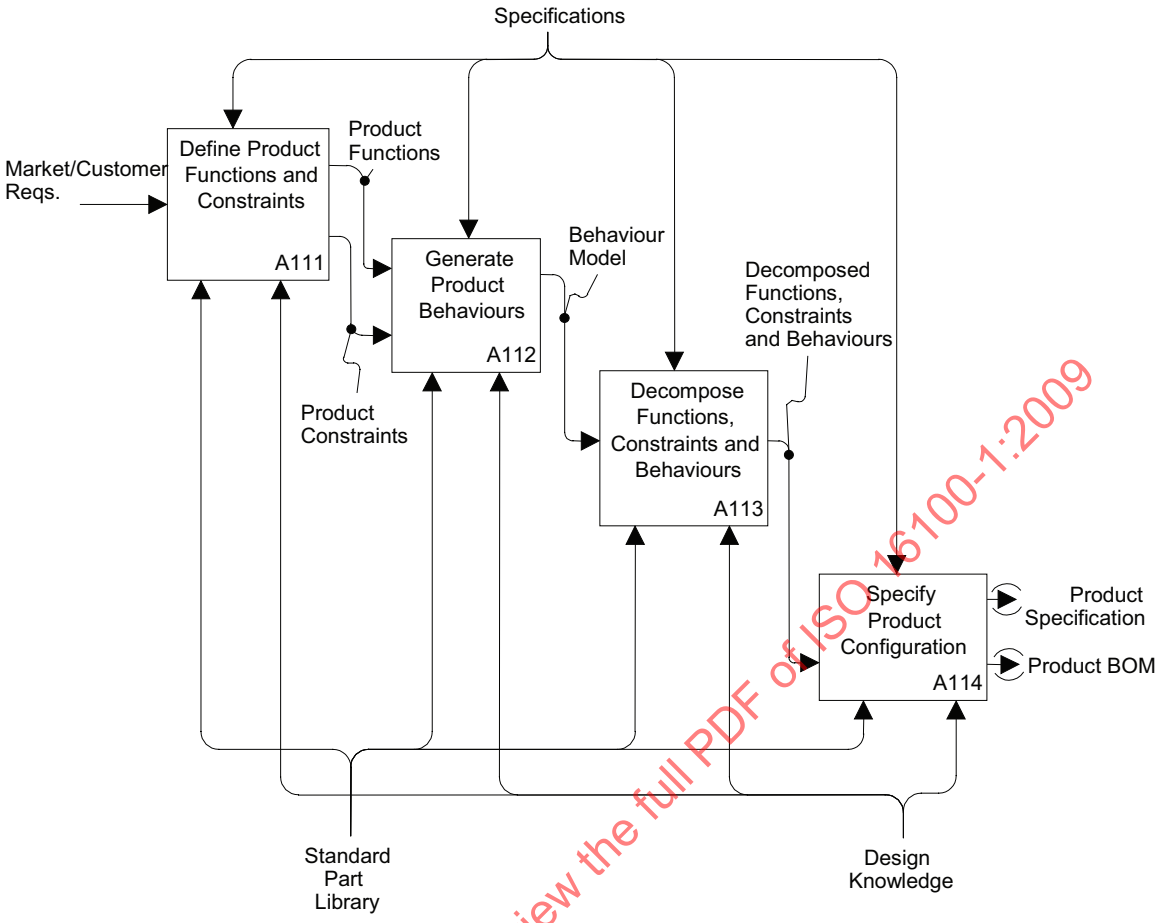
Figure B.1 — Develop Products activity



No.	Activity	Description
A11	Develop Conceptual Design	A decision-making process that generates product concepts. A product concept includes product requirements, functions, behaviours, form, possible materials, structure and constraints.
A12	Develop Detailed Design	A decision-making process that generates detailed geometry, topology, dimensions, tolerances, surface finishes, surface hardness and material specification of a product.

See Table B.1 for explanations of the other elements in this figure.

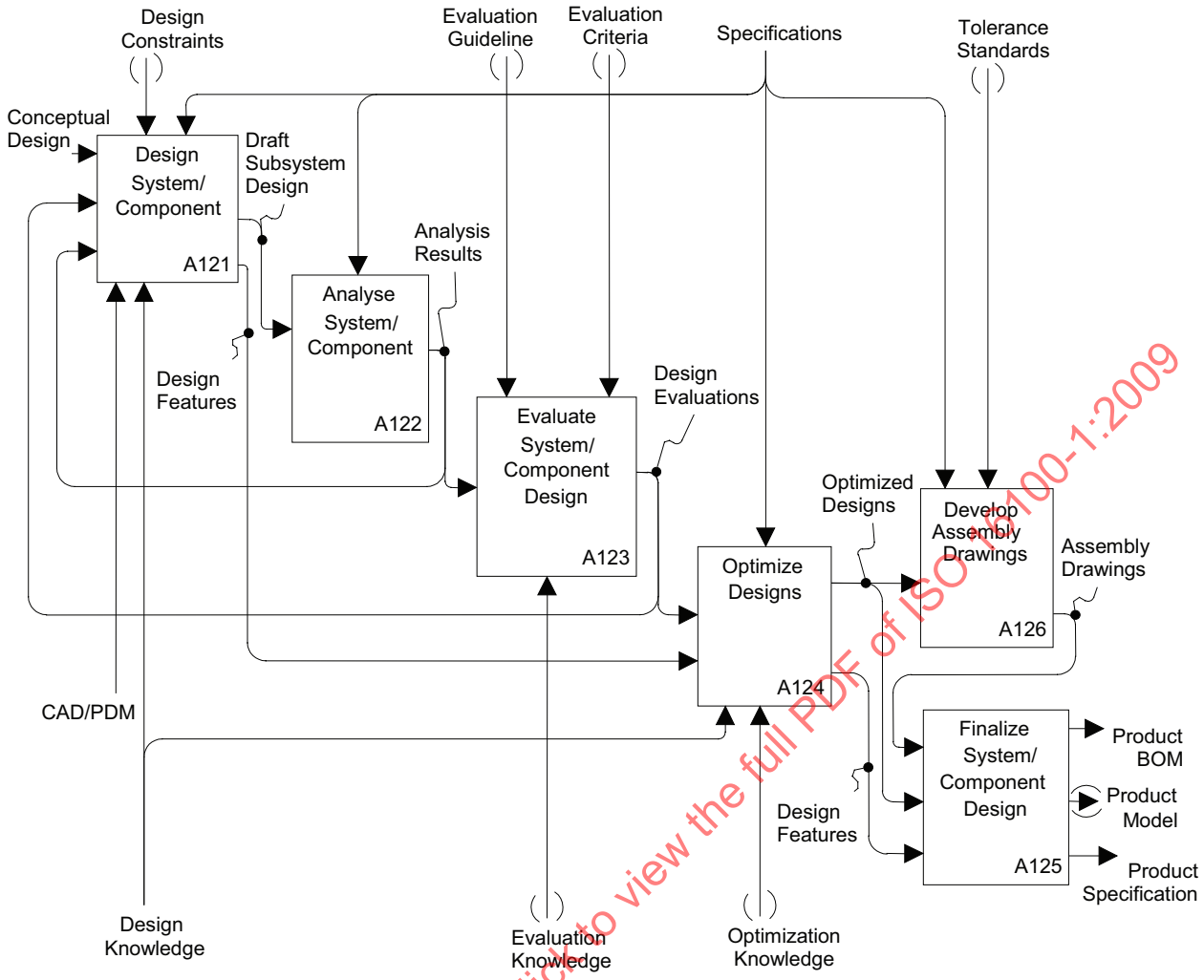
Figure B.2 — Design Products activity



No.	Activity	Description
A111	Define Product Functions and Constraints	The activity is to define product functions and constraints based on engineering requirements.
A112	Generate Product Behaviours	The activity is to generate product behaviours based on product functions and constraints.
A113	Decompose Functions, Constraints and Behaviours	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.
A114	Specify Product Configuration	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.

See Table B.1 for explanations of the other elements in this figure.

