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Enterprise - Control System Integration
Part 1: Models and Terminology

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ISA
67 Alexander Drive
P. O. Box 12277
Research Triangle Park, NC 27709

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Gregory Winchester	Nat'l Electrical Mfrs. Assn.
Richard Winslow	Sterling Diagnostic Imaging
Bill Wray *	Lyondell Chemical Co.

* Chairman

** Editor

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Part 1: Models and Terminology

FOREWORD

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

The scope of Part 1 of the standard is limited to describing the relevant functions in the enterprise and the control domain and which objects are normally exchanged between these domains. Following parts of the standard will address how these objects can be exchanged in a robust, safe, and cost effective manner preserving the integrity of the complete system.

This Part is structured to follow the IEC guidelines. Therefore, the first three sections discuss the *Scope* of the standard, *Normative References*, and *Definitions*, in that order.

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

Section 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. This section, being normative, contains formal definitions of the models and terminology.

Section 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. This section, being normative, contains formal definitions of the models and terminology.

Section 7 is normative. The intent is to define in detail the objects that make up the information streams defined in Section 6. The purpose is to establish a common terminology for the elements of information exchanged. This section, 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 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 rational 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 Sections 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 standard (Part 1, Models and Terminology) is intended for people who are

— involved in designing, building, or operating manufacturing facilities;
— responsible for specifying interfaces between manufacturing and process control systems and other systems of the business enterprise; or
— 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 Section 7.

INTRODUCTION

This clause of the 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

- emphasize good integration practices of control systems with enterprise systems during the entire life cycle of the systems;
- can be used to improve existing integration capability of manufacturing control systems with enterprise systems; and
- 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:

- reduce the user's time to reach full production levels for new products,
- enable vendors to supply appropriate tools for implementing integration of control systems to enterprise systems,
- enable users to better identify their needs,
- reduce the cost of automating manufacturing processes,
- optimize supply chains, and
- reduce life-cycle engineering efforts.

It is not the intent of this standard to

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

This clause of the 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.

ENTERPRISE/CONTROL SYSTEM INTEGRATION

Part 1: Models and Terminology

1. Scope

This clause of the 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 definition of the scope of the manufacturing operations & control domain,
- a definition of the organization of physical assets of an enterprise involved in manufacturing, and
- a definition of the functions associated with the interface between control functions and enterprise functions,
- a definition of the information which is shared between control functions and enterprise functions.

2. Normative references

The following normative documents contain provisions, which through reference in this text, constitute provisions of this clause of this 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 clause of this standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. Members of IEC and ISO maintain registers of currently valid normative documents.

- IEC 61512-01:1997, Batch Control – Part 1: Models and Terminology
- ISA S88.01-1995, Batch Control – Part 1: Models and Terminology

3. Definitions

For the purposes of this clause of this 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. May include a list or reference of analysis results and process information. 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 materials or are not individually accounted for in specific production requests.

3.9 Control domain – In this standard, Control Domain is synonymous to the Manufacturing Operations & 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 & control domain.

3.13 Finished good waivers - Approvals for deviation from normal product specifications.

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[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

3.14 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 & 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.

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 sublot - 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 which 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[1].

3.24 Production rules - The information used to instruct a manufacturing operation how to produce a product.

3.25 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.

3.26 Resource – A resource is a collection of personnel, equipment, and/or material.

3.27 Unattainable capability – The portion of the production capability that can not be attained. This is typically due to factors such as equipment unavailability, sub-optimal scheduling, or resource limitations.

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[1] Cox III, ibid.

3.28 Work cell - Dissimilar machines grouped together to produce a family of parts having similar manufacturing requirements.

4. Enterprise/control system integration overview

4.1 Introduction

Successfully addressing the issue of enterprise/control system integration requires identifying the boundary between the enterprise and manufacturing operations & control domains. 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.

- Hierarchy models that describe the levels of functions and domains of control associated within manufacturing organizations are defined in Section 5. These models are based on *The Purdue Reference Model for CIM*, referenced as PRM[1], on the MESA International Functional Model[2], and the equipment hierarchy model from the IEC 61512-01 (ISA S88.01) standard.
- A data flow model that describes the functional and data flows within manufacturing organizations is defined in Section 6. This model is also based on *The Purdue Reference Model for CIM*.
- An object model that describes the information that may cross the enterprise and control system boundary is defined in Section 7.

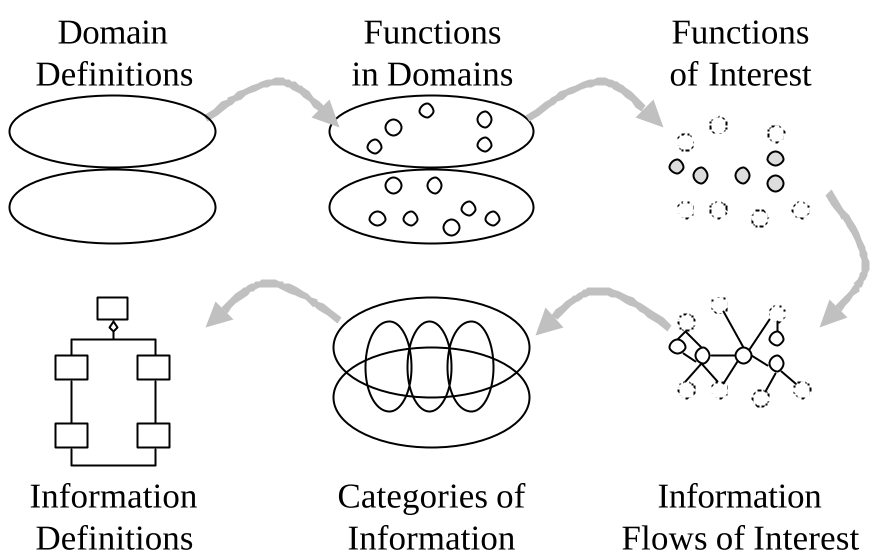

Figure 1 - Outline of models in the standard

[1] Selected elements of the *Purdue Reference Model for CIM* are included in Annex D

[2] 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, and the figure 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 Section 5.

Functions within the domains are defined in Sections 5 and 6. Functions of interest that are relevant to the standard are also given a detailed definition in Section 6. The Information Flows of Interest between the relevant functions are defined in Section 6.2.

The Categories of Information are defined in Section 7.1. The formal object model of the information of interest is defined in Sections 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.

- The function is critical to maintaining regulatory compliance. This includes such factors as safety, environmental, and CGMP (Current Good Manufacturing Practices) compliance.
- The function is critical to plant reliability.
- The function impacts the operation phase of the facility's life, as opposed to the design, construction, and disposal phases of a facility's life.
- 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 non-control functions, the gray circles indicate functions which 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.

