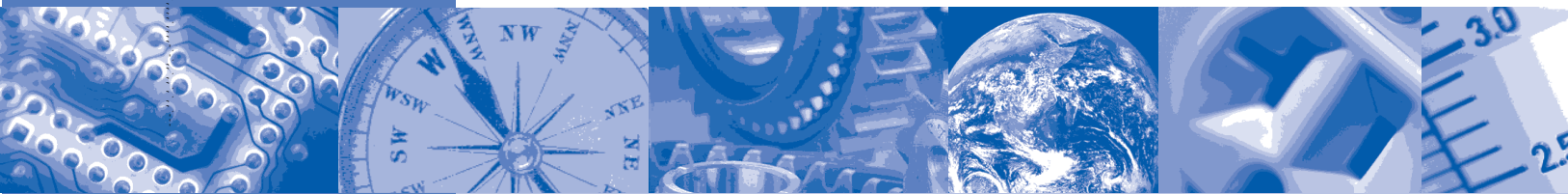


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Enterprise-Control System Integration Part I: Models and Terminology



**ISA—The Instrumentation,
Systems, and
Automation Society**

Approved 15 July 2000



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ANSI/ISA-S95.00.01-2000
Enterprise-Control System Integration
Part 1: Models and Terminology

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**This standard is dedicated to the memory of Dr. Guido Carlo-Stella,
in recognition of and gratitude for his leadership in earlier work
that made this standard possible.**

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FOREWORD

This standard is Part 1 of a multi-part set of standards that defines the interfaces between enterprise activities and control activities.

The scope of this Part 1 standard is limited to describing the relevant functions in the enterprise and the control domain and which objects are normally exchanged between these domains. Subsequent parts will address how these objects can be exchanged in a robust, secure, and cost-effective manner preserving the integrity of the complete system. In this standard, the terms “enterprise,” “controls,” “process control,” and “manufacturing” are used in their most general sense and are held to be applicable to a broad sector of industries.

This Part 1 standard is structured to follow IEC (International Electrotechnical Commission) guidelines. Therefore, the first three clauses present the *scope* of the standard, *normative references*, and *definitions*, in that order.

Clause 4 is informative. The intent is to describe the context of the models in clause 5 and clause 6. It defines the criteria used to determine the scope of the manufacturing control system domain. Clause 4, being informative, does not contain the formal definitions of the models and terminology. It describes the context to understand the normative clauses.

Clause 5 is normative. The intent is to describe hierarchy models of the activities involved in manufacturing control enterprises. It defines in general terms the activities that are associated with manufacturing control and the activities that occur at the business logistics level. It also defines an equipment hierarchy model of equipment associated with manufacturing control. Clause 5, being normative, contains formal definitions of the models and terminology.

Clause 6 is normative. The intent is to describe a general model of the functions within an enterprise, which are concerned with the integration of business and control. It defines, in detail, an abstract model of control functions and, in less detail, the business functions that interface to control. The purpose is to establish a common terminology for functions involved in information exchange. Clause 6, being normative, contains formal definitions of the models and terminology.

Clause 7 is normative. The intent is to define in detail the objects that make up the information streams defined in clause 6. The purpose is to establish a common terminology for the elements of information exchanged. Clause 7, being normative, contains formal definitions of the models and terminology. The attributes and properties are not formally defined in this clause of the standard.

Annex A is informative. It presents a bibliography of informative references and a list of the abbreviations used in the document.

Annex B is informative. The intent is to define the business reasons for the information exchange between business and control functions. The purpose is to establish a common terminology for the reason for information exchange.

Annex C is informative. It discusses the rationale for multiple models.

Annex D is informative. It contains selected elements from the Purdue Reference Model that can be used to place the functions described in clauses 5 and 6 in context with the entire model.

Annex E is informative. It correlates the Purdue Reference Model to the MESA International model.

This Part 1 standard is intended for those who are:

- a) involved in designing, building, or operating manufacturing facilities;
- b) responsible for specifying interfaces between manufacturing and process control systems and other systems of the business enterprise; or
- c) involved in designing, creating, marketing, and integrating automation products used to interface manufacturing operations and business systems.

Future parts of this standard may address models of level 3 functions, definitions of level 2-3 interfaces, and data structures for information exchange including the attributes and properties of the data model in clause 7.

INTRODUCTION

This Part 1 standard provides standard models and terminology for defining the interfaces between an enterprise's business systems and its manufacturing control systems. The models and terminology defined in this standard:

- a) emphasize good integration practices of control systems with enterprise systems during the entire life cycle of the systems;
- b) can be used to improve existing integration capabilities of manufacturing control systems with enterprise systems; and
- c) can be applied regardless of the degree of automation.

Specifically, this standard provides a standard terminology and a consistent set of concepts and models for integrating control systems with enterprise systems that will improve communications between all parties involved. Some of the benefits produced will:

- a) reduce users' times to reach full production levels for new products;
- b) enable vendors to supply appropriate tools for implementing integration of control systems to enterprise systems;
- c) enable users to better identify their needs;
- d) reduce the costs of automating manufacturing processes;
- e) optimize supply chains; and
- f) reduce life-cycle engineering efforts.

It is not the intent of this standard to:

- a) suggest that there is only one way of implementing integration of control systems to enterprise systems;
- b) force users to abandon their current methods of handling integration; or
- c) restrict development in the area of integration of control systems to enterprise systems.

This Part 1 standard defines the interface content between manufacturing control functions and other enterprise functions, based upon the Purdue Reference Model for CIM (hierarchical form) as published by ISA.

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1 Scope

This Part 1 standard defines the interface content between manufacturing control functions and other enterprise functions. The interfaces considered are the interfaces between levels 3 and 4 of the hierarchical model defined by this standard. The goal is to reduce the risk, cost, and errors associated with implementing these interfaces.

The standard may be used to reduce the effort associated with implementing new product offerings. The goal is to have enterprise systems and control systems that inter-operate and easily integrate.

The scope of Part 1 is limited to:

- a) a definition of the scope of the manufacturing operations and control domain;
- b) a definition of the organization of physical assets of an enterprise involved in manufacturing;
- c) a definition of the functions associated with the interface between control functions and enterprise functions; and
- d) a definition of the information that is shared between control functions and enterprise functions.

2 Normative references

The following normative documents contain provisions that, through reference in this text, constitute provisions of this Part 1 standard. At the time of publication, the editions indicated were valid. All normative documents are subject to revision, and parties to agreements based on this Part 1 standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. Member organizations of the IEC and ISO (International Standards Organization) maintain registers of currently valid normative documents.

- a) IEC 61512-1:1997, Batch Control – Part 1: Models and Terminology
- b) ANSI/ISA-88.01-1995, Batch Control – Part 1: Models and Terminology

3 Definitions

For the purposes of this Part 1 standard, the following definitions apply.

3.1 Area:

a physical, geographical or logical grouping determined by the site. It may contain process cells, production units, and production lines.

3.2 Available capability:

the portion of the production capability that can be attained but is not committed to current or future production.

3.3 Bill of lading:

a contract or receipt for goods that a carrier agrees to transport from one place to another and to deliver to a designated person or that it assigns for compensation upon the conditions stated therein.

3.4 Bill of material:

a listing of all the subassemblies, parts, and/or materials that are used in the production of a product.¹ It includes the quantity of each material required to make a product.

3.5 Bill of resources:

a listing of all resources and when in the production process they are needed to produce a product.² Also a listing of the key resources required to manufacture a product, organized as segments of production. It is often used to predict the impact of activity changes in the master production schedule on the supply of resources.

3.6 Certificate of analysis:

a certification of conformance to quality standards or specifications for products or materials. It may include a list or reference of analysis results and process information. It is often required for custody transfer of materials.

3.7 Committed capability:

the portion of the production capability that is currently in use or is scheduled for use.

3.8 Consumables:

resources that are not normally included in bills of material or are not individually accounted for in specific production requests.

3.9 Control domain:

in this Part 1 standard, control domain is synonymous with the manufacturing operations and control domain.

3.10 Enterprise:

any undertaking, venture, initiative, or business organization with a defined mission.

3.11 Equipment class:

a means to describe a grouping of equipment with similar characteristics for purposes of scheduling and planning.

3.12 Finished goods:

final materials on which all processing and production is completed. Finished goods may no longer be under the manufacturing operations and control domain.

3.13 Finished good waivers:

approvals for deviation from normal product specifications.

3.14 In-process waiver requests:

requests for waivers on normal production procedures due to deviations in materials, equipment, or quality metrics, where normal product specifications are maintained.

3.15 Manufacturing operations and control domain (MO&C domain):

this domain includes all the activities in level 3 and information flows to and from levels 0, 1, and 2 across the boundary to level 4.