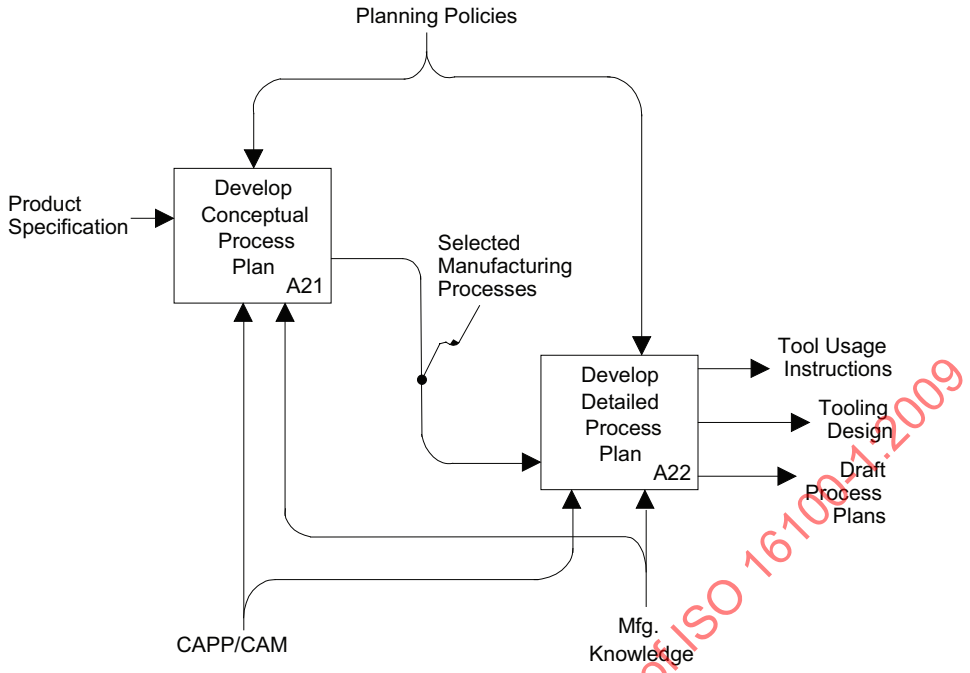
Figure B.3 — Develop Conceptual Design activity



No.	Activity	Description
A121	Design System/ Component	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.
A122	Analyse System/ Component	Perform engineering analysis of the characteristics and behaviour of components and subsystems. Determine and quantify the response of the designed system to both external and internal signals (e.g. forces). Both mathematical and visual simulations may be used.
A123	Evaluate System/ Component Design	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.
A124	Optimize Designs	Create a rigorous mathematical model of the system and optimize interrelated design parameters using various mathematical and engineering techniques.
A125	Finalize System/ Component Design	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.
A126	Develop Assembly Drawings	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.

See Table B.1 for explanations of the other elements in this figure.

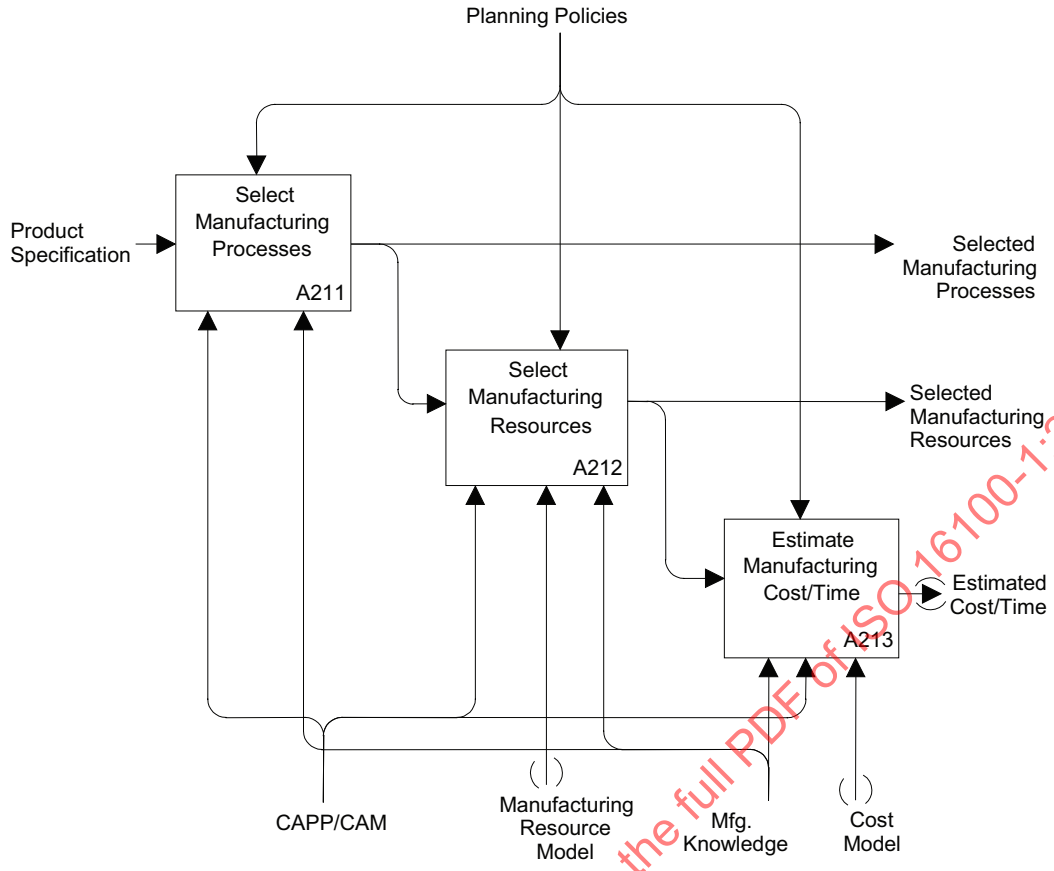
Figure B.4 — Develop Detailed Design activity



No.	Activity	Description
A21	Develop Conceptual Process Plan	Conceptual Process Planning is an activity to select manufacturing processes and resources, and to estimate manufacturing cost and time in the early design stage.
A22	Develop Detailed Process Plan	Detailed 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.

See Table B.1 for explanations of the other elements in this figure.