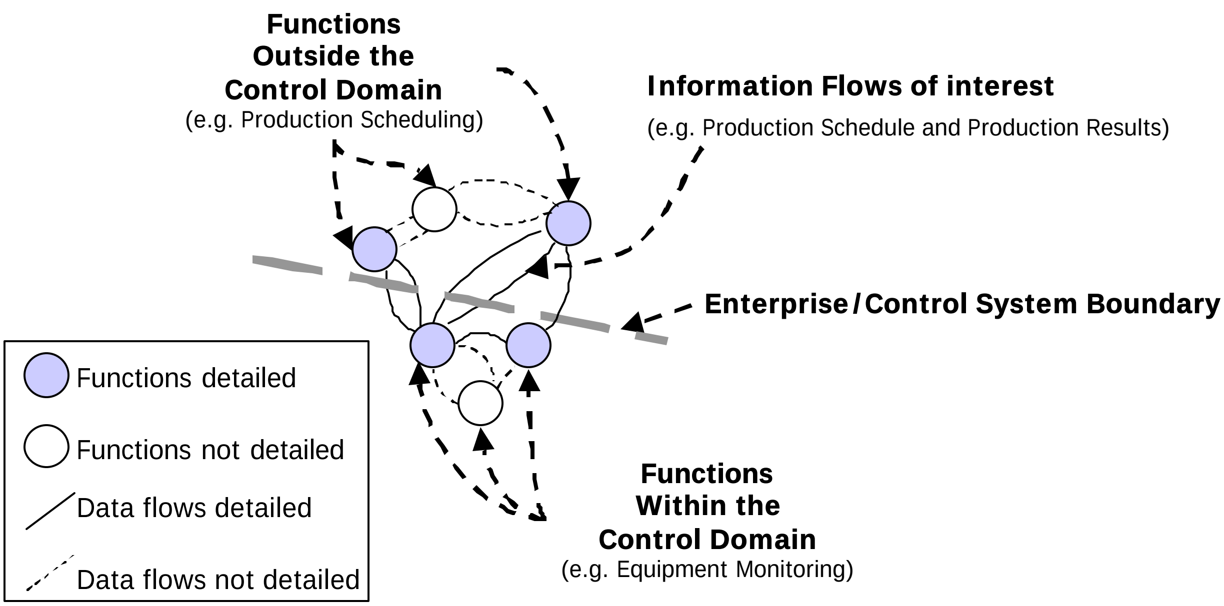

Figure 2 – Enterprise/control system interface

5. Hierarchy Models

This section 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[1]. 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.

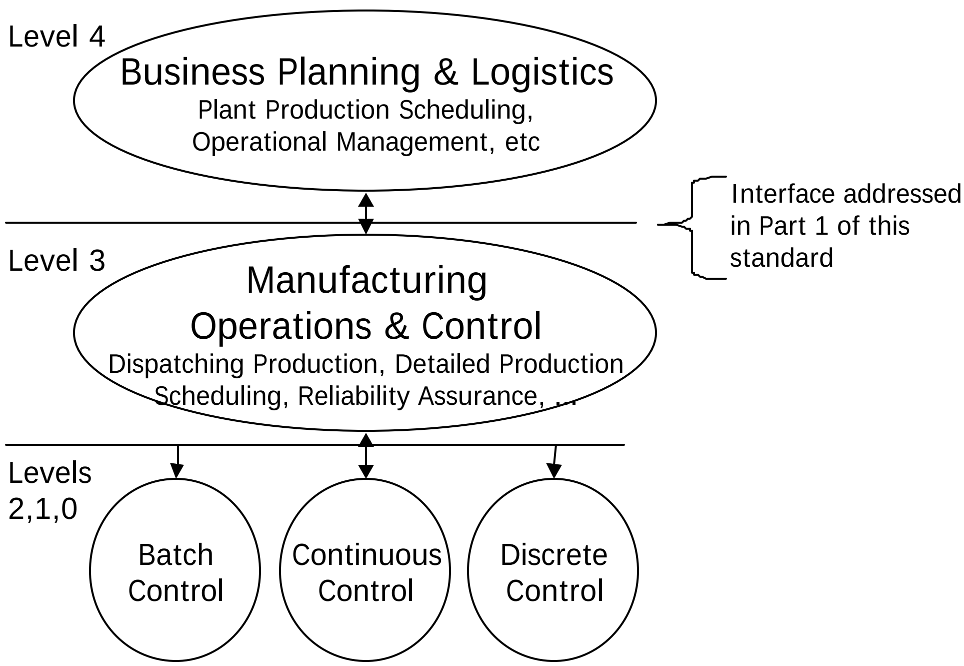

Figure 3 – Functional hierarchy

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.

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[1] 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.

5.1.1 Level 4 activities

The level 4 activities include:

- Collecting and maintaining raw material and spare parts usage and available inventory. Providing data for purchasing of raw material and spare parts.
- Collecting and maintaining overall energy use and available inventory and providing data for purchasing 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.
- Developing optimum preventive maintenance and equipment renovation schedules in coordination with the basic production schedule.
- Determining the optimum inventory levels of raw materials, energy sources, spare parts, and of goods in process at each storage point. These functions also include material requirements planning (MRP) and spare parts procurement.
- Modifying the basic production schedule as necessary whenever major production interruptions occur.
- Capacity planning, based on all of the above activities

5.1.2 Level 3 activities

Level 3 activities include:

- Reporting on area production including variable manufacturing costs.
- Collecting and maintaining area data on production, inventory, manpower, raw materials, spare parts and energy usage.
- Performing data collection and off-line analysis as required by engineering functions. This may include statistical quality analysis and related control functions.
- Carrying out needed personnel functions such as: work period statistics (time, task, etc.), vacation schedule, work force schedules, union line of progression, and in-house training and personnel qualification

— Establishing the immediate detailed production schedule for its own area including maintenance, transportation and other production-related needs.

— Locally optimizing the costs for its individual production area while carrying out the production schedule established by the level 4 functions.

— 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 insures 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 is 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 tracking and management of off-line inspection operations and analysis in laboratory information management system (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 person(s) are aware of process changes which 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 which, when scheduled in sequence properly, minimize set-up. It is finite and it recognizes alternative and overlapping/parallel operations in order to calculate in detail 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, 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. It 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 insure the equipment and tools availability for manufacturing. They also may include scheduling for periodic or preventive maintenance as well as the 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 61512-01 and ISA S88.01, 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.

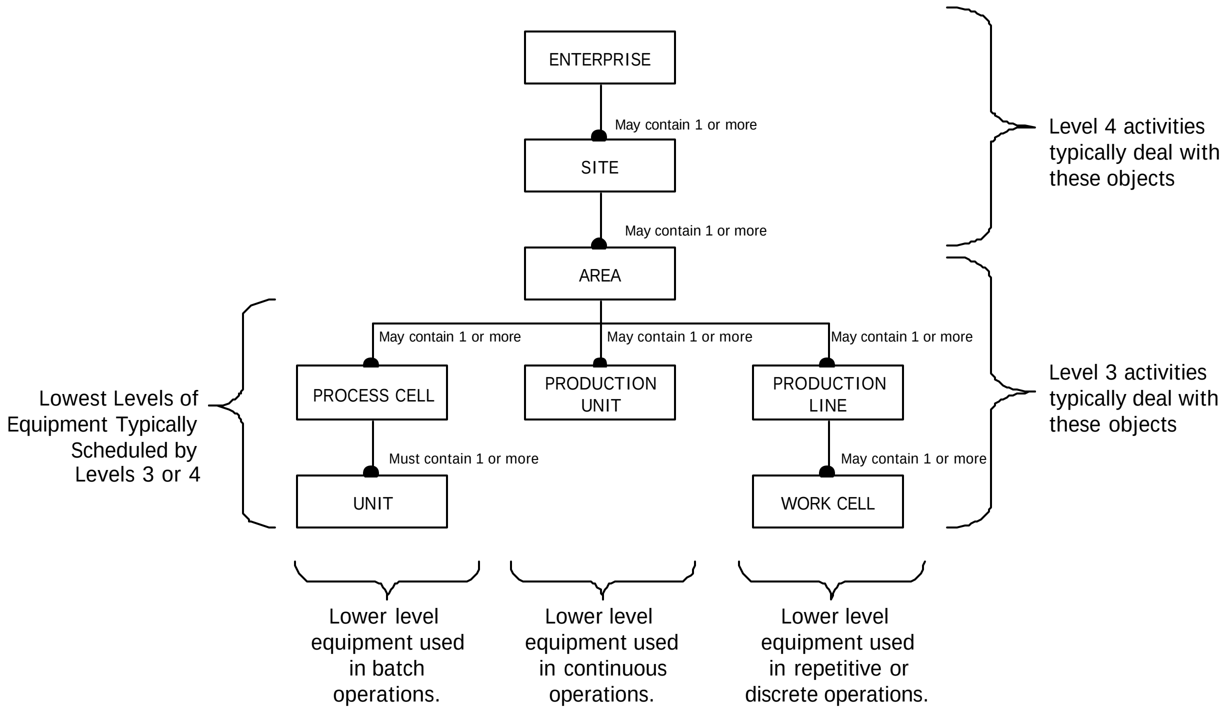

Figure 4 - Equipment hierarchy

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.