¹ Adapted from Cox III, James F., Blackstone Jr., John H., *APICS Dictionary Ninth Edition*, APICS - The Educational Society for Resource Management, Alexandria, VA. ISBN: 1-55822-162-X, 1998.

² *ibid*

3.16 Material class:

a means to describe a grouping of materials with similar characteristics for purposes of scheduling and planning.

3.17 Material lot:

a uniquely identifiable amount of a material. This describes the actual total quantity or amount of material available, its current state, and its specific property values.

3.18 Material definition:

a definition of the properties and characteristics for a substance.

3.19 Material subplot:

a uniquely identifiable subset of a material lot, containing quantity and location. May be a single item.

3.20 Personnel class:

a means to describe a grouping of persons with similar characteristics for purposes of scheduling and planning.

3.21 Production capability:

- a) The highest sustainable output rate that could be achieved for a given product mix, raw materials, worker effort, plant, and equipment.
- b) The collection of personnel, equipment, material, and process segment capabilities.
- c) The total of the current committed, available, and unattainable capability of the production facility. The capability includes the capacity of the resource.

3.22 Production control:

the collection of functions that manages all production within a site or area.

3.23 Production line:

a series of pieces of equipment dedicated to the manufacture of a specific number of products or families.³

3.24 Production rules:

the information used to instruct a manufacturing operation how to produce a product.

3.25 Production unit:

a set of production equipment that converts, separates, or reacts one or more feedstocks to produce intermediate or final products.

3.26 Product segments:

the shared information between a plan-of-resources and a production-rule for a specific product. It is a logical grouping of personnel resources, equipment resources, and material specifications required to carry out the production step.

3.27 Resource:

a collection of personnel, equipment, and/or material.

3.28 Unattainable capability:

the portion of the production capability that cannot be attained. This is typically due to factors such as equipment unavailability, suboptimal scheduling, or resource limitations.

³ Cox III. *ibid*

3.29 Work cell:

dissimilar machines grouped together to produce a family of parts having similar manufacturing requirements.

4 Enterprise-control system integration overview (informative)

4.1 Introduction

Successfully addressing the issue of enterprise-control system integration requires identifying the boundary between the enterprise and the manufacturing operations and control domains (MO&C). The boundary is identified using relevant models that represent functions, physical equipment, information within the MO&C domain, and information flows between the domains.

Multiple models define the functions and integration associated with control and enterprise systems.

- a) Hierarchy models that describe the levels of functions and domains of control associated within manufacturing organizations are defined in clause 5. These models are based on *The Purdue Reference Model for CIM*, referenced as PRM;⁴ the MESA International Functional Model;⁵ and the equipment hierarchy model from the IEC 61512-1 (ANSI/ISA-88.01-1995) standard.
- b) A data flow model that describes the functional and data flows within manufacturing organizations is defined in clause 6. This model is also based on *The Purdue Reference Model for CIM*.
- c) An object model that describes the information that may cross the enterprise and control system boundary is defined in clause 7.

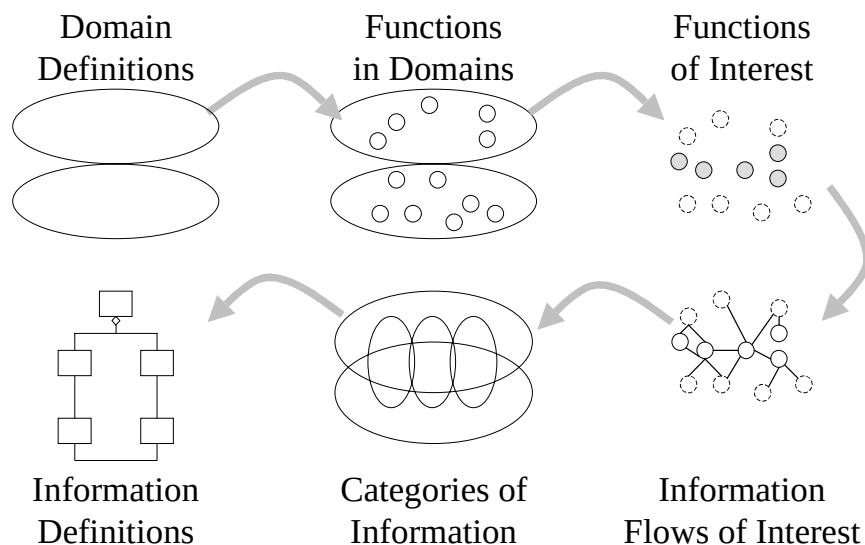


Figure 1 — Outline of models in the standard

⁴ Selected elements of the *Purdue Reference Model for CIM* are included in annex D.

⁵ MESA International, *MES Functionality and MRP to MES Data Flow Possibilities - White Paper Number 2* (1994).

This standard provides models and information in multiple levels of detail and abstraction. These levels are illustrated in Figure 1, which serves as a map to the rest of the document. Each model and diagram increases the level of detail defined in the previous model.

The models start with a definition of the domain of control systems and the domain of enterprise systems. The domain definitions are contained in clause 5.

Functions within the domains are defined in clauses 5 and 6. Functions of interest that are relevant to the standard are also given a detailed definition in clause 6. The information flows of interest between the relevant functions are defined in clause 6.2.

The categories of information are defined in clause 7.1. The formal object model of the information of interest is defined in clauses 7.3, 7.4, and 7.5.

4.2 Criteria for inclusion in manufacturing operations & control domain

The hierarchy and data flow models describe most of the functions within a manufacturing enterprise. Only some of those functions are associated with manufacturing control and manufacturing control systems. The following list defines the criteria used to determine which functions and which information flows are included in this standard.

- a) The function is critical to maintaining regulatory compliance. This includes such factors as safety, environmental, and CGMP (Current Good Manufacturing Practices) compliance.
- b) The function is critical to plant reliability.
- c) The function impacts the operation phase of a facility's life, as opposed to the design, construction, and disposal phases of a facility's life.
- d) The information is needed by facility operators in order to perform their jobs.

The information that flows between functions identified as being within the control domain and those outside the control domain defines the enterprise-control system boundary. Information exchanged between functions within the control domain and information exchanged between functions outside the control domain are outside the scope of this document. Figure 2 illustrates the enterprise-control system interface, as depicted in the data flow model, between control and noncontrol functions; the gray circles indicate functions that exchange information, and are described in the data flow model. Functions depicted as white circles and data flows depicted as dashed lines are those defined as outside the scope of this standard.

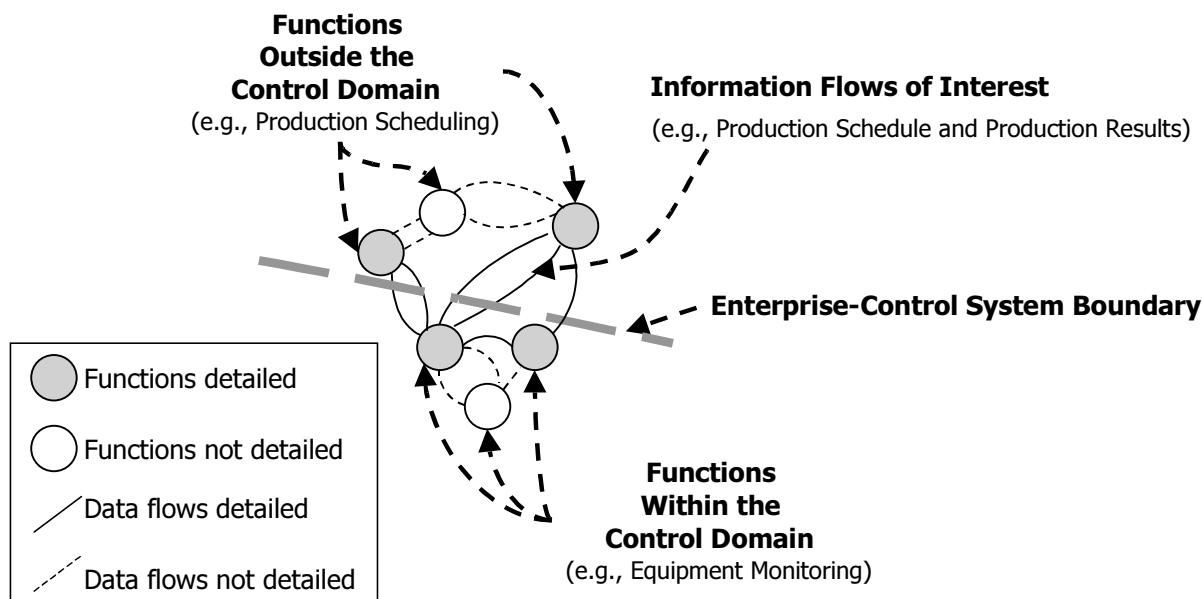


Figure 2 — Enterprise-control system interface

5 Hierarchy models

This clause defines the hierarchy models associated with manufacturing control systems and other business systems.