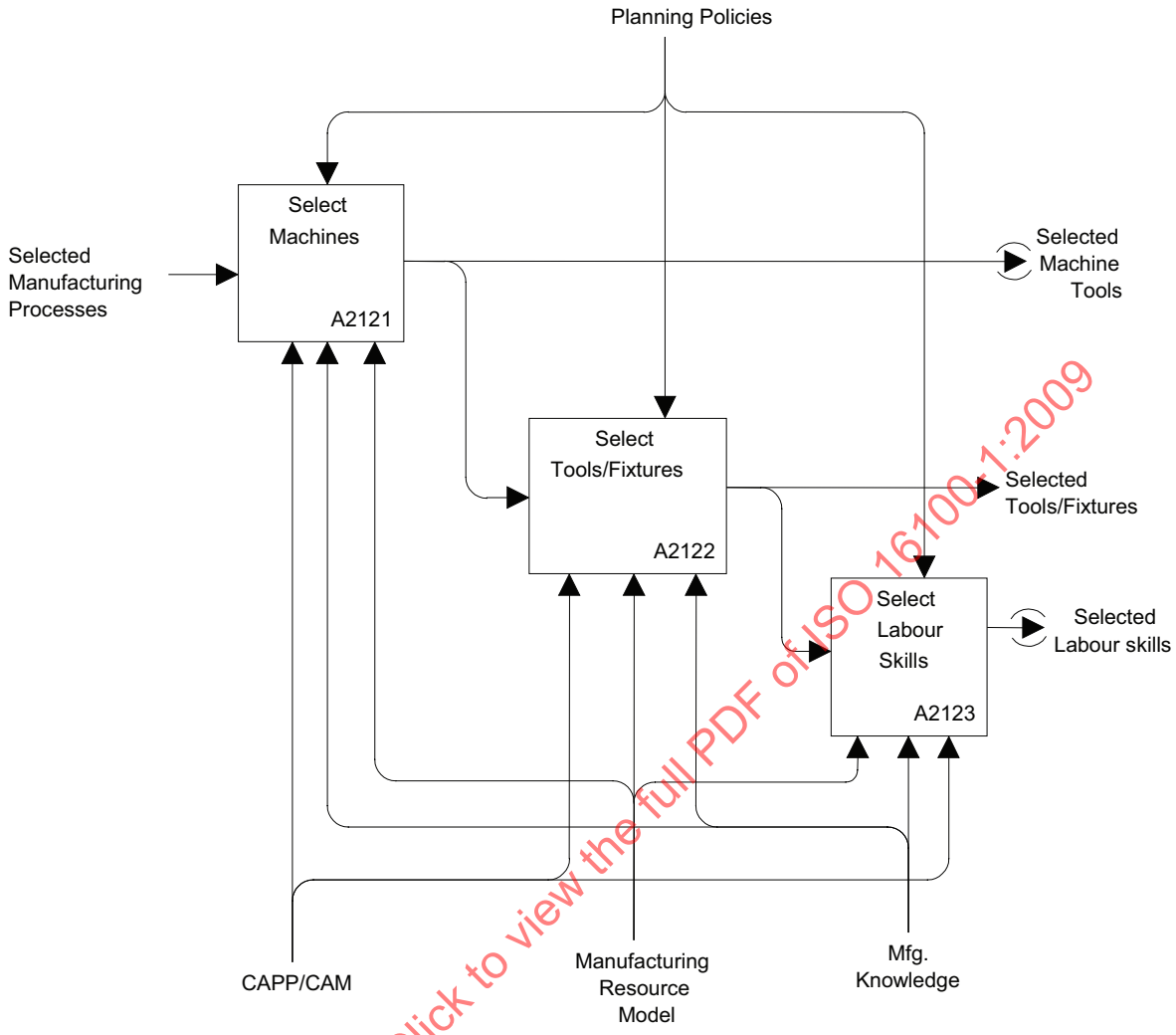
Figure B.5 — Engineer Process activity



No.	Activity	Description
A211	Select Manufacturing Processes	Select primary manufacturing processes, such as casting, forging, moulding and machining, based on conceptual design.
A212	Select Manufacturing Resources	Choose appropriate manufacturing resources including both physical resources and human resources. Physical resources include machines, tools, fixtures and gauges. Human resources include labour skills.
A213	Estimate Manufacturing Cost/Time	Estimate cost/time based on selected manufacturing processes and resources. Manufacturing cost covers material, purchased parts, labour, tooling, machine usage and overhead.

See Table B.1 for explanations of the other elements in this figure.

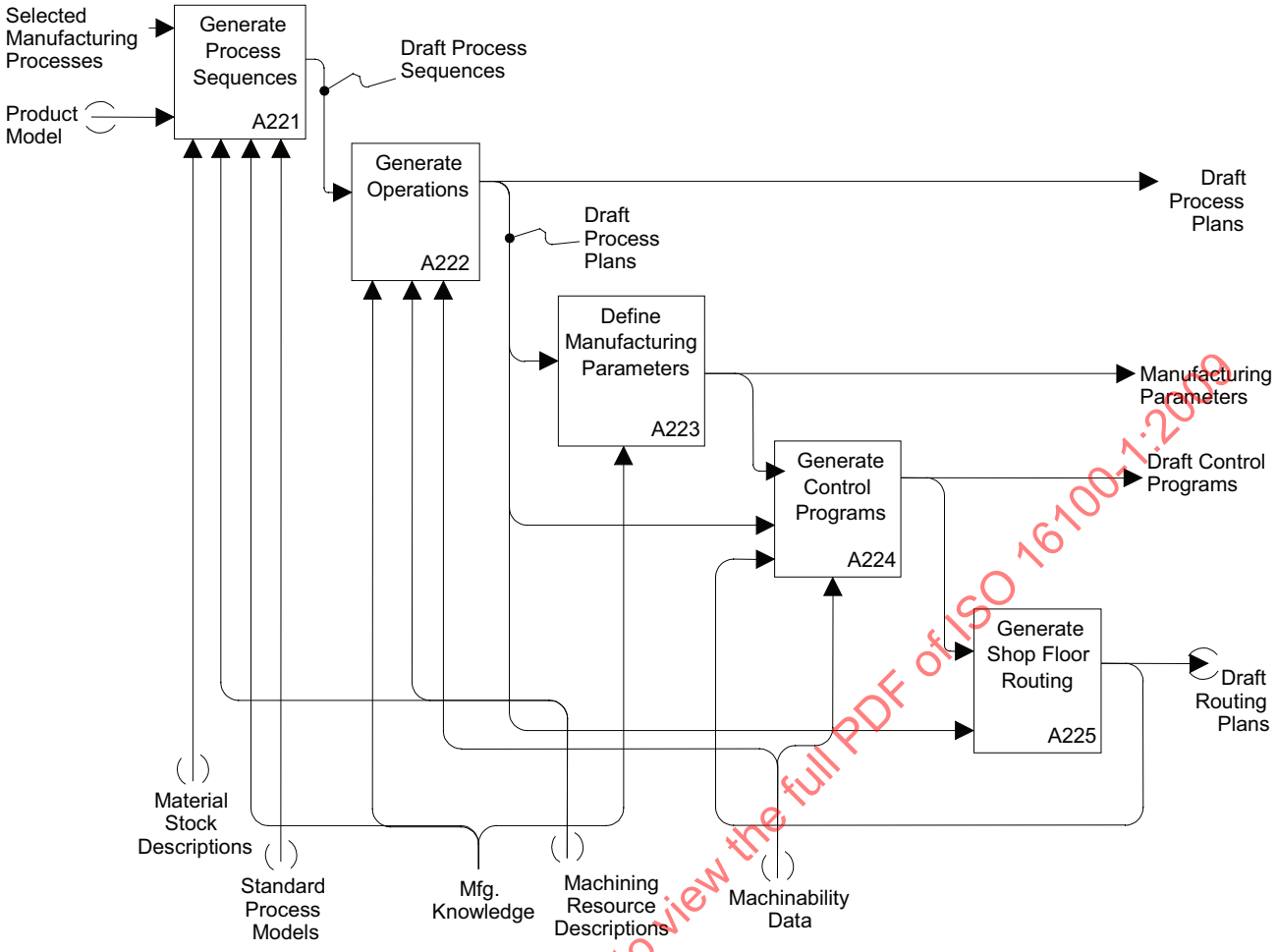
Figure B.6 — Conceptual Process Planning activity



No.	Activity	Description
A2121	Select Machines	Select Machines is an activity to select manufacturing machine or equipment based on manufacturing processes and product information.
A2122	Select Tools/Fixtures	Select Tools/Fixture is an activity to select manufacturing tools/fixtures based on manufacturing processes, product information and selected machines.
A2123	Select Labour Skills	Select Labour Skills is an activity to select proper labour skills based on manufacturing processes.

See Table B.1 for explanations of the other elements in this figure.