Their geographical location and their main production capability usually identify sites. 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 non-repetitive) 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 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.

The major processing activity or product generated often identifies the production unit. Examples of production unit identifications are “Catalytic Cracker #1”, “East Acid Reactor”, and “Distillation Column #15”.

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 and ISA S88.01 standard.

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 section presents:

- The functions of an enterprise involved with manufacturing.
- 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-Demarco[1] notational methodology.

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

Symbol	Definition
Function (4.0)	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.
External Entity	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.
Data Flow Name ——▶	A solid line with an arrow represents a grouping of data that flows between functions, data stores, or external entities, which is defined in the enterprise/control integration model. All solid lines have a name for the data flows. Data flows 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, which is not pertinent to the enterprise/control integration model, but is 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.

Table 1- Yourdon notation used

The functional model is depicted in Figure 5. The dotted line (▪ ▪ ▪ ▪ ▪ ▪ ▪) illustrates the boundary of the enterprise/control interface. The line is equivalent to the Level 3 - Level 4 interface defined in Section 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

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flows of importance to manufacturing control. The heavy 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 subsections in this section list and describe each of the functions contained in the model, and list and describe the information that flows between the functions.

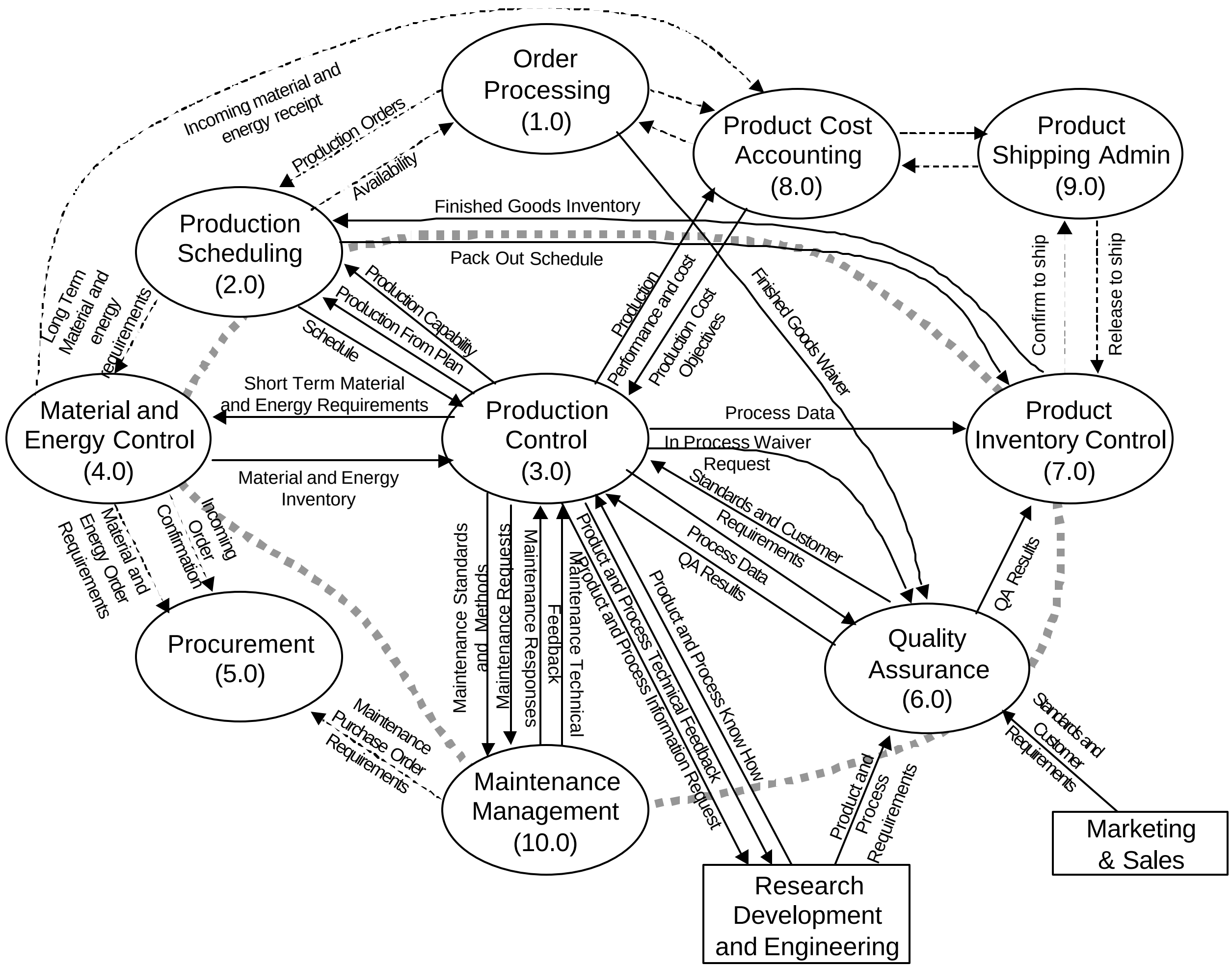


Figure 5 - Functional enterprise/control model

6.1 Functions

6.1.1 Order processing (1.0)

The general functions of order processing include:

— Customer order handling, acceptance and confirmation

— Sales forecasting

— Waiver and reservation handling

— Gross margin reporting

— 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:

— Determine production schedule

— Identify long term raw material requirements

— Determine pack-out schedule for end products

— Determine available product for sales

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

— The production schedule

— The actual production versus the planned production

— The production capacity and resource availability

— 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:

— Control of transformation of raw materials into end product in accordance with production schedule and production standards

— Plant engineering and updating of process plans, etc.

— Issue requirements for raw materials

— Produce reports of performance and costs

— Evaluate constraints to capacity and quality

— Self test and diagnostics of production and control equipment

— Creation of 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:

- Issuing requests for modification or maintenance.
- Coordinating maintenance and engineering functions.
- Providing technical standards and methods to operations and maintenance function.
- Following up on equipment and process performance.
- Providing technical support to operators.
- Following up on technological developments.

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

- Minor equipment and process modifications, this may include new design drawings.
- Instructions on how to handle equipment, this may include standard operating procedures.
- Instructions on how to make products, this includes production rules and the standard materials, equipment, and other resources used.
- Material Safety Data Sheets (MSDS).
- Instructions on how to install equipment, this may include vendor equipment.
- Environmental and safety operating limits and constraints.
- Engineering standards for process equipment design techniques and process operational methods, and on-line operating instructions.
- 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:

- Producing the product according to schedule and specifications.
- Reporting production, process, and resource information.
- Monitoring equipment, validating operational measurements, and determining the need for maintenance.
- Prepare equipment for maintenance and return it to service after maintenance.
- Perform diagnostics and self-check of production and control equipment.
- Balancing and optimizing production within the site or area.

- 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:

- Status of production requests
- Selected production data, such as data to calculate production cost, and production performance
- Selected process data, such as equipment performance feedback
- Status of resources
- Status of maintenance work order requests
- Requests for maintenance
- Diagnostic and self test results
- Process history
- Requests for process support engineering support
- Request for analysis of material

6.1.3.3 Operations planning

The functions of operations planning include:

- Setting up a short term production plan based on the production schedule.
- Checking the schedule against raw material availability and product storage capacity.
- Checking the schedule against equipment and personnel availability.
- Determining the percent of capacity status.
- 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:

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

6.1.4 Material and energy control (4.0)

The functions of materials and energy control include:

- Manages inventory, transfers, and quality of material and energy.