5.1 Scheduling and control hierarchy

Figure 3 depicts the different levels of a functional hierarchy model: business planning & logistics, manufacturing operations & control, and batch, continuous, or discrete control.⁶ The model defines hierarchical levels at which decisions are made. The interface addressed in this standard is between level 4 and level 3 of the hierarchy model. This is generally the interface between plant production scheduling and operation management and plant floor coordination.

⁶ The figure is a simplified version of the Purdue Hierarchy Model, as shown in figures D-1, D-2, D-3, and D-4 of annex D.

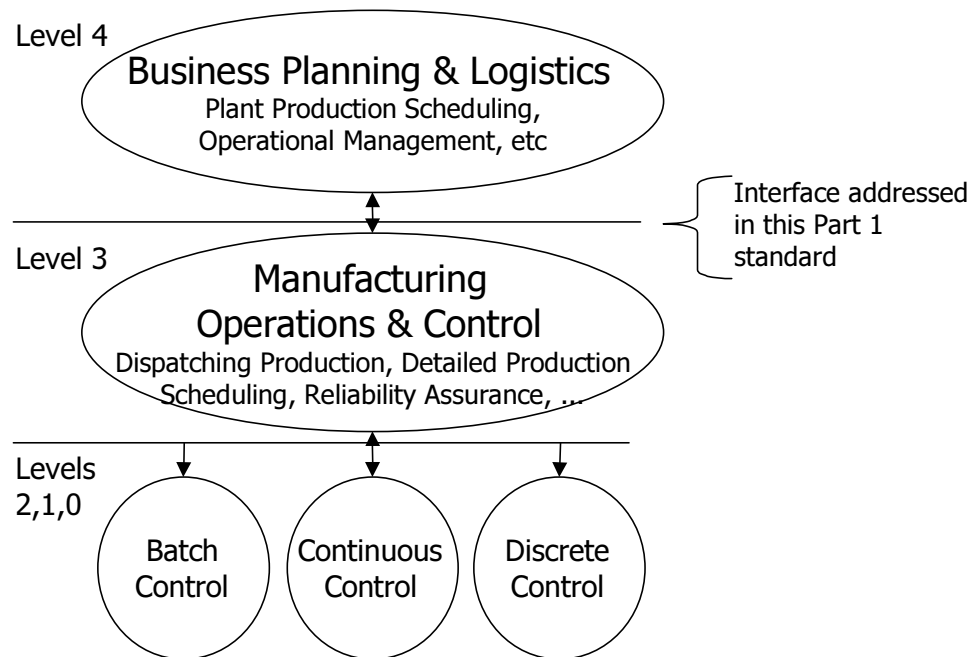


Figure 3 — Functional hierarchy

Levels 2, 1, and 0 define the cell or line supervision functions, operations functions, and process control functions. There are several different models for the functions at these levels based on the actual production strategy used.

5.1.1 Level 4 activities

Level 4 activities include:

- Collecting and maintaining raw material and spare parts usage and available inventory, and providing data for purchase of raw material and spare parts.
- Collecting and maintaining overall energy use and available inventory and providing data for purchase of energy source.
- Collecting and maintaining overall goods in process and production inventory files.
- Collecting and maintaining quality control files as they relate to customer requirements.
- Collecting and maintaining machinery and equipment use and life history files necessary for preventive and predictive maintenance planning.
- Collecting and maintaining manpower use data for transmittal to personnel and accounting.
- Establishing the basic plant production schedule.
- Modifying the basic plant production schedule for orders received, based on resource availability changes, energy sources available, power demand levels, and maintenance requirements.

- i) Developing optimum preventive maintenance and equipment renovation schedules in coordination with the basic plant production schedule.
- j) Determining the optimum inventory levels of raw materials, energy sources, spare parts, and goods in process at each storage point. These functions also include materials requirements planning (MRP) and spare parts procurement.
- k) Modifying the basic plant production schedule as necessary whenever major production interruptions occur.
- l) Capacity planning, based on all of the above activities.

5.1.2 Level 3 activities

Level 3 activities include:

- a) Reporting on area production including variable manufacturing costs.
- b) Collecting and maintaining area data on production, inventory, manpower, raw materials, spare parts and energy usage.
- c) Performing data collection and off-line analysis as required by engineering functions. This may include statistical quality analysis and related control functions.
- d) Carrying out needed personnel functions such as: work period statistics (for example, time, task), vacation schedule, work force schedules, union line of progression, and in-house training and personnel qualification.
- e) Establishing the immediate detailed production schedule for its own area including maintenance, transportation and other production-related needs.
- f) Locally optimizing the costs for its individual production area while carrying out the production schedule established by the level 4 functions.
- g) Modifying production schedules to compensate for plant production interruptions that may occur in its area of responsibility.

Additional descriptions of the activities contained within level 3 are provided below. The standard assumes all activities not explicitly defined as part of the level 3, control domain, to be part of the enterprise domain. See annex E for a correlation of the activities to the MESA International model.

5.1.2.1 Resource allocation and control

The control domain includes the functionality of managing resources directly associated with control and manufacturing. The resources include machines, tools, labor skills, materials, other equipment, documents, and other entities that must be available for work to start and to be completed. The management of these resources may include local resource reservation to meet production-scheduling objectives.

The control domain also ensures that equipment is properly set up for processing, including any allocation needed for setup. The control domain also is responsible for providing real-time statuses of the resources and a detailed history of resource use.

5.1.2.2 Dispatching production

The control domain includes the functionality of managing the flow of production in the form of jobs, orders, batches, lots, and work orders, by dispatching production to specific equipment and personnel. Dispatch information is typically presented in the sequence in which the work needs to be done and may change in real time as events occur on the factory floor.

The control domain may alter the prescribed schedules, within agreed upon limits, based on local availability and current conditions. Dispatching of production includes the ability to control the amount of work in process at any point through buffer management and management of rework and salvage processes.

5.1.2.3 Data collection and acquisition

The control domain includes the functionality of obtaining the operational production and parametric data that are associated with the production equipment and production processes.

The control domain also is responsible for providing real-time statuses of the production equipment and production processes and a history of production and parametric data.

5.1.2.4 Quality management

The control domain includes the functionality of providing real-time measurements collected from manufacturing and analysis in order to assure proper product quality control and to identify problems requiring attention. It may recommend actions to correct the problem, including correlating the symptoms, actions and results to determine the cause.

It includes SPC/SQC (statistical process control/statistical quality control) tracking and management of off-line inspection operations and analysis in laboratory information management systems (LIMS).

5.1.2.5 Process management

The control domain includes the functionality of monitoring production and either automatically corrects or provides decision support to operators for correcting and improving in-process functions. These functions may be intra-operational and focus specifically on machines or equipment being monitored and controlled, as well as inter-operational, tracking the process from one operation to the next.

It may include alarm management to make sure factory persons are aware of process changes that are outside acceptable tolerances.

5.1.2.6 Production planning and tracking

The control domain includes the functionality of providing the status of production and the disposition of work. Status information may include personnel assigned to the work; component materials used in production; current production conditions; and any alarms, rework, or other exceptions related to the product. The functionality includes the capability of recording the production information to allow forward and backward traceability of components and their use within each end product.

5.1.2.7 Performance analysis

The control domain includes the functionality of providing up-to-the-minute reporting of actual manufacturing operations results along with comparisons to past history and expected results. Performance results include such measurements as resource utilization, resource availability, product unit cycle time, conformance to schedule, and performance to standards. Performance analysis may include

SPC/SQC analysis and may draw from information gathered by different control functions that measure operating parameters.

5.1.2.8 Operations and detailed scheduling

The control domain includes the functionality of providing sequencing based on priorities, attributes, characteristics, and production rules associated with specific production equipment and specific product characteristics, such as shape, color sequencing or other characteristics that, when scheduled in sequence properly, minimize setup. Operations and detailed scheduling is finite and it recognizes alternative and overlapping/parallel operations in order to calculate in detail the exact time of equipment loading and adjustment to shift patterns.

5.1.2.9 Document control

The control domain includes some of the functionality of controlling records and forms that must be maintained with the production unit. The records and forms include work instructions, recipes, drawings, standard operation procedures, part programs, batch records, engineering change notices, shift-to-shift communication, as well as the ability to edit "as planned" and "as built" information. It sends instructions down to the operations, including providing data to operators or recipes to device controls. It would also include the control and integrity of regulatory, documentation, environmental, health and safety regulations, and SOP information such as corrective action procedures.

5.1.2.10 Labor management

The control domain includes some of the functionality of providing status of personnel in an up-to-the minute time frame. The functions include time and attendance reporting, certification tracking, as well as the ability to track indirect functions such as material preparation or tool room work as a basis for activity-based costing. Labor management may interact with resource allocation to determine optimal assignments.