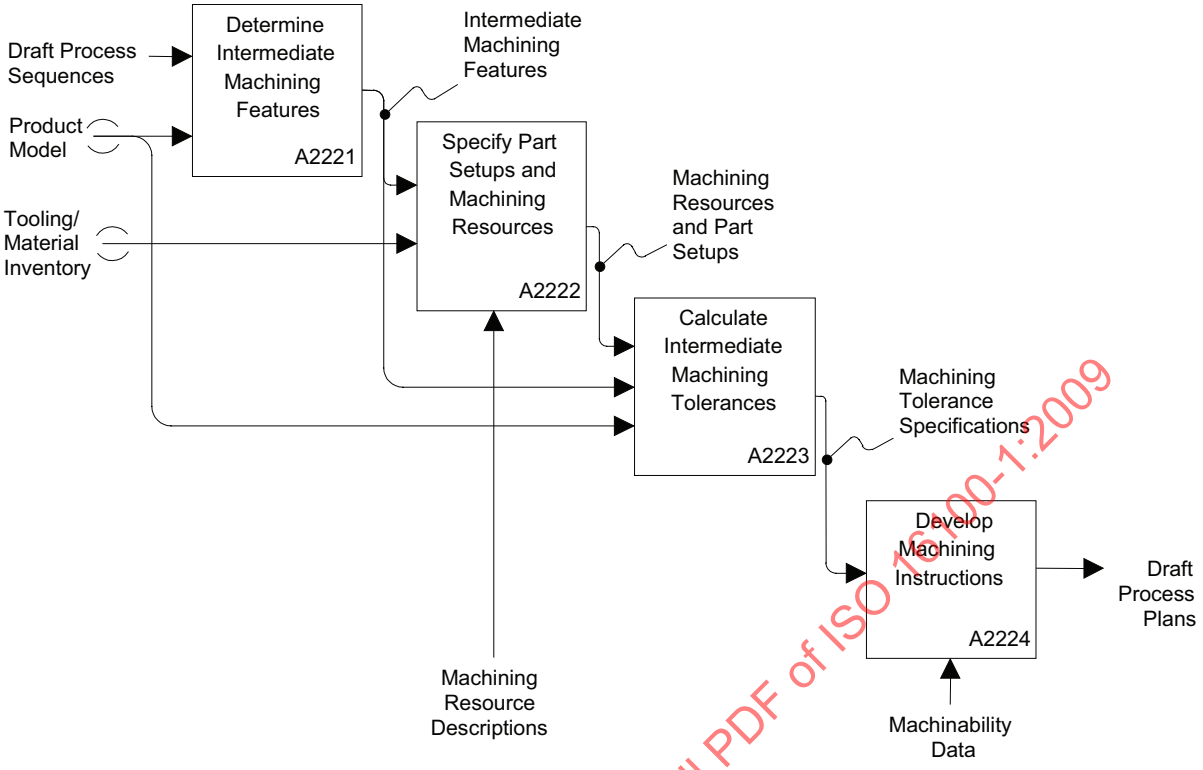
Figure B.7 — Select Manufacturing Resources activity



No.	Activity	Description
A221	Generate Process Sequences	The activity is to select and sequence a set of processes to transform material stocks to finished parts. Alternative sets of sequenced processes may be produced.
A222	Generate Operations	The activity is to develop detailed machining instructions for each operation in the process routing. The information used in an operation includes machining surfaces/features, workpiece setups, machines, tools and fixtures selected, machining dimensions and tolerances, etc.
A223	Define Manufacturing Parameters	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.
A224	Generate Control Programs	The activity is to create computer programs that control machine tools and workpiece handling and transportation machines on the shop floor. The computer code includes programs such as the numerical control (NC) programs for the machining centres, robot programs and automatic guided vehicle (AGV) programs.
A225	Generate Shop Floor Routing	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.

See Table B.1 for explanations of the other elements in this figure.

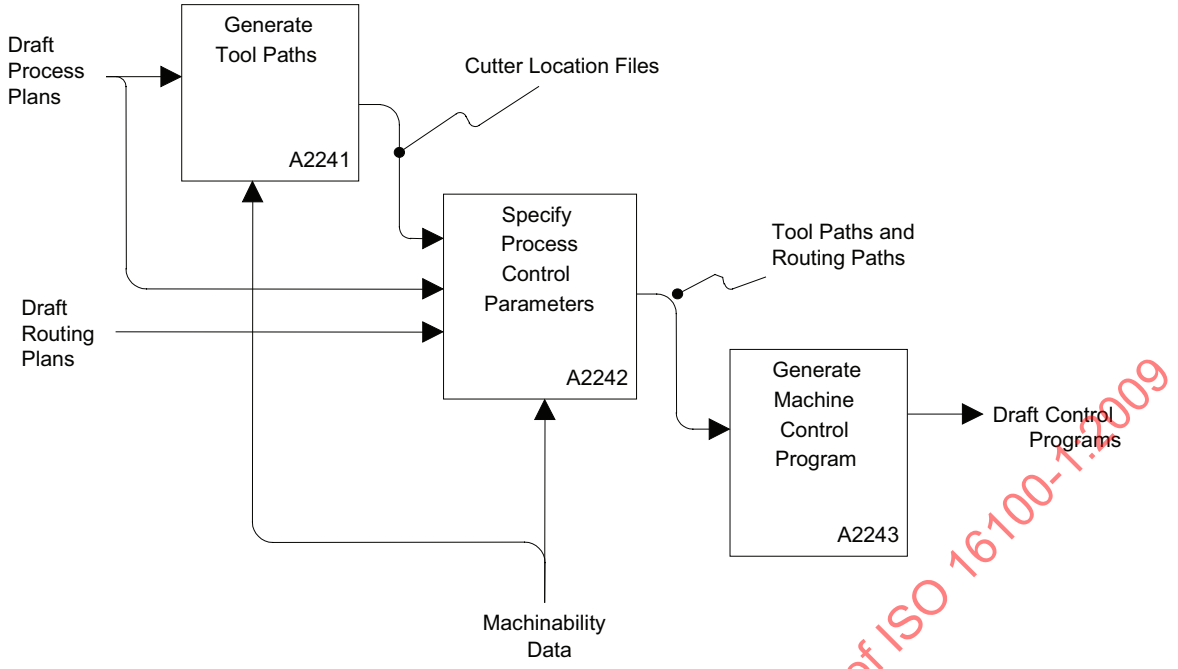
Figure B.8 — Develop Detailed Process Plan activity



No.	Activity	Description
A2221	Determine Intermediate Machining Features	The activity is to determine intermediate machining surfaces and features in each operation of the generated process sequences.
A2222	Specify Part Setups and Machining Resources	The activity is to choose the type of 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.
A2223	Calculate Intermediate Machining Tolerances	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.
A2224	Develop Machining Instructions	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.

See Table B.1 for explanations of the other elements in this figure.

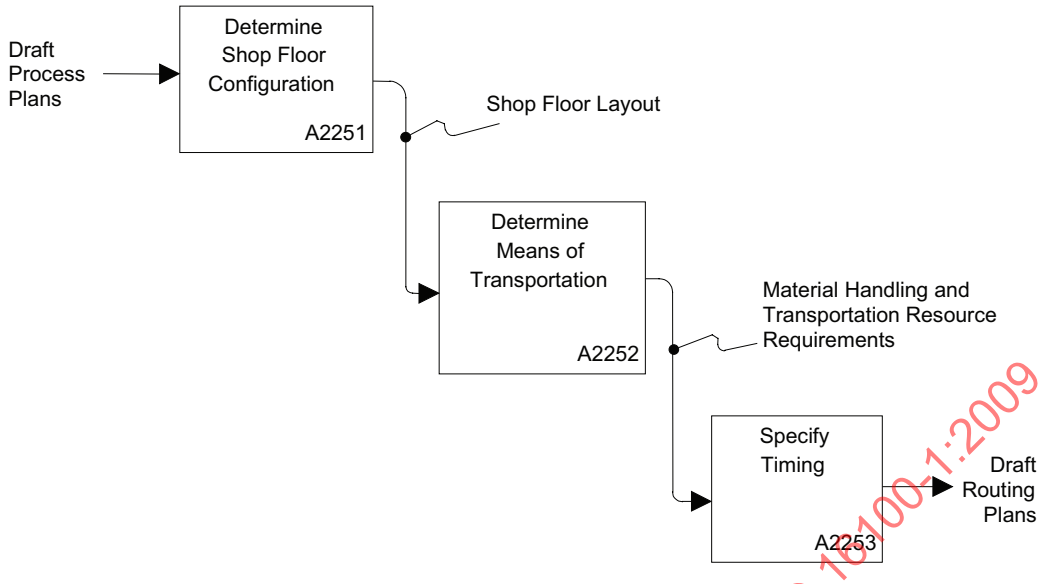
Figure B.9 — Generate Operations activity



No.	Activity	Description
A2241	Generate Tool Paths	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.
A2242	Specify Process Control Parameters	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.
A2243	Generate Machine Control Program	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.