— Generating requests for purchasing of materials and energy based on short and long term requirements.

— Calculate and report inventory balance and losses of raw material and energy utilization.

— Receive incoming material and energy supplies and request quality assurance tests.

— 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:

— Material and energy order requests

— Incoming confirmation of received materials and energy

— Material and energy inventory report

— 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:

— Placing orders with suppliers for raw materials, supplies, spare parts, tools, equipment and other required materials

— Monitoring progress of purchases and report to requisitioners

— Releasing incoming invoices for payment after arrival and approval of goods

— The collection 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:

— Expected material and energy delivery schedules

6.1.6 Quality assurance (6.0)

The functions of quality assurance include:

— Testing and classification of materials.

— Setting standard for material quality

— Issuing standards to manufacturing and testing laboratories in accordance with requirements from technology, marketing and customer services.

— Collecting and maintaining material quality data.

— Release material for further use (delivery or further processing).

— Certify that product was produced according to standard process conditions.

— Checking of product data versus customer's requirements and statistical quality control routines to assure adequate quality before shipment.

— Relay material deviations to process engineering for reevaluation to upgrade processes.

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

— Quality assurance test results

— Approval to release materials, or waivers on compliance

— 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, e.g., 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:

— Managing inventory of finished products

— Making reservation for specific product in accordance with product selling directives

— Pack-out end product in accordance with delivery schedule

— Reporting on inventory to production scheduling

— Reporting on balance and losses to product cost accounting

— 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:

— Finished goods inventory

— Inventory balances

— Pack Out Schedule

— Release to ship

— Confirm to ship

— 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:

- Calculate and report on total product cost
- Report cost results to production for adjustment
- Setting cost objectives for production
- Collection of raw material, labor, energy and other costs for transmission to accounting.
- Calculate and report on total production cost, report cost results to production for adjustment
- 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:

- Cost objectives to production
- Performance and costs from production
- 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:

- Organizing transport for product shipment in accordance with accepted orders requirements
- Negotiating and place orders with transport companies
- Accepting freight items on site and release material for shipment
- Preparing accompanying documents for shipment (BOL, customs clearance)
- Confirming shipment and release for invoicing to general accounting
- Reporting on shipping costs to product cost accounting

6.1.10 Maintenance management (10.0)

The functions of maintenance management include

- Providing maintenance for existing installations.
- Providing preventative maintenance program.
- Providing equipment monitoring to anticipate failure including self-check and diagnostic programs.
- Placing purchase order request for materials and spare parts.
- Developing maintenance cost reports, and coordinating outside contract work effort.
- 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:

- Maintenance schedules that specify the plan for future work orders.
- Maintenance work orders that specify specific equipment to be taken out of service and available for maintenance functions.
- 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:

- Development of new products
- Definition of process requirements
- 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:

- Generating sales plans
- Generating marketing plans
- Determination of customer requirements for products
- Determination of requirements and standards for products
- Interaction 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 Section 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, and how much is to be made, and when it is to be made. Elements of the schedule information are defined in Sections 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 Sections 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 Section 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 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 they must use the definitions relating to material and energy detailed in the Section 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 Section 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 they must use the definitions relating to material and energy detailed in the Section 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. This may include:

- Requests for materials that may include deadlines.
- Reservations for materials.
- Indications of actual consumption.
- Release of reservations.
- Adjustments to consumption.

Material is represented in Figure 19 in Section 7.3.4 and the material and energy requirements are represented in Figure 22 in Section 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 Section 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 Sections 7.1.2 and 7.4 and show 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 *material and energy receipt* information flows from the Material and Energy Control (4.0) functions to the Product Cost Accounting (8.0) functions.

Incoming order confirmations are 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 (Section 6.2.5) information flow.

This information is not detailed in the Section 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 Section 7.3).

6.2.14 Product and process requirements

The *product and process requirement* 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 Section 7.4.

6.2.15 Finished goods waiver

Finished good waiver information flows from the Order Processing (1.0) functions to the Quality Assurance (6.0) functions.

Finished good waivers are approvals for deviation from normal product specifications. *Finished good waivers* may be negotiated customer deviations from specifications defined in the standards and customer requirements (Section 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 which 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 Section 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 Sections 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 Section 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 (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 (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 (10.0) functions.

Maintenance standards and methods are accepted practices and procedures which maintenance must follow in performing their functions.

6.2.25 Maintenance technical feedback

Maintenance technical feedback information flows from the Maintenance (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. 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 (10.0) 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

Section 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 Sections 7.3, 7.4, and 7.5.

7.1 Categories of information

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

- Information required to produce a product
- Information about the capability to produce a product
- 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.

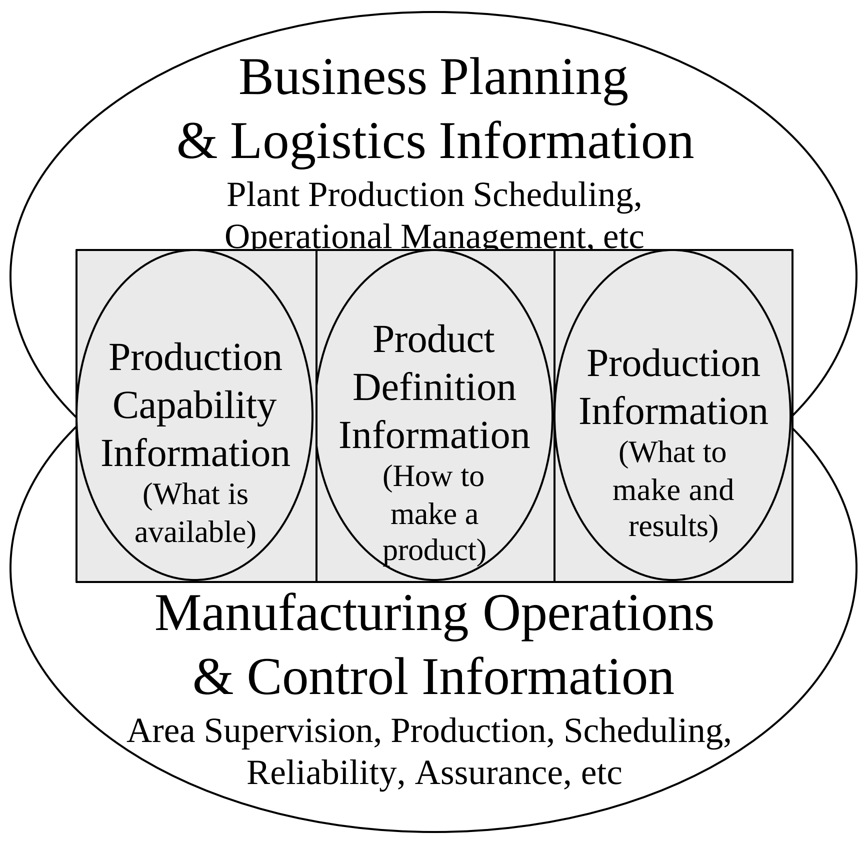


Figure 6 - Areas of information exchange

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.