5.1.2.11 Maintenance management

The control domain includes some of the functionality of maintaining equipment and tools. The functions ensure the equipment and tools availability for manufacturing. They also may include scheduling for periodic or preventive maintenance as well as responding to immediate problems. Maintenance management maintains a history of past events or problems to aid in diagnosing problems.

5.2 Equipment hierarchy model

The physical assets of an enterprise involved in manufacturing are usually organized in a hierarchical fashion as described in Figure 4. This is an expansion of the model described in IEC 61512-1 and ANSI/ISA-88.01-1995, and it includes the definition of assets for discrete and continuous manufacturing. Lower level groupings are combined to form higher levels in the hierarchy. In some cases, a grouping within one level may be incorporated into another grouping at that same level.

This model defines the areas of responsibility for the different function levels defined in the hierarchical model. The equipment hierarchy model additionally defines some of the objects utilized in information exchange between functions.



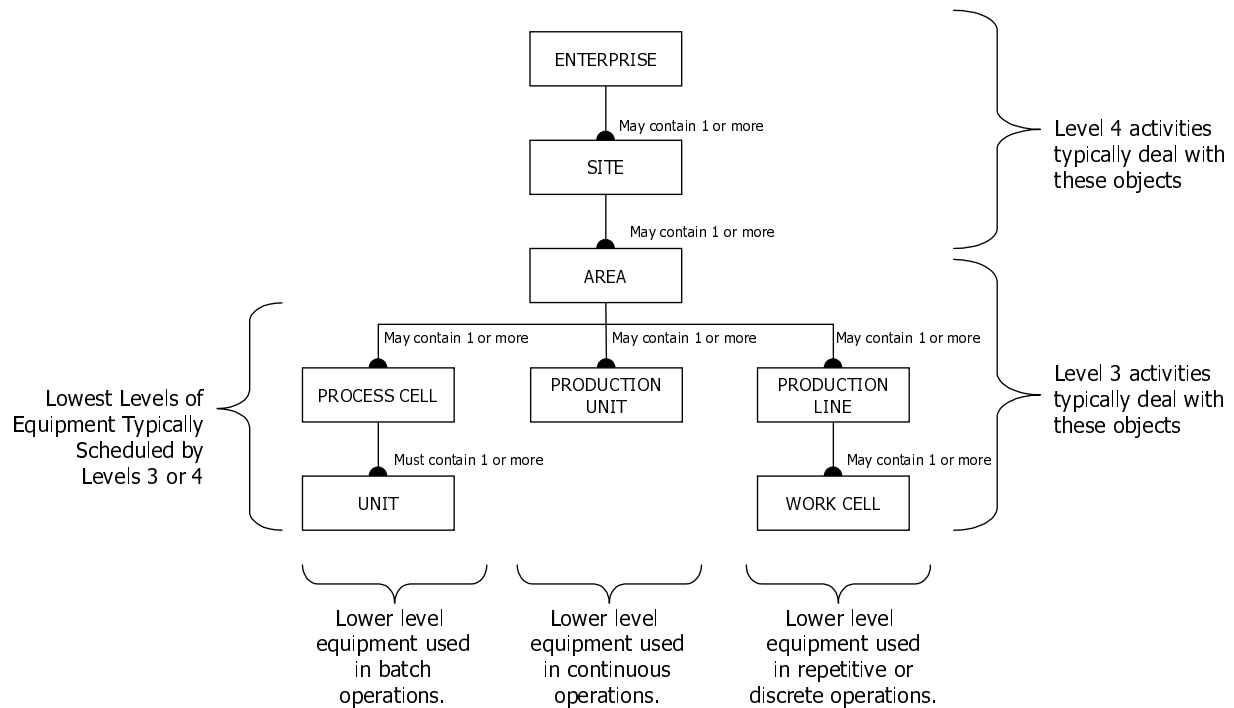


Figure 4 — Equipment hierarchy

5.2.1 Enterprise

An enterprise is a collection of one or more sites and may contain sites and areas. The enterprise is responsible for determining what products will be manufactured, at which sites they will be manufactured, and in general how they will be manufactured.

Level 4 functions are generally dealing at the enterprise and site levels. However, enterprise planning and scheduling may involve areas, cells, lines, or units within an area.

5.2.2 Site

A site is a physical, geographical, or logical grouping determined by the enterprise. It may contain areas, production lines, process cells, and production units. The level 4 functions at a site are involved in local site management and optimization. Site planning and scheduling may involve cells, lines, or units within the areas.

A geographical location and main production capability usually identifies a site. Examples of site identifications are “Dallas Expressway Plant” site, “Deer Park Olefins Plant,” and “Johnson City Manufacturing Facility.” Sites are often used for rough-cut planning and scheduling. Sites generally have well-defined manufacturing capabilities.

5.2.3 Area

An area is a physical, geographical, or logical grouping determined by the site. It may contain process cells, production units, and production lines. Most level 3 functions occur within the area. The main

production capability and geographical location within a site usually identify areas. Examples of area identifications are “CMOS Facility,” “North End Tank Farm,” and “Building 2 Electronic Assembly.”

Areas generally have well-defined manufacturing capabilities and capacities. The capabilities and capacities are used for level 3 and level 4 planning and scheduling.

An area is made up of lower-level elements that perform the manufacturing functions. There are three types of elements defined that correspond to continuous manufacturing models, discrete (repetitive and nonrepetitive) manufacturing models, and batch manufacturing models. An area may have one or more of any of the lower-level elements depending upon the manufacturing requirements. Many areas will have a combination of production lines for the discrete operations, production units for the continuous processes, and process cells for batch processes. For example, a beverage manufacturer may have an area with continuous mixing in a production unit, which feeds a batch process cell for batch processing, feeding a bottling line for a discrete bottling process.

Depending on the planning and scheduling strategy selected, the level 4 functions may stop at the area level, or they may schedule the functions of the lower-level elements within the areas.

5.2.4 Production unit

Production units are the lowest level of equipment typically scheduled by the level 4 or level 3 functions for continuous manufacturing processes. Production units are composed of lower level elements, such as equipment modules, sensors, and actuators, but definitions of these are outside the scope of this standard. A production unit generally encompasses all of the equipment required for a segment of continuous production, that operates in a relatively autonomous manner. It generally converts, separates, or reacts one or more feedstocks to produce intermediate or final products.

The major processing activity or product generated often identifies the production unit. Examples of production unit identifications are “Catalytic Cracker #1,” “Steam Cracker #59,” and “Alkylation Unit 2.”

Production units have well-defined processing capabilities and throughput capacities and these are used for level 3 functions. The capacities and capabilities are also often used as input to level 4 scheduling, even if the production units are not scheduled by the level 4 functions.

5.2.5 Production line and work cell

Production lines and work cells are the lowest levels of equipment typically scheduled by the level 4 or level 3 functions for discrete manufacturing processes. Work cells are usually only identified when there is flexibility in the routing of work within a production line. Production lines and work cells may be composed of lower-level elements, but definitions of these are outside the scope of this document.

The major processing activity often identifies the production line. Examples of production line identifications are “Bottling Line #1,” “Capping Line #15,” “CMOS Line #2,” and “Water Pump Assembly Line #4.”

Production line and work cells have well-defined manufacturing capabilities and throughput capacities and these are used for level 3 functions. The capacities and capabilities are also often used as input to level 4 scheduling, even if the production lines and work cells are not scheduled by the level 4 functions.

5.2.6 Process cell and unit

Process cells and units are the lowest level of equipment typically scheduled by the level 4 and level 3 functions for batch manufacturing processes. Units are usually only identified at level 3 and 4 if there is

flexibility in the routing of product within a process cell. The definitions for process cells and units are contained in the IEC 61512-1 and ANSI/ISA-88.01-1995 standards.

The major processing capability or family of products produced often identifies the process cell. Examples of process cell identifications are “Mixing Line #5,” “West Side Glue Line,” and “Detergent Line 13.”

Process cells and units have well-defined manufacturing capabilities and batch capacities and these are used for level 3 functions. The capacities and capabilities may also be used as input data for level 4 scheduling, even if the process cells or units are not scheduled by the level 4 functions.

6 Functional data flow model

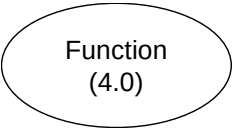
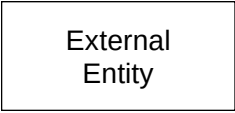
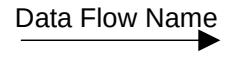
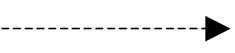
This clause presents:

- a) The functions of an enterprise involved with manufacturing.
- b) The information flows between the functions that cross the enterprise-control interface.