See Table B.1 for explanations of the other elements in this figure.

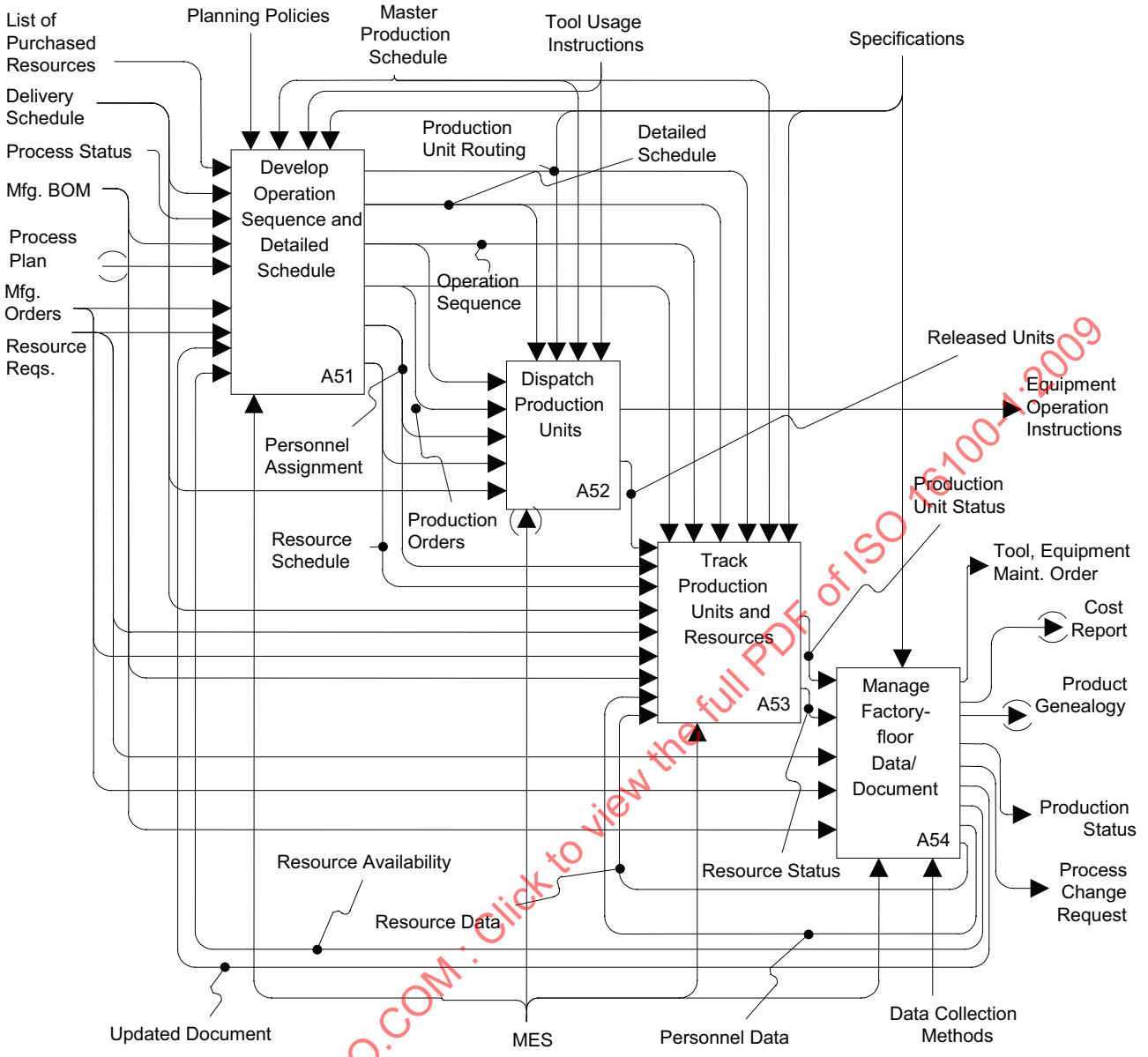
Figure B.10 — Generate Control Programs activity



No.	Activity	Description
A2251	Determine Shop Floor Configuration	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.
A2252	Determine Means of Transportation	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.
A2253	Specify Timing	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.

See Table B.1 for explanations of the other elements in this figure.

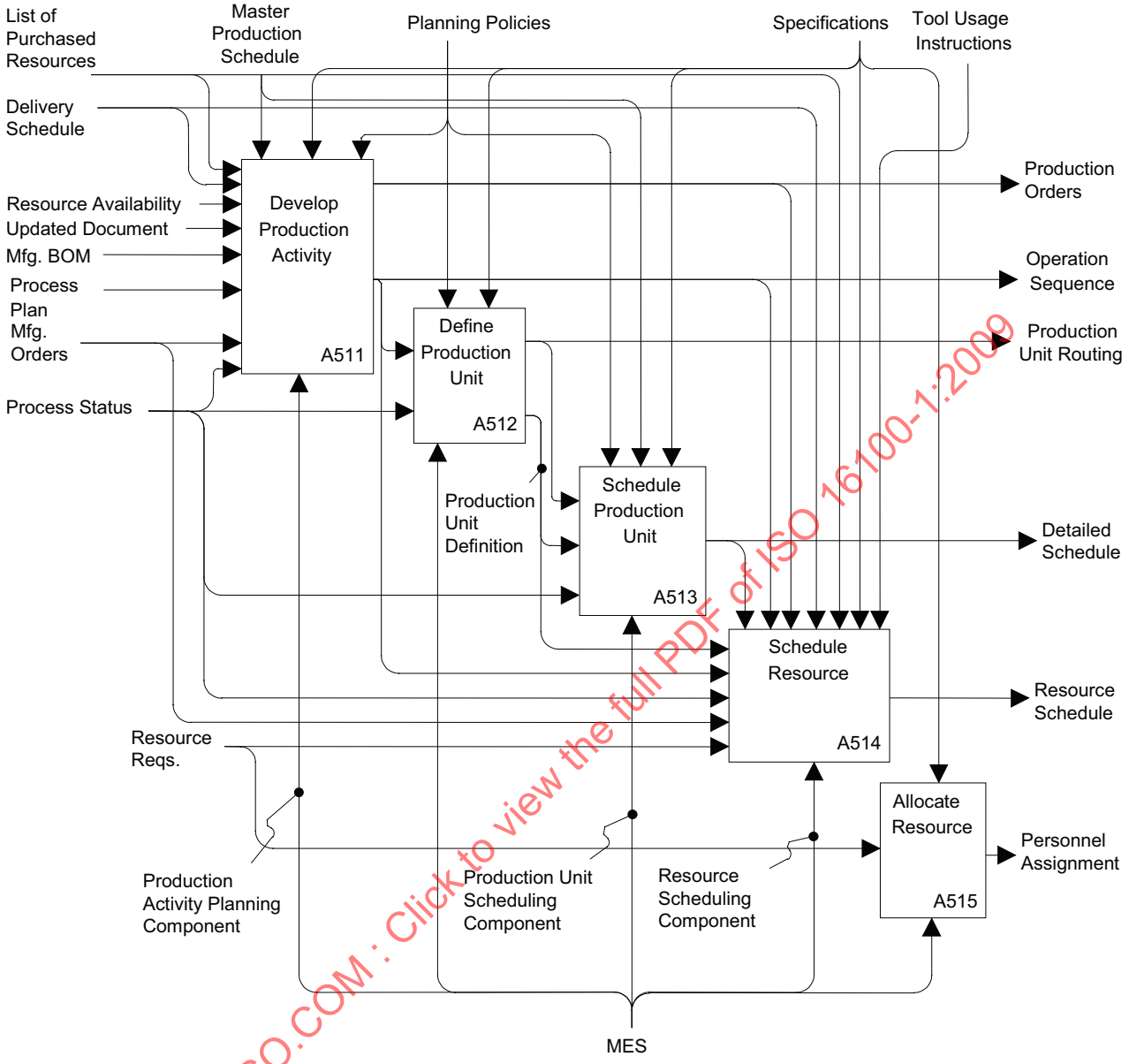
Figure B.11 — Generate Shop Floor Routing activity



No.	Activity	Description
A51	Develop Operation Sequence and Detailed Schedule	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.
A52	Dispatch Production Units	Determine which production unit in the queue is best processed next. The objective is to minimize the lead time and lateness.
A53	Track Production Units and Resources	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.
A54	Manage Factory-floor Data/ Document	Provide hardware/software interface links to obtain mission-critical data pertinent to production activities. Collect the data from the factory and analyse 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.