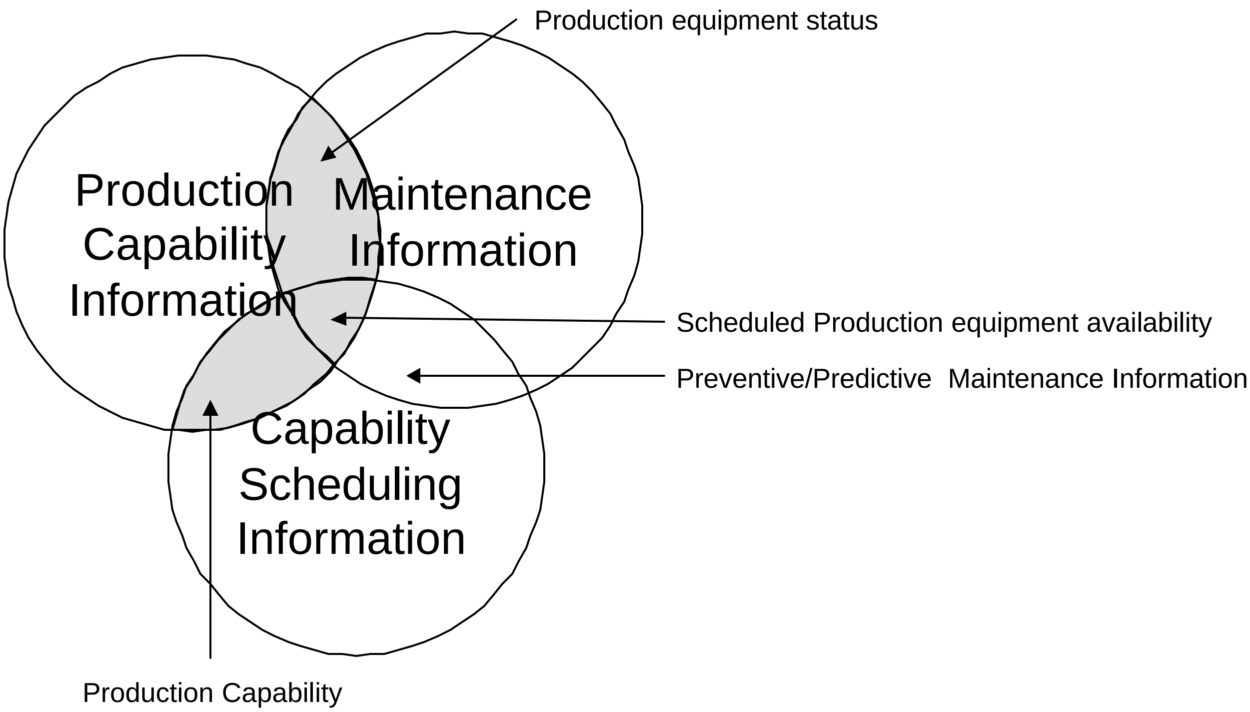


Figure 7 - Production capability information

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 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

The 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

The 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.

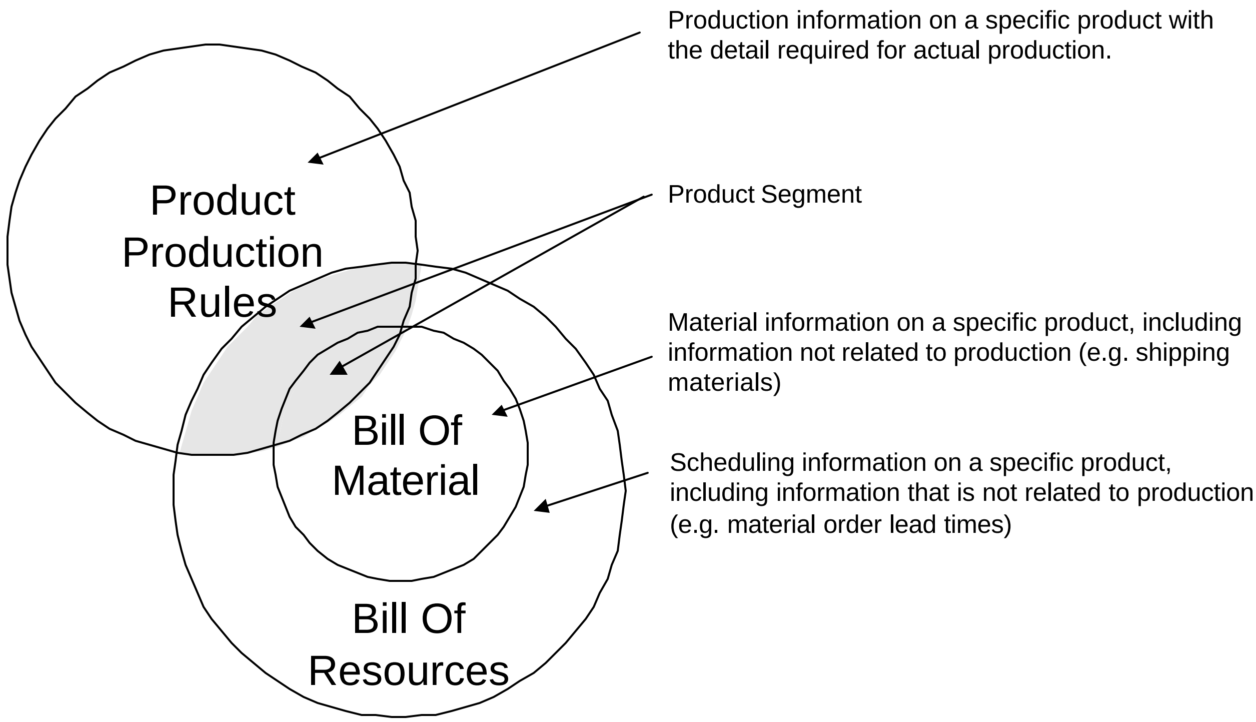


Figure 8 - Production definition information

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 and ISA S88.01 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.

7.1.2.4 Product segment

Product segment is defined as the overlap of information between product production rules and the bill of resources. It describes a job or task consisting of one of more work elements, usually done essentially in one location. A product segment is the most detailed process view for the business system to control material, labor, resource usage, cost, and quality in order to control the production.

Product segments may correspond to:

— IEC 61512-01 and ISA S88.01 process stages or process operations for batch manufacturing,

— unit operations for continuous manufacturing,

— assembly steps and assembly actions for discrete manufacturing,

— other types of identifiable time spans for other types of manufacturing.

The example in Figure 9 illustrates product segments in Gantt type chart with time on the horizontal axis and each box corresponding to a different product segment.

Production routing is the overlap of information between the product production rule information and bill of resources information without the bill of material information. It represents all of the non-material aspects of production such as equipment, labor, and energy. Production routings include an ordered sequence of product segments.

Material Routing is the overlap of information between the production rule information and the bill of material information. It represents both the production material inputs and where they are used in product segments.