The enterprise-control interface is described using a data flow model. The model is defined using the Yourdon-Demarco⁷ notational methodology.

Table 1 defines the Yourdon notation used in the functional model.

Table 1 — Yourdon notation used

Symbol	Definition
	A function is represented as a labeled ellipse. A function is a group of tasks that can be classified as having a common objective. Functions are organized in a hierarchical manner and are identified with a name and a number. The number represents an identification of the data model hierarchy level.
	An external entity is represented as a labeled rectangle. An external entity is a component outside the model boundaries that sends data to and/or receives data from the functions.
	A solid line with an arrow represents a grouping of data that flows between functions, data stores, or external entities. The data are defined in the enterprise-control integration model. All solid lines have a name for the data flows. A data flow at one level of the functional hierarchy may be represented by one or more flows at the lower level of the hierarchy.
	A dashed line with an arrow represents a grouping of data that flows between functions, data stores, or external entities. The data are not pertinent to the enterprise-control integration model, but are shown to illustrate the context of functions. Dashed line data flows without names are not identified in this model, but are defined in annex D.

⁷ Adapted from STRUCTURED ANALYSIS AND SYSTEM SPECIFICATION by DeMarco, © 1978, Prentice Hall, Inc., Upper Saddle River, NJ.

The functional model is depicted in Figure 5. The wide dotted line illustrates the boundary of the enterprise-control interface. The line is equivalent to the level 3 - level 4 interface defined in clause 5.1. The manufacturing control side of the interface includes most of the functions in production control and some of the activities in the other major functions. The labeled lines indicate information flows of importance to manufacturing control. The wide dotted line intersects functions that have sub-functions that may fall into the control domain, or fall into the enterprise domain depending on organizational policies.

The model structure does not reflect an organizational structure within a company, but an organizational structure of functions. Different companies will place the functions in different organizational groups.

The following subclauses in this clause list and describe each of the functions contained in the model, and list and describe the information that flows between the functions.

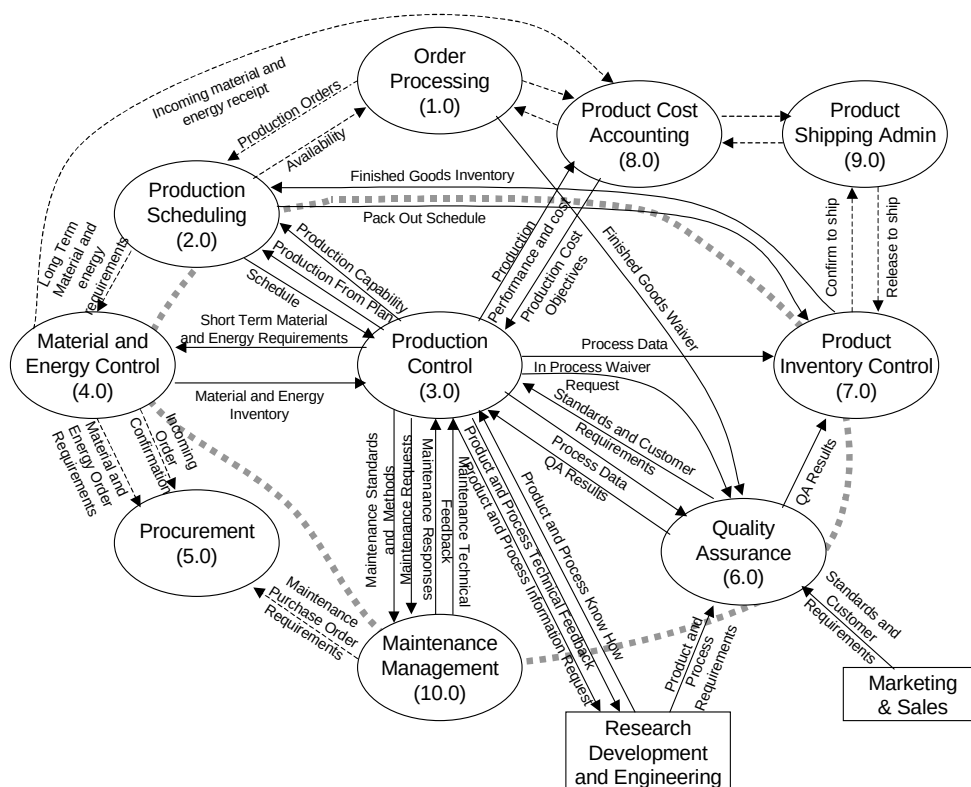


Figure 5 — Functional enterprise-control model

6.1 Functions

6.1.1 Order processing (1.0)

The general functions of order processing include:

- a) Customer order handling, acceptance and confirmation
- b) Sales forecasting
- c) Waiver and reservation handling
- d) Gross margin reporting
- e) Determining production orders

There is generally no direct interface between the functions of order processing and the manufacturing control functions.

6.1.2 Production scheduling (2.0)

Production scheduling functions interface to the manufacturing control system functions through a production schedule, actual production information, and production capability information. This information exchange is defined in the production control functions.

Detailed scheduling, within an area, is defined as a control function.

The general functions of production scheduling include:

- a) Determine production schedule
- b) Identify long-term raw material requirements
- c) Determine pack-out schedule for end products
- d) Determine available product for sales

The information generated or modified by the production scheduling functions includes:

- a) The production schedule
- b) The actual production versus the planned production
- c) The production capacity and resource availability
- d) Current order status

6.1.3 Production control (3.0)

The production control functions encompass most of the functions associated with manufacturing control. The functions of production control include:

- a) Controlling the transformation of raw materials into end product in accordance with production schedule and production standards

- b) Performing plant engineering activities and updating of process plans
- c) Issuing requirements for raw materials
- d) Producing reports of performance and costs
- e) Evaluating constraints to capacity and quality
- f) Self-test and diagnostics of production and control equipment
- g) Creating production standards and instructions for SOPs (standard operating procedures), recipes, and equipment handling for specific processing equipment

The main functions in production control include process support engineering, operations control, and operations planning.

6.1.3.1 Process support engineering

The functions of process support engineering include:

- a) Issuing requests for modification or maintenance
- b) Coordinating maintenance and engineering functions
- c) Providing technical standards and methods to operations and maintenance functions
- d) Following up on equipment and process performance
- e) Providing technical support to operators
- f) Following up on technological developments

The functions of process support engineering generate or modify the following information for use in other control functions:

- a) Minor equipment and process modifications; this may include new design drawings
- b) Instructions on how to handle equipment; this may include standard operating procedures
- c) Instructions on how to make products; this includes production rules and the standard materials, equipment, and other resources used
- d) Material safety data sheets (MSDS)
- e) Instructions on how to install equipment; this may include vendor equipment
- f) Environmental and safety operating limits and constraints
- g) Engineering standards for process equipment design techniques and process operational methods, and online operating instructions
- h) Instructions for plant trials or plant tests

6.1.3.2 Operations control

Operations control is the collection of functions that manages all production within a site or area.

The functions of production control include:

- a) Producing the product according to schedule and specifications
- b) Reporting production, process, and resource information
- c) Monitoring equipment, validating operational measurements, and determining the need for maintenance
- d) Preparing equipment for maintenance and returning it to service after maintenance
- e) Performing diagnostics and self-check of production and control equipment
- f) Balancing and optimizing production within the site or area
- g) May include local site or area labor management and document management

The functions of production control generate or modify the following information for use in other control functions:

- a) Status of production requests
- b) Selected production data, such as data to calculate production cost, and production performance
- c) Selected process data, such as equipment performance feedback
- d) Status of resources
- e) Status of maintenance work order requests
- f) Requests for maintenance
- g) Diagnostic and self-test results
- h) Process history
- i) Requests for process support engineering support
- j) Request for analysis of material

6.1.3.3 Operations planning

The functions of operations planning include:

- a) Setting up a short-term production plan based on the production schedule
- b) Checking the schedule against raw material availability and product storage capacity
- c) Checking the schedule against equipment and personnel availability

- d) Determining the percent of capacity status
- e) Modifying the production plan hourly to account for equipment outage, manpower and raw materials availability

The functions of operations planning generate or modify the following information for use in other control functions:

- a) Material and energy inventory report
- b) Material and energy requirements required to meet the production plan
- c) Site or area production plan for operations control
- d) Available capability of the production resources

6.1.4 Material and energy control (4.0)

The functions of materials and energy control include:

- a) Managing inventory, transfers, and quality of material and energy
- b) Generating requests for purchasing of materials and energy based on short- and long-term requirements
- c) Calculating and reporting inventory balance and losses of raw material and energy utilization
- d) Receiving incoming material and energy supplies and requesting quality assurance tests
- e) Notifying purchasing of accepted material and energy supplies

The functions of materials and energy control generate or modify the following information for use in other control functions:

- a) Material and energy order requests
- b) Incoming confirmation of received materials and energy
- c) Material and energy inventory report
- d) Manual and automated transfer instructions for operations control

Some of the functions within material and energy control may be inside the control domain, based on local organizational structures. Therefore, selected data flows into and out of material and energy control are defined because they may cross the enterprise-control system boundary.