See Table B.1 for explanations of the other elements in this figure.

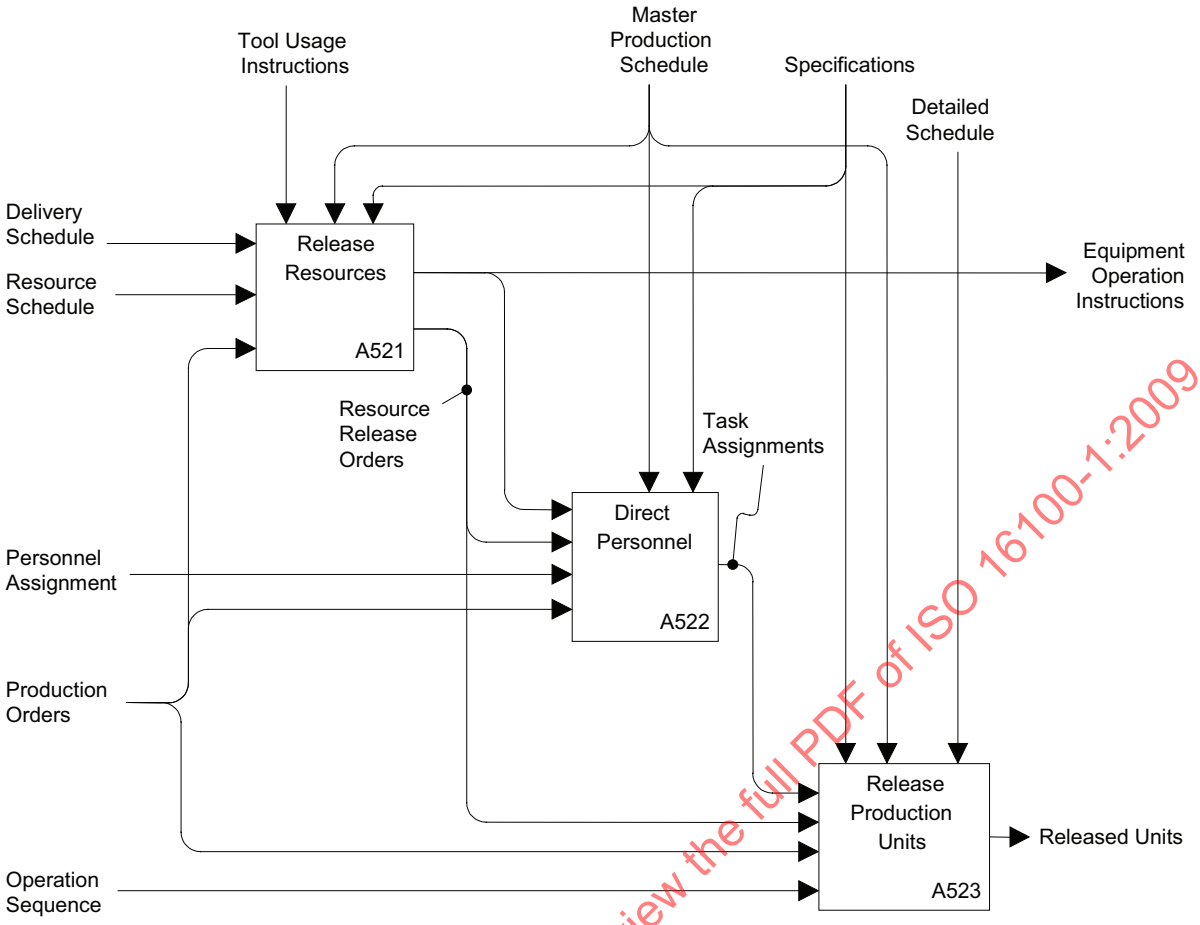
Figure B.12 — Execute Manufacturing Orders activity



No.	Activity	Description
A511	Develop Production Activity	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.
A512	Define Production Unit	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.
A513	Schedule Production Unit	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.
A514	Schedule Resource	Add start and finish time information on each resource that is used by operation(s) in the production.
A515	Allocate Resource	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.

See Table B.1 for explanations of the other elements in this figure.

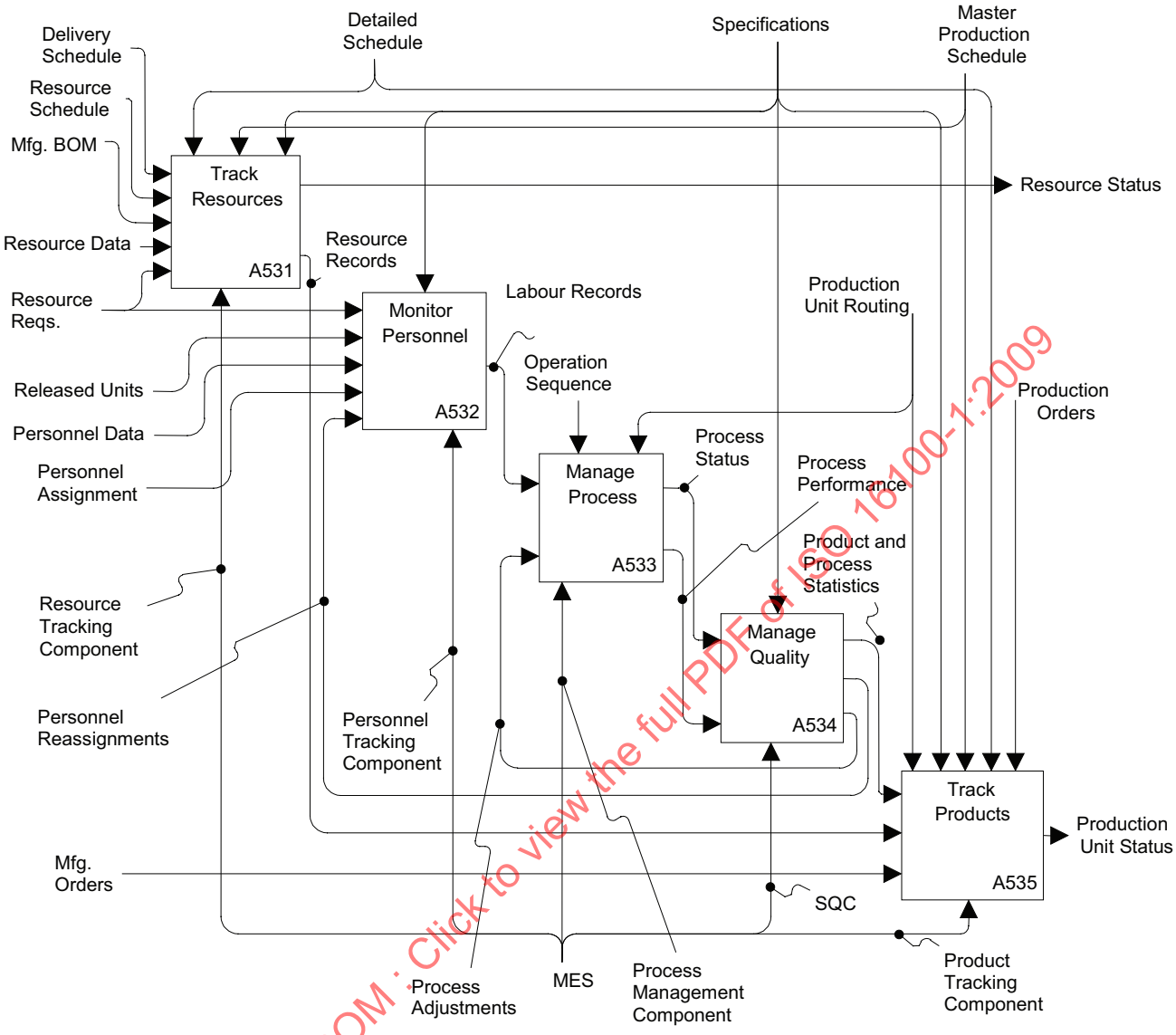
Figure B.13 — Develop Operation Sequence and Detailed Schedule activity



No.	Activity	Description
A521	Release Resources	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.
A522	Direct Personnel	Assign workers with adequate skills to perform specific operations according to the detailed schedule.
A523	Release Production Units	Based on the detailed schedule, release production units to work cells or workstations and initiate processing of the production units.