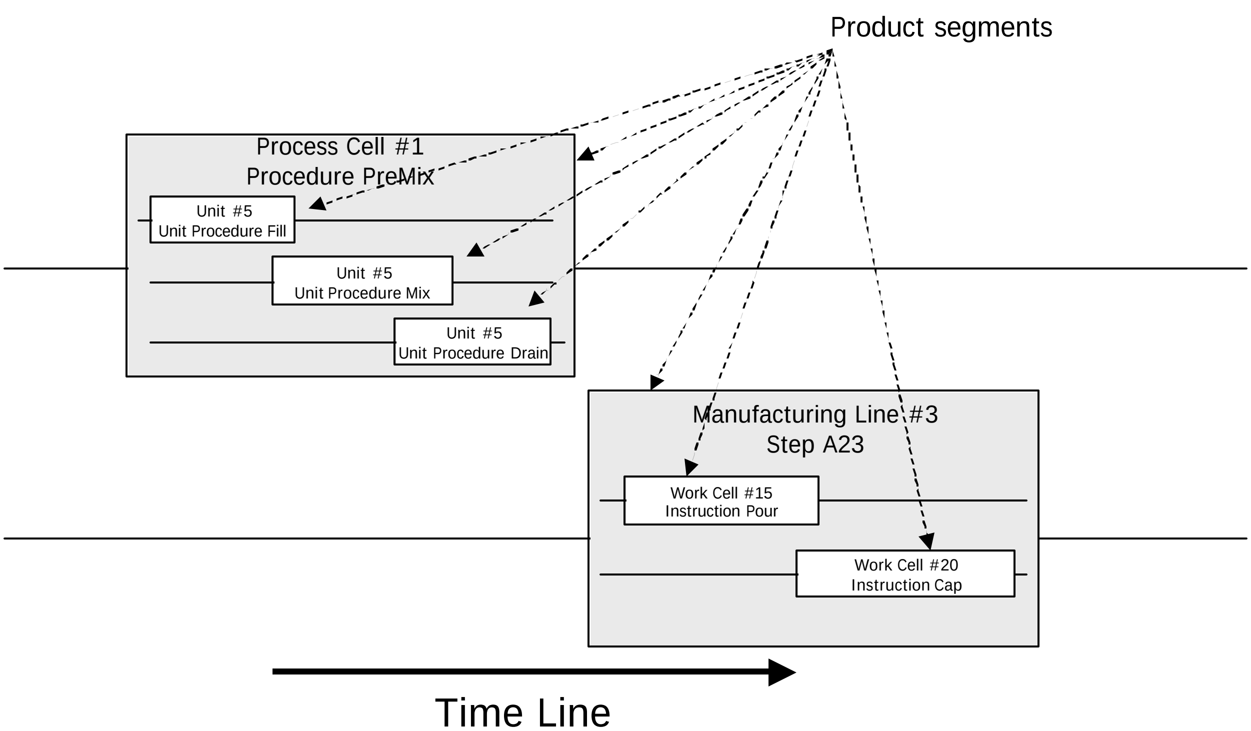


Figure 9 - Example of product segments

7.1.2.5 Overlapping areas

Figure 8 illustrates the overlap of information between different areas, but is not meant to represent the amount or importance of the information. Different manufacturing and business strategies will have different amounts of information shared between the different areas. Figure 10 illustrates the amount of information in two examples. The left side of the figure shows an example where the manufacturing systems maintain most of the information required for a product. The right side of the figure shows an example where the business systems maintain most of the information.

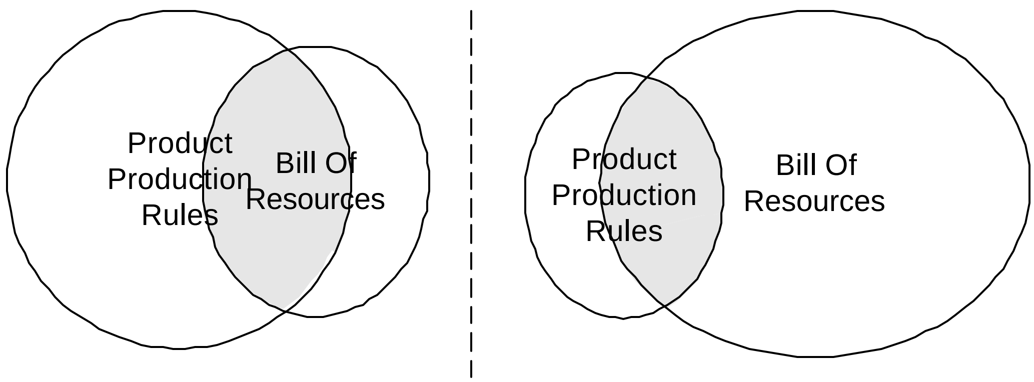


Figure 10 - Possible information overlaps

7.1.3 Production information

There are three main areas of information about actual production that have significant overlap. These three areas are production information, inventory information, and the production scheduling information. Figure 11 shows the overlap between the areas of information

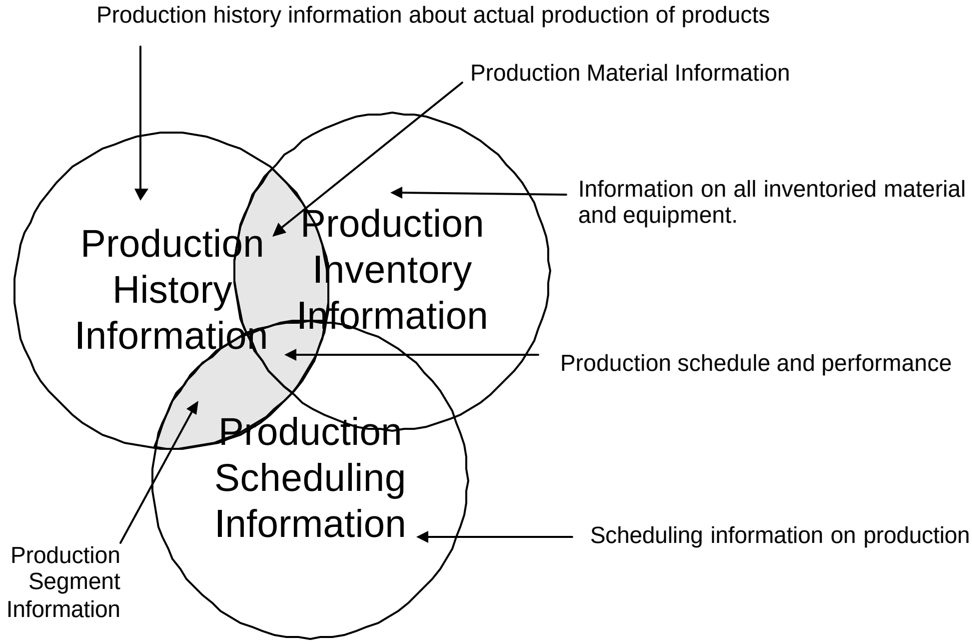


Figure 11 - Production information

7.1.3.1 Production history information

Production history information is all of the information recorded about production of a product. This may be called by many names, such as the batch journal, product log, or traveler.

7.1.3.2 Production inventory information

Production inventory information is all of the information about inventoried materials, including the current status of the materials. Typically all consumed and produced materials are maintained in the production inventory information, and sometimes intermediates are maintained if they are needed for financial evaluation. In some industries this may include energy information.

7.1.3.3 Production scheduling information

The scheduling model contains all of the information about the execution of scheduled production runs.

7.1.3.4 Production segment information

The Production Segment Information is the part of the production history information that contains information on the segments of production and is used for scheduling.

7.1.3.5 Production material information

The Production Material Information is the part of the production history information that contains information on material that is used by inventory.

7.1.3.6 Production schedule and performance

Production schedule and performance information is shared among production information, inventory information, and scheduling information. This includes the definition of the raw materials consumed, materials produced, and materials scrapped. It also includes the definition of the how long segments of production actually took and how much materials was produced and consumed by specific segments of production. This information is generally used to track actual production against production requests and as feedback to the scheduling cycle.

7.1.4 Process Segment

Given the previous definitions, a process segment is defined as the collection of capabilities needed for a segment of production, independent of any particular product. This may include material, energy, personnel, or equipment capabilities. The capabilities may specify specific capabilities or the class of capability (such as class of equipment) needed for the process segment. Figure 12 illustrates how capabilities relate to process segments.

- A manual segment may define the class of materials and class of personnel needed for production.
- A semi-automated segment may define the class of materials, personnel, and equipment needed.
- A non-material segment, such as an equipment setup segment, may define the class of equipment and personnel used.
- An automated segment may only define the material and equipment classes needed.