6.1.5 Procurement (5.0)

The functions of procuring resources include:

- a) Placing orders with suppliers for raw materials, supplies, spare parts, tools, equipment and other required materials
- b) Monitoring progress of purchases and reporting to requisitioners

- c) Releasing incoming invoices for payment after arrival and approval of goods
- d) Collecting and processing of unit requests for raw materials, spare parts, etc., for order placement to vendors

The functions of procurement generate or modify the following information for use in other control functions:

- a) Expected material and energy delivery schedules

6.1.6 Quality assurance (6.0)

The functions of quality assurance include:

- a) Testing and classification of materials
- b) Setting standards for material quality
- c) Issuing standards to manufacturing and testing laboratories in accordance with requirements from technology, marketing and customer services
- d) Collecting and maintaining material quality data
- e) Releasing material for further use (delivery or further processing)
- f) Certifying that product was produced according to standard process conditions
- g) Checking of product data versus customer's requirements and statistical quality control routines to assure adequate quality before shipment
- h) Relaying material deviations to process engineering for re-evaluation to upgrade processes

The functions of quality assurance generate or modify the following information for use in other control functions:

- a) Quality assurance test results
- b) Approval to release materials, or waivers on compliance
- c) Applicable standards and customer requirements for material quality

Some of the functions within quality assurance may be inside the control domain, based on local organizational structures; for example, quality assurance requests. Therefore, selected data flows into and out of quality assurance are defined because they may cross the enterprise-control system boundary.

6.1.7 Product inventory control (7.0)

The functions of product inventory control include:

- a) Managing inventory of finished products
- b) Making reservations for specific product in accordance with product selling directives
- c) Generating the pack-out end product in accordance with delivery schedule

- d) Reporting on inventory to production scheduling
- e) Reporting on balance and losses to product cost accounting
- f) Arranging physical loading/shipment of goods in coordination with product shipping administration

The functions of product inventory control generate or modify the following information for use in other control functions:

- a) Finished goods inventory
- b) Inventory balances
- c) Pack-out schedule
- d) Release to ship
- e) Confirm to ship
- f) Requirements

Some of the functions within product inventory control may be inside the control domain, based on local organizational structures. Therefore, selected data flows into and out of product inventory control are defined because they may cross the enterprise-control system boundary.

6.1.8 Product cost accounting (8.0)

The functions of cost accounting include:

- a) Calculating and reporting on total product cost
- b) Reporting cost results to production for adjustment
- c) Setting cost objectives for production
- d) Collecting raw material, labor, energy and other costs for transmission to accounting
- e) Calculating and reporting on total production cost, reporting cost results to production for adjustment
- f) Setting cost objectives for materials and energy supply and distribution

The functions of cost accounting generate or modify the following information for use in other control functions:

- a) Cost objectives to production
- b) Performance and costs from production
- c) Parts and energy incoming to accounting from material and energy control

6.1.9 Product shipping administration (9.0)

The functions of product shipping administration include:

- a) Organizing transport for product shipment in accordance with accepted orders requirements
- b) Negotiating and placing orders with transport companies
- c) Accepting freight items on site and releasing material for shipment
- d) Preparing accompanying documents for shipment (BOL, customs clearance)
- e) Confirming shipment and releasing for invoicing to general accounting
- f) Reporting on shipping costs to product cost accounting

6.1.10 Maintenance management (10.0)

The functions of maintenance management include:

- a) Providing maintenance for existing installations
- b) Providing preventative maintenance program
- c) Providing equipment monitoring to anticipate failure, including self-check and diagnostic programs
- d) Placing purchase order requests for materials and spare parts
- e) Developing maintenance cost reports, and coordinating outside contract work effort
- f) Providing status and technical feedback on performance and reliability to process support engineering

The functions of maintenance management generate or modify the following information for use in other control functions:

- a) Maintenance schedules that specify the plan for future work orders
- b) Maintenance work orders that specify specific equipment to be taken out of service and available for maintenance functions
- c) Diagnostic and self-test requests to be performed on the equipment

Some of the functions within maintenance management may be inside the control domain, based on local organizational structures. Therefore selected data flows into and out of maintenance management are defined because they may cross the enterprise-control system boundary.

6.1.11 Research, development, and engineering

The general functions of research, development and engineering include:

- a) Development of new products
- b) Definition of process requirements
- c) Definition of product requirements, as relates to the production of the products

6.1.12 Marketing and sales

The general functions of marketing and sales include:

- a) Generating sales plans
- b) Generating marketing plans
- c) Determining customer requirements for products
- d) Determining requirements and standards for products
- e) Interacting with customers

6.2 Information flows

The information flows between the functions that are labeled in Figure 5 are listed below. The information in the information flows is defined in clause 7.

6.2.1 Schedule

The *schedule* information flows from the production scheduling (2.0) functions to the production control (3.0) functions.

This contains the information, to production, on what product is to be made, how much is to be made, and when it is to be made. Elements of the schedule information are defined in clauses 7.5.1 and 7.5.2, and are shown in Figure 22.

6.2.2 Production from plan

The *production-from-plan* information flows from the production control (3.0) functions to the production scheduling (2.0) functions.

This contains information about the current and completed production results from execution of the plan. It contains what was made, how much was made, how it was made, and when it was made. Elements of the production-from-plan information are defined in clauses 7.5.3 and 7.5.4, and shown in Figure 23.

6.2.3 Production capability

The *production capability* information flows from the production control (3.0) functions to the production scheduling (2.0) functions.

Production capability information defines the current committed, available, and unattainable capability of the production facility. This includes materials, equipment, labor, and energy. Elements of the production capability information are defined in clause 7.1.1 and shown in Figure 15.

6.2.4 Material and energy order requirements

The *material and energy order requirement* information flows from the material and energy control (4.0) functions to the procurement (5.0) functions.

Material and energy order requirements define future requirements for materials and energy required to meet short-term and long-term requirements based on the current availability.

There are no object models for the material and energy order requirements, but the information may use the definitions relating to material and energy detailed in the clause 7 object model.

6.2.5 Incoming order confirmation

The *incoming order confirmation* information flows from the material and energy control (4.0) functions to the procurement (5.0) functions.

Incoming order confirmations are the notification that the material or energy has been received.

This information is not detailed in the clause 7 object model because it does not cross the interface between the enterprise and control domains.

6.2.6 Long-term material and energy requirements

The *long-term material and energy requirements* information flows from the production scheduling (2.0) functions to the material and energy control (4.0) functions.

The *long-term material and energy requirements* are time-sequenced definitions of material and energy resources that will be needed for planned production.

There are no object models for the long-term material and energy requirements, but the information may use the definitions relating to material and energy detailed in the clause 7 object model.

6.2.7 Short-term material and energy requirements

The *short-term material and energy requirements* information flows from the production control (3.0) functions to the material and energy control (4.0) functions.

The *short-term material and energy requirements* are requirements for resources that are needed for currently scheduled or executing production. These may include:

- a) Requests for materials that may include deadlines
- b) Reservations for materials
- c) Indications of actual consumption
- d) Release of reservations
- e) Adjustments to consumption

Material is represented in Figure 19 in clause 7.3.4 and the material and energy requirements are represented in Figure 22 in clause 7.5.2.

6.2.8 Material and energy inventory

The *material and energy inventory* information flows from the material and energy control (4.0) functions to the production control (3.0) functions.

The *material and energy inventory* information flows are the currently available material and energy that can be used for short-term planning and for production. This information deals with raw materials. *Material and energy inventory* information is defined in clause 7.3.4.

6.2.9 Production cost objectives

The *production cost objectives* information flows from the product cost accounting (8.0) functions to the production control (3.0) functions.

Production cost objectives are the production performance targets in terms of resources. This could be related to a product or to a process. This may include materials, labor hours, energy, equipment usage, or actual costs. Elements of the production cost objectives are defined in clauses 7.1.2 and 7.4 and shown in Figure 21.

6.2.10 Production performance and costs

The *production performance and costs* information flows from the production control (3.0) functions to the product cost accounting (8.0) functions.

Production performance and costs are the actual use and results associated with specific production activities. This includes materials, labor hours, energy, and equipment usage. Results may be identified by products, by-products, co-products, and scrap. This information would be in sufficient detail to identify all costs by product, co-products, and scrap.

6.2.11 Incoming material and energy receipt

The *incoming material and energy receipt* information flows from the material and energy control (4.0) functions to the product cost accounting (8.0) functions.