See Table B.1 for explanations of the other elements in this figure.

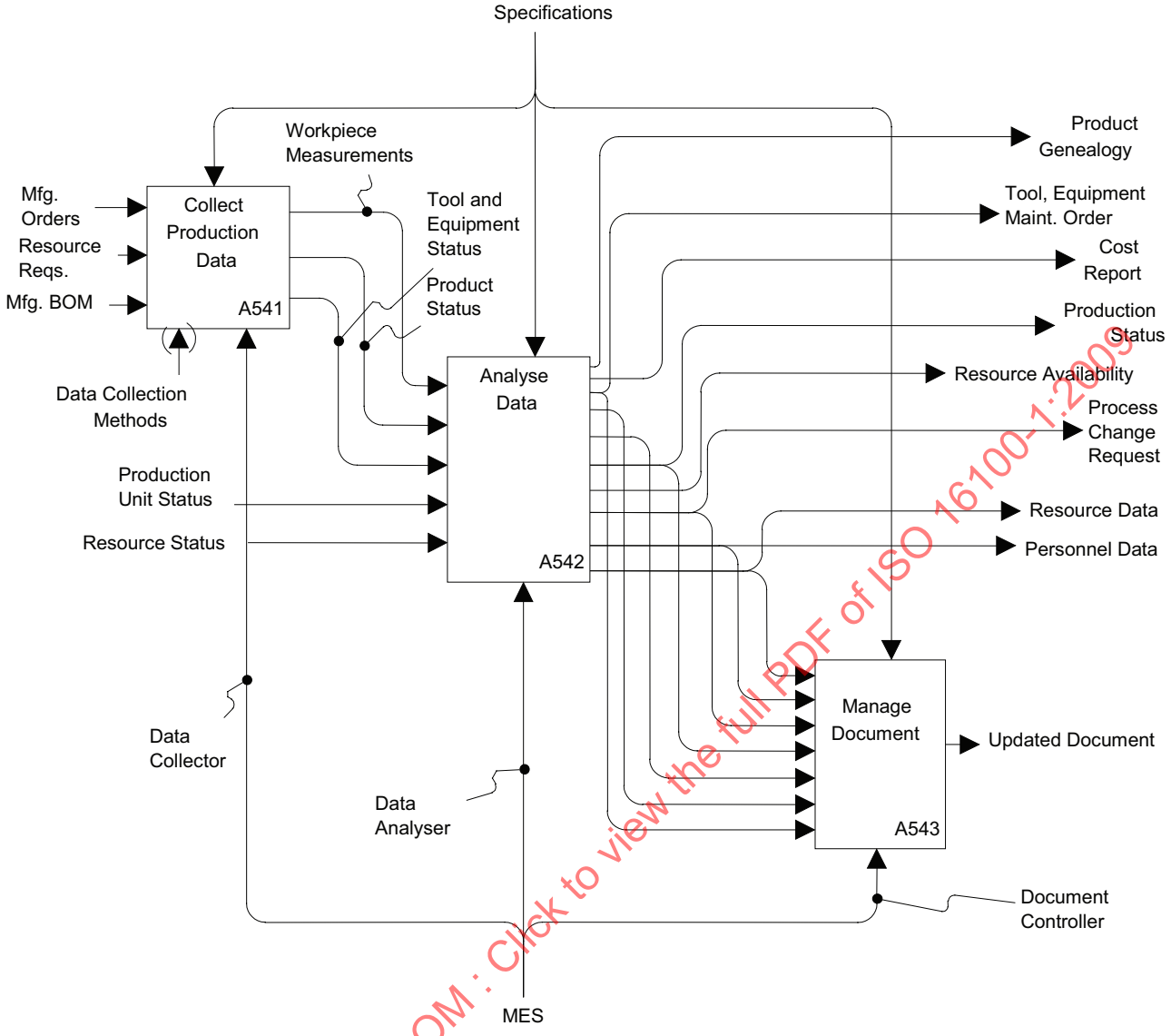
Figure B.14 — Dispatch Production Units activity



No.	Activity	Description
A531	Track Resources	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.
A532	Monitor Personnel	Follow up personnel status and report the status. The report includes attendance, labour skill changes, job assignments, time performed on each assignment, and material/tool preparation time.
A533	Manage Process	Monitor a production process and make timely 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 aid in diagnosing problems.
A534	Manage Quality	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.
A535	Track Products	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.

See Table B.1 for explanations of the other elements in this figure.

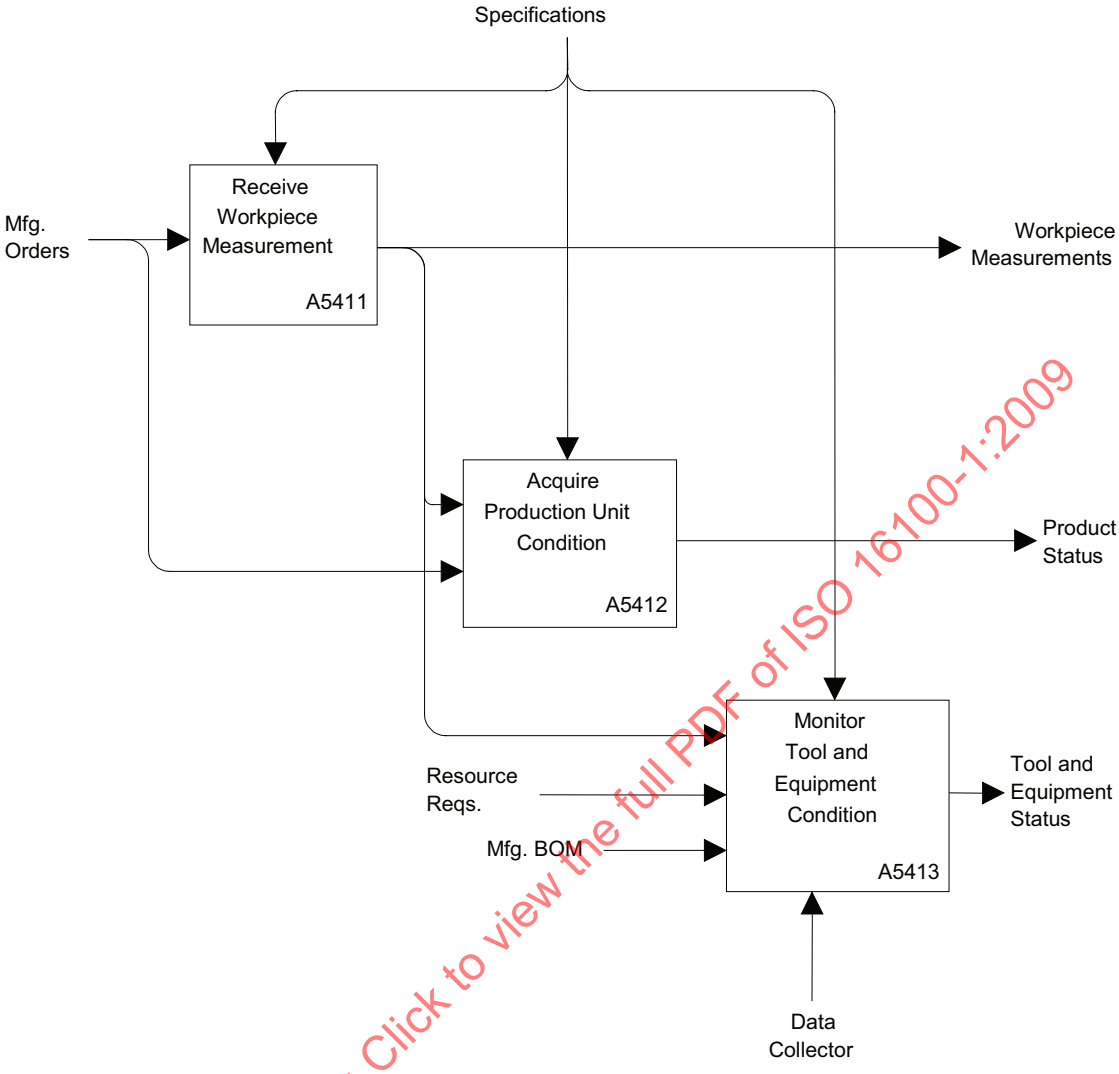
Figure B.15 — Track Production Units and Resources activity