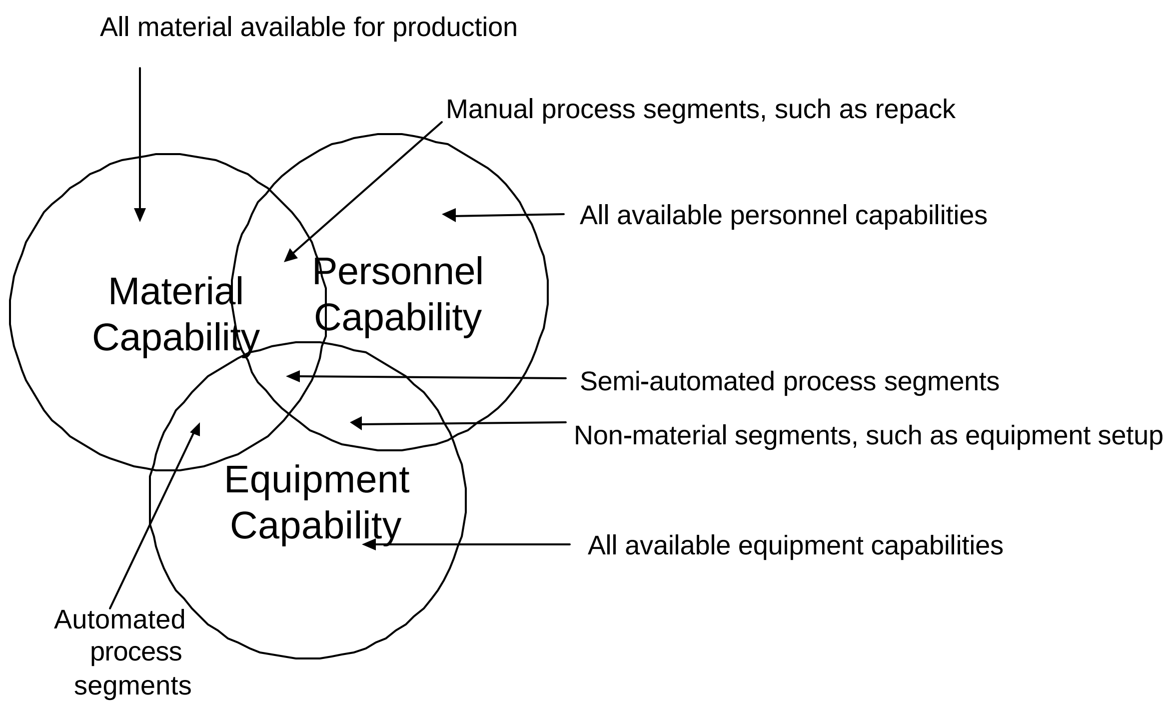


Figure 12 - Process segment capabilities

There is a relationship among the collection of process segments, the product segment definitions for each product, and the segment requirements for any specific production request. This concept is illustrated in Figure 13. A product segment must reference a process segment known to production, and a segment requirement must reference a known product segment of the product being manufactured.

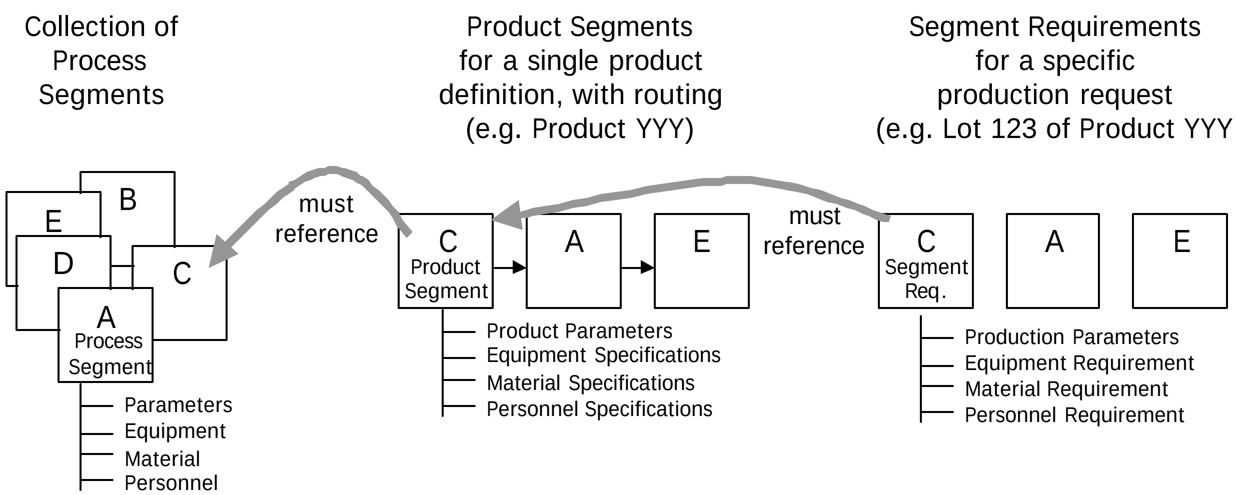


Figure 13 - Segment relations

7.2 Object Model Structure

The object models are depicted using the Unified Modeling Language[1] (UML) notational methodology. The diagrams have been kept simple and as a result objects may appear on multiple diagrams.

The general model for allowing extensibility to the information exchange is through the addition of properties to the objects. There may be sets of extensions which are business specific, for example the Food and Beverage business may have commonly understood extensions which relate to nutritional content and caloric content.

Table 2 defines the UML notations used in the object diagrams.

Symbol	Definition

[1] J.Rumbaugh/I. Jacobson, THE UNIFIED MODELING LANGUAGE REFERENCE MANUAL, © 1999 by Addison Wesley Longman, Inc. Reprinted by permission of Addison Wesley Longman.

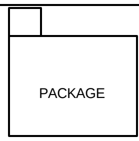
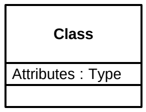
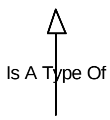
	Defines a package, a collection of object models, state models, use classes, and other UML models. In this document a package is used to specify an external model, such as a production rule model, or a reference to another part of the model.
	Defines a class of objects, each with the same types of attributes. Each object must be uniquely identifiable or enumerable. No operations or methods are listed for the classes. Attributes with a '-' before their name indicate attributes which are generally optional in any use of the class.
	An association between elements of a class and elements of another or the same class. Each association is identified. Can have the expected number or range of members of the subclass, when 'n' indicates an indeterminate number. E*g.*, 0,n means that zero or more members of the subclass may exist.
	Generalization (Arrow points to the super class) shows that an element of the class is a specialized type of the super class.
	Dependence (tightly bound relationship between the items) shows that an element of the class depends on an element of another class.
	Aggregation (made up of), shows that an element of the class is made up of elements of other classes.

Table 2 – UML notation used

7.3 Production capability information

The production capability information is the collection of information about all resources for production for selected times. This information corresponds to the overlap of information depicted in Figure 7. This is made up of information about equipment, material, personnel, and process segments. It describes the names, terms, status, and quantities of which the manufacturing control system has knowledge. The production capability information contains the 'vocabulary' for capacity scheduling and maintenance information.

7.3.1 Production capability

Production capability is the collection of available capability, committed capability, and unattainable capability, as depicted in Figure 14. The *production capability* is the theoretical maximum capability available for use in production.

— Committed capability defines resources that are committed to future production, usually due to existing schedules and/or materials in production.

— Unattainable capability defines resources which are not attainable given the equipment condition (such as equipment out of service for maintenance), equipment utilization (such as 75% of a vessel filled and the other 25% not available for other products), personnel availability (such as vacations), and material availability.

— Available capability defines the resources that are available additional production and not committed to production.

— A capability may be identified as current, or may be identified for future times, as depicted in Figure 14.

— Production capability may change over time as equipment, material, and personnel capability is added, modified, or removed.

— The capability includes the capacity of the resource.