Incoming material and energy receipt is the notification that the material or energy has been received and additional information needed for cost accounting. This may also include the BOL (bill of lading), MSDS (material safety data sheet), and COA (certificate of analysis). This information is coordinated with the incoming order confirmation (clause 6.2.5) information flow.

This information is not detailed in the clause 6 object model because it generally does not cross the interface between the enterprise and control domains.

6.2.12 Quality assurance results

The *quality assurance (QA) results* information flows from the quality assurance (6.0) functions to the product inventory control (7.0) functions and the production control, operations control (3.2) functions.

Quality assurance results are the results from QA tests performed on raw materials, in-process materials, or products. *Quality assurance results* may concern tests performed in the product or in-process tests performed in a particular segment of production. *Quality assurance results* may include granting of in-process waivers.

A positive QA result may be required before product inventory management may ship a product. A positive QA result may be required before production control transfers product to product inventory control.

6.2.13 Standards and customer requirements

The *standards and customer requirements* information flows from the marketing and sales functions to the quality assurance (6.0) functions, and from quality assurance to production control (3.0).

Standards and customer requirements are the specific values for attributes of the product that satisfy the customer needs. This may include specific processing specifications as well as material properties. This

information may result in changes or additions to material, equipment, and personnel properties and associated tests (see clause 7.3).

6.2.14 Product and process requirements

The *product and process requirements* information flows from the research, development and engineering (RD&E) functions to the quality assurance (6.0) functions.

The *product and process requirements* define how to make a product. This corresponds to general or site recipes in batch manufacturing, assembly instructions and drawings in discrete manufacturing, and process descriptions in continuous manufacturing. Information about specific equipment, personnel, and material requirements may be specified according to the models in clause 7.4.

6.2.15 Finished goods waiver

Finished goods waiver information flows from the order processing (1.0) functions to the quality assurance (6.0) functions.

Finished goods waivers are approvals for deviation from normal product specifications. *Finished goods waivers* may be negotiated customer deviations from specifications defined in the standards and customer requirements (clause 6.2.13).

6.2.16 In-process waiver request

In-process waiver request information flows from production control (3.0) to the quality assurance (6.0) functions.

In-process waiver requests are requests for waivers on normal production procedures due to deviations in materials, equipment, or quality metrics, where normal product specifications are maintained. The response to the request is in the *quality assurance results*.

6.2.17 Finished goods inventory

The *finished goods inventory* information flows from the product inventory control (7.0) functions to the production scheduling (2.0) functions.

The *finished goods inventory* is information on the current inventory of finished goods that is maintained by product inventory control. This may include quantity, quality, and location information that can be used for scheduling of new production, and as feedback on previously scheduled production. This is the total finished product available for distribution or shipment. This information is described in clause 7.3.4.

6.2.18 Process data

The *process data* information flows from the production control (3.0) functions to the product inventory control (7.0) functions and the quality assurance (6.0) functions.

Process data is information about production processes, as related to specific products and production requests, and is described in clauses 7.5.3 and 7.5.4. *Process data* may be used by quality assurance as part of the QA functions, and may be used by product inventory control where this information is needed as part of the finished product deliverables.

6.2.19 Pack out schedule

The *pack out schedule* information flows from the production scheduling (2.0) functions to the product inventory control (7.0) functions.

A *pack out schedule* is the consolidation of produced items of one or more SKUs (stock-keeping unit) for delivery to customers, inventory, or others.

6.2.20 Product and process know-how

The *product and process know how* information flows from the research, development and engineering (RD&E) functions to the production control (3.0) functions.

Product and process know-how includes standard operating procedures, recipes, critical safety limits, and analytical methods. This may be generated in response to an operations requests or originated by RD&E for new products and processes.

Elements of the *product and process know-how* information are defined in clause 7.4 and in Figure 21.

6.2.21 Product and process information request

The *product and process information request* flows from the production control (3.0) functions to the RD&E functions.

A *product and process information request* is a request for new or modified product definitions and process definitions.

6.2.22 Maintenance requests

The *maintenance request* information flows from the production control (3.0) functions to the maintenance management (10.0) functions.

Maintenance requests are requests for a maintenance function. This may be a planned request or an unplanned request due to an unplanned event, such as a lightning strike on a transformer.

6.2.23 Maintenance responses

The *maintenance response* information flows from the maintenance management (10.0) functions to the production control (3.0) functions.

Maintenance responses are the logged status or completion of routine, scheduled, or unplanned maintenance.

6.2.24 Maintenance standards and methods

Maintenance standards and methods information flows from the production control (3.0) functions to the maintenance management (10.0) functions.

Maintenance standards and methods are accepted practices and procedures that maintenance must follow in performing its functions.

6.2.25 Maintenance technical feedback

Maintenance technical feedback information flows from the maintenance management (10.0) functions to the production control (3.0) functions.

Maintenance technical feedback is information about the performance and reliability of production equipment and may include reporting on performed maintenance. Reports on maintenance may include scheduled, preventive, or predictive.

6.2.26 Product and process technical feedback

Product and process technical feedback information flows from the production control (3.0) functions to the RD&E functions.

Product and process technical feedback is information about the performance of production equipment and product. This information generally results from performance tests and study requests to operations control.

6.2.27 Maintenance purchase order requirements

Maintenance purchase order requirements information flows from the maintenance management (10.0) functions to the procurement (5.0) functions.

Maintenance purchase order requirements is information about materials and supplies required to perform maintenance tasks.

6.2.28 Production order

Production order information flows from order processing (1.0) functions to production scheduling (2.0) functions.

Production order is information about accepted customer orders that defines work for the plant.

6.2.29 Availability

Availability information flows from the production scheduling (2.0) functions to the order processing (1.0) functions.

Availability is information about the plant's ability to fulfill the order.

6.2.30 Release to ship

Release to ship information flows from the product shipping administration (9.0) functions to the product inventory control (7.0) functions.

Release to ship is information about the permission to ship the product.

6.2.31 Confirm to Ship

Confirm to ship information flows from the product inventory control (7.0) functions to the product shipping administration (9.0).

Confirm to ship is information about the actual shipment of product.

7 Object Model

Clause 7.1 is an overview of the information contained in the object model and provides a context for the object models. It defines the general categories of information in clauses 7.3, 7.4, and 7.5.

7.1 Categories of information

Most of the information described in the clause 6 model falls into three main areas:

- a) Information required to produce a product
- b) Information about the capability to produce a product
- c) Information about actual production of the product

Some information in each of these three areas must be shared between the manufacturing control systems and the other business systems, as illustrated in Figure 6. Venn diagrams are used to illustrate the overlap of information. This standard is only concerned with the overlapping information in the Venn diagrams, and with defining a model and common terminology for that information.

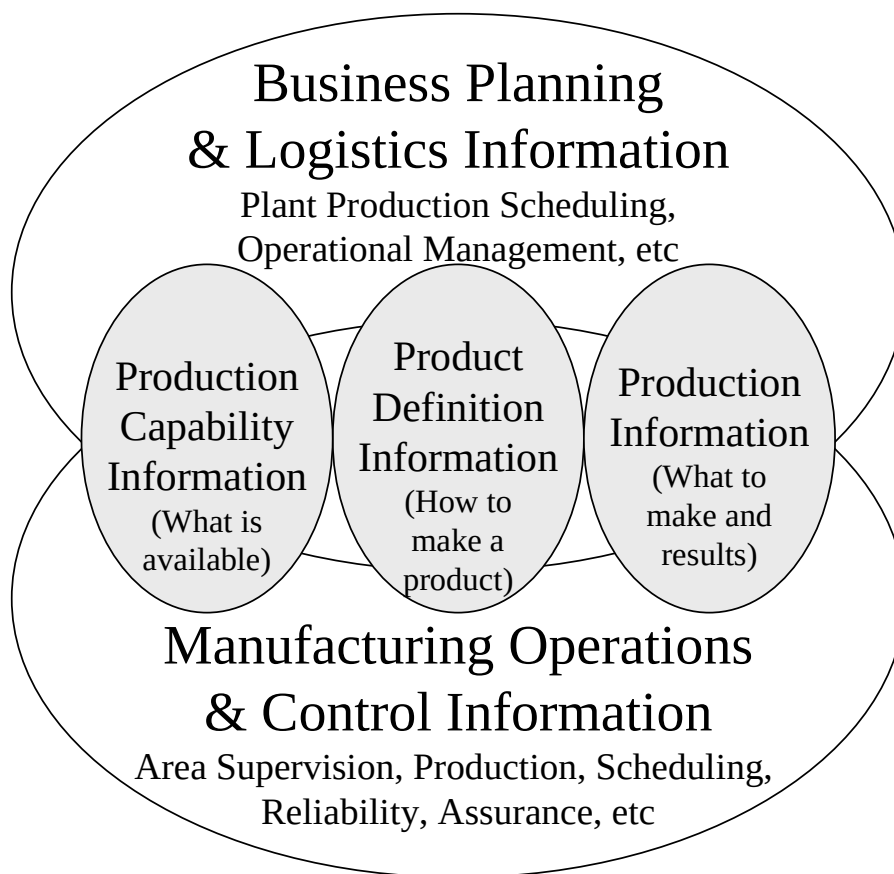


Figure 6 — Areas of information exchange

7.1.1 Production capability information

There are three main areas of information about the production capability that have significant overlap. The three areas of information are production capability information, maintenance information, and capability scheduling information. Figure 7 illustrates the overlapping information.