No.	Activity	Description
A541	Collect Production Data	Using data collection devices, acquire data by measuring and sampling workpieces, products and production processes to support the management of product, quality and process.
A542	Analyse Data	Using collected data and adequate algorithms, analyse the data and generate record and reports, and make them available for decision making and product tracking.
A543	Manage Document	Collect (or generate), maintain and distribute production-related documents and records to support the production, factory-floor decision making and product traceability.

See Table B.1 for explanations of the other elements in this figure.

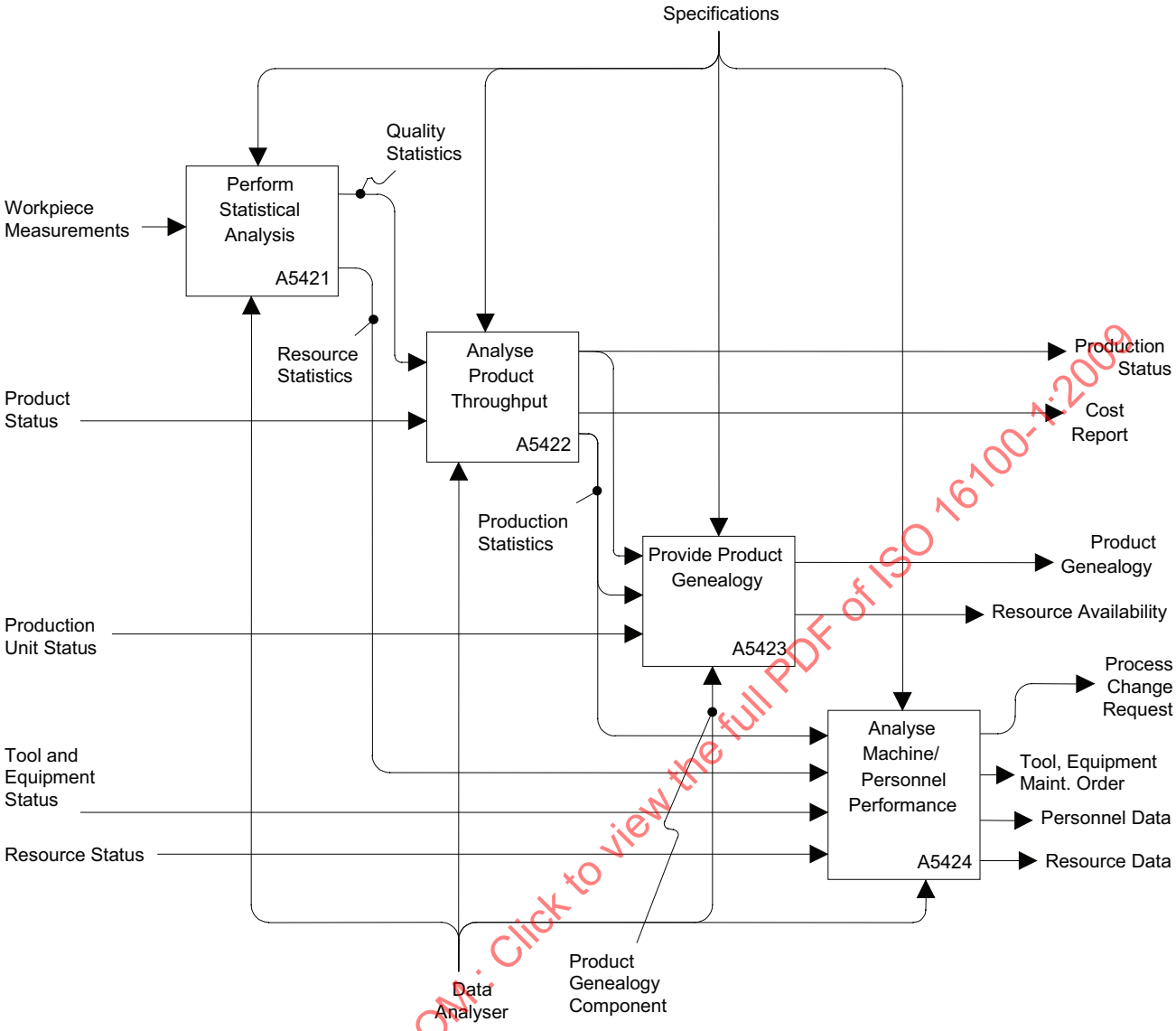
Figure B.16 — Manage Factory-floor Data/Document activity



No.	Activity	Description
A5411	Receive Workpiece Measurement	Using factory-floor data collection devices, acquire and collect measurements on workpieces, labour records, process conditions to monitor the process performance and product quality.
A5412	Acquire Production Unit Condition	Using data collection mechanisms, such as bar code readers or manual input devices, acquire data on the production units to determine where they are and how many units of a product have been finished. Provide on-line, up-to-minute product status information. The data are made available and visible to production as well as business management.
A5413	Monitor Tool and Equipment Condition	Using the data measured from product and process, indicate the status of tools, devices and machines being used in production to determine whether they are still proper to function or need adjustment or maintenance.

See Table B.1 for explanations of the other elements in this figure.

Figure B.17 — Collect Production Data activity



No.	Activity	Description
A5421	Perform Statistical Analysis	Conduct statistical analysis on data collected from the shop floor for tracking process performance and ensuring product quality.
A5422	Analyse Product Throughput	Calculate the quantity of a product completed, check it against the schedule, and make it available to authorized personnel to view.
A5423	Provide Product Genealogy	Create record on the product for traceability, including operations, process parameters, lot number, batch number, supplier, operator identifications, product measurements and any exceptional processing conditions occurred. Make the record available to authorized personnel.
A5424	Analyse Machine/Personnel performance	Using the collected process data, analyse machine usage, production rate, and capability and estimate maintenance schedule. Also, analyse worker's performance, such as productivity, labour skill and attendance record.

See Table B.1 for explanations of the other elements in this figure.

Figure B.18 — Analyse Data activity

Table B.1 — Explanation of elements contained in manufacturing activity reference models

Element	Explanation
Actual Production Step	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.
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.
Behaviour Model	A mathematical model of how an artefact 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 artefact in a specified environment.
Conceptual Design	The product concept that includes product functions, behaviours, form, kinds of materials, structures, constraints and engineering requirements.
Cost Model	A model to represent manufacturing cost structure of product based on manufacturing activity.
Cost Report	A report on manufacturing cost of producing a part. It contains the costs for items such as material, labour and usage of equipment.
Cutter Location Files	The files specify cutter paths and machine controls for machining. The files are used to create APT and NC programs.
Data Analyser	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.
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.
Decomposed Functions, Constraints and Behaviours	Product Functions, Constraints and Behaviours are decomposed into sub-functions, sub-constraints and sub-behaviours based on physical principles.
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.
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 include 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.
Detailed Schedule	A plan that specifies starting time and finishing 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.
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 (ECOs), shift-to-shift communication records, etc.
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.