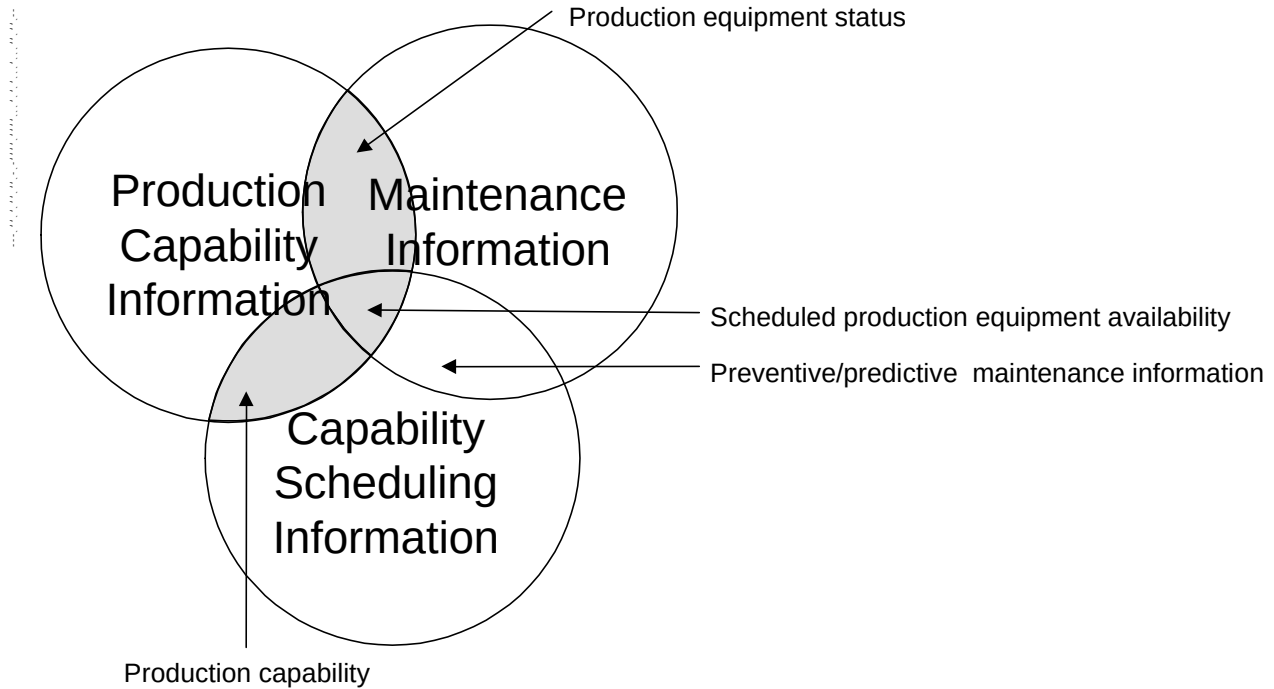


Figure 7 — Production capability information

7.1.1.1 Production capability information

For each site, area, and element within the area there is a definition of the production capability of the personnel, equipment, and materials.

The production capability information includes the current state of what is available as updated by the production capability model in Figure 15.

7.1.1.2 Maintenance information

For each site, area, and element within the area there is a definition of the equipment as required for maintenance. This includes maintenance records and other information that is not part of the production capability model.

The maintenance information includes the current maintenance state of the equipment, as defined by information in the production capability model shown in Figure 15.

7.1.1.3 Capability scheduling information

The capability scheduling information contains the process segments available for the product unit, process cell, or production line.

For each site, area, and equipment element within the area there is a definition of the production capability of the personnel, equipment, and materials needed for scheduling of production.

7.1.1.4 Production equipment status

Production equipment status is information shared between the equipment's capacity and capability model and the maintenance model. This includes the definition of the equipment, the current status of the equipment, and the usage history of the equipment.

7.1.1.5 Production capability

Production capability is defined as the information shared between the production capability model and the capacity scheduling model. This includes the definition of the capacity, and current status of the personnel, equipment, and materials.

7.1.1.6 Scheduled production equipment availability

Scheduled production equipment availability is a dynamic interaction of production capability information, maintenance information, and capability scheduling information that allows forecasting of scheduled production equipment availability.

7.1.1.7 Preventive/predictive maintenance information

Preventive/predictive maintenance information is the correlation of equipment health and maintenance requirements with capability scheduling information as to align maintenance processes and adjust the capability scheduling information during the maintenance processes.

7.1.2 Product definition information

There are three main areas of information required for production of a specific product that have significant overlap. The three areas are information for scheduling, material information, and production rules. Figure 8 illustrates the overlapping information.

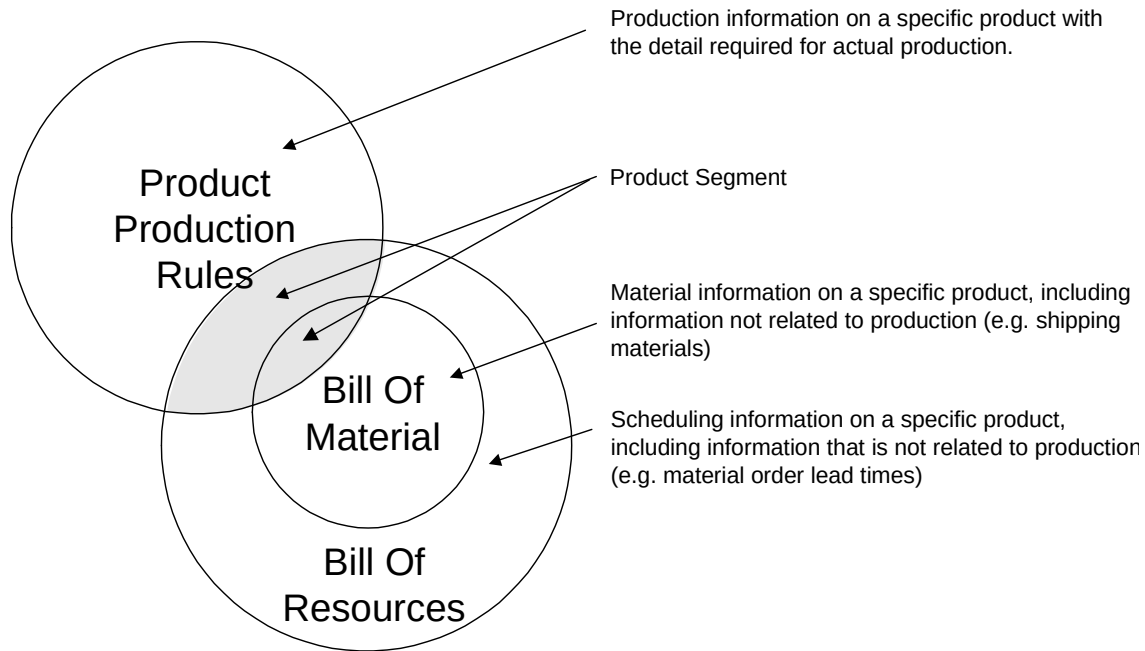


Figure 8 — Production definition information

7.1.2.1 Product production rules

Product production rules are defined as the information used to instruct a manufacturing operation how to produce a product. This may be called a general, site or master recipe (IEC 61512-1 and ANSI/ISA-88.01-1995 definition), standard operating procedure (SOP), standard operating conditions (SOC), routing, or assembly steps based on the production strategy used.

7.1.2.2 Bill of material

The bill of material is a list of all materials required to produce a product showing the quantity of each required. These may be raw materials, intermediate materials, subassemblies, parts, and consumables. This list does not contain the breakdown of where the materials are used or when they are needed, but it may be organized in a hierarchical manner that maps to some of the production steps. The bill of material often includes material that is not related to production of the product, such as shipping materials or included documentation. The bill of material is a subset of the bill of resources.

The manufacturing bill is the subset of the bill of material that is related to production.

7.1.2.3 Bill of resources

The bill of resources is the list of all resources required to produce a product. Resources may include materials, personnel, equipment, energy, and consumables. The bill of resources does not contain the specific production steps, but it may be organized in a hierarchical manner that maps to some of the production steps.