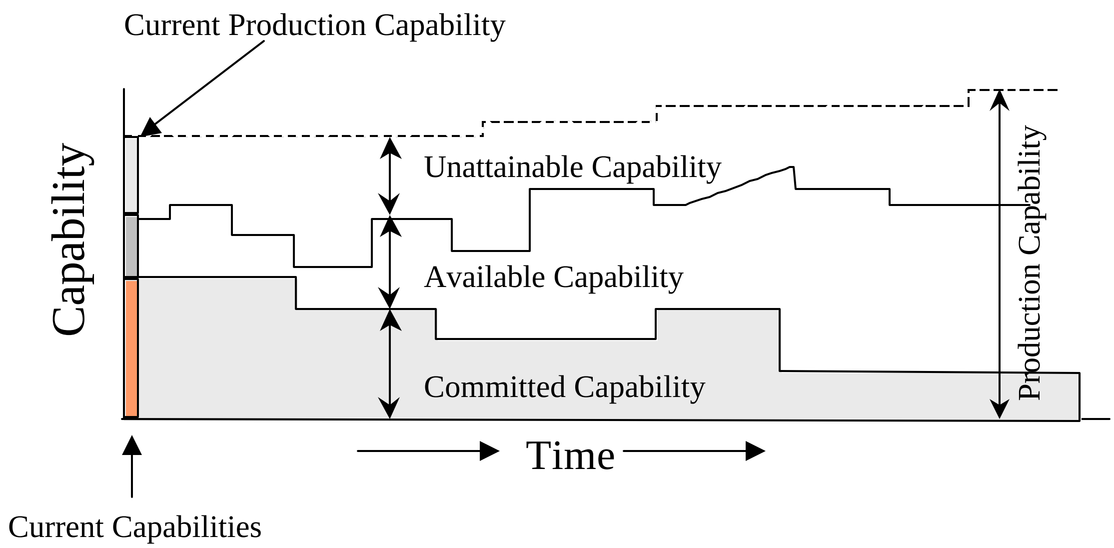


Figure 14 - Current and future capabilities

Figure 15 illustrates the model for *production capability*. A *production capability* is defined as a collection of *personnel capabilities*, *equipment capabilities*, *material capabilities*, and *process segment capabilities*, for a given segment of time (current or future), and defined as committed, available, and unattainable.

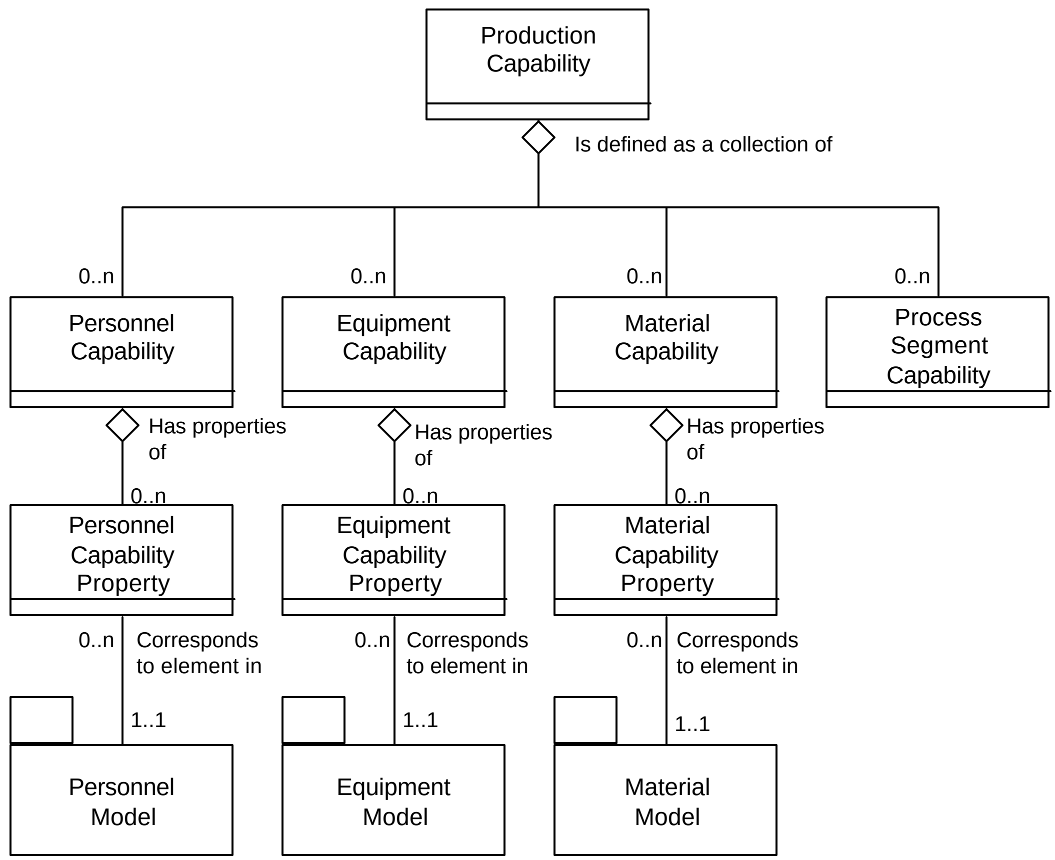


Figure 15 – Production capability model

7.3.1.1 Personnel capability

Personnel capability is defined as a set of references to *persons* or *personnel classes* committed, available, or unattainable for a defined time. *Personnel capability* contains references to *persons* or *personnel classes*. *Persons* and *personnel classes* are defined in the Personnel Model in Section 7.3.2.

Personnel capability will usually identify:

— the capability type (available, unattainable, committed),

— the time associated with the capability (e.g. third shift on a specific date).

Specific *personnel capabilities* are defined in *personnel capability properties*. The *personnel capability property* may include the quantity of the resource referenced, such as 3 horizontal drill press operators available for the third shift on February 29, 2000.

7.3.1.2 Equipment capability

Equipment capability is defined as a set of references to *equipment* or *equipment classes* committed, available, or unavailable for a defined time. *Equipment capability* contains references to *equipment* or *equipment classes*. *Equipment* and *equipment classes* is defined in the Equipment Model in Section 7.3.3.

Equipment capability will usually identify:

— the capability type (available, unattainable, committed),

— the time associated with the capability (e.g. third shift on a specific date).

Specific *equipment capabilities* are defined in *equipment capability properties*. The *equipment capability properties* may include the quantity of the resource referenced, such as 3 horizontal drill presses currently available.

7.3.1.3 Material capability

Material capability is defined as a set of references to *material lots* or *sublots* committed, available, or unavailable for a defined time. This includes information that is associated with the functions of Material and Energy Control (4.0) and Product Inventory Control (7.0). The currently available and committed *material capability* is the inventory. WIP (Work In Progress) is a *material capability* currently under the control of production.

Material capability will usually identify:

— the capability type (available, unattainable, committed),

— the time associated with the capability (e.g. third shift on a specific date).

Specific *material capabilities* are defined in *material capability properties*. The *material capability properties* may include the quantity of the material referenced, such as 3 sublots in Building 3 of material Starch Lot #12345 committed to production for February 29, 2000.

7.3.1.4 Process segment capability

A *process segment capability* is defined as a logical grouping of personnel resources, equipment resources, and material that is committed, available, or unavailable for a defined process segment for a specific time..

A *process segment capability* is related to a *product segment* that can occur during production, as defined in the Product Information Model in Section 7.4. A *process segment capability* may relate to one or more products.

Process segment capability will usually identify:

— the capability type (available, unattainable, committed),

— the time associated with the capability (e.g. third shift on a specific date), *Process segment capabilities* are made up of:

- *Personnel segment capabilities*, which may define specific properties required in *personnel segment capability properties*.
- *Equipment segment capabilities*, which may define specific properties required in *equipment segment capability properties*.
- *Material segment capabilities*, which may define specific properties required in *material segment capability properties*.
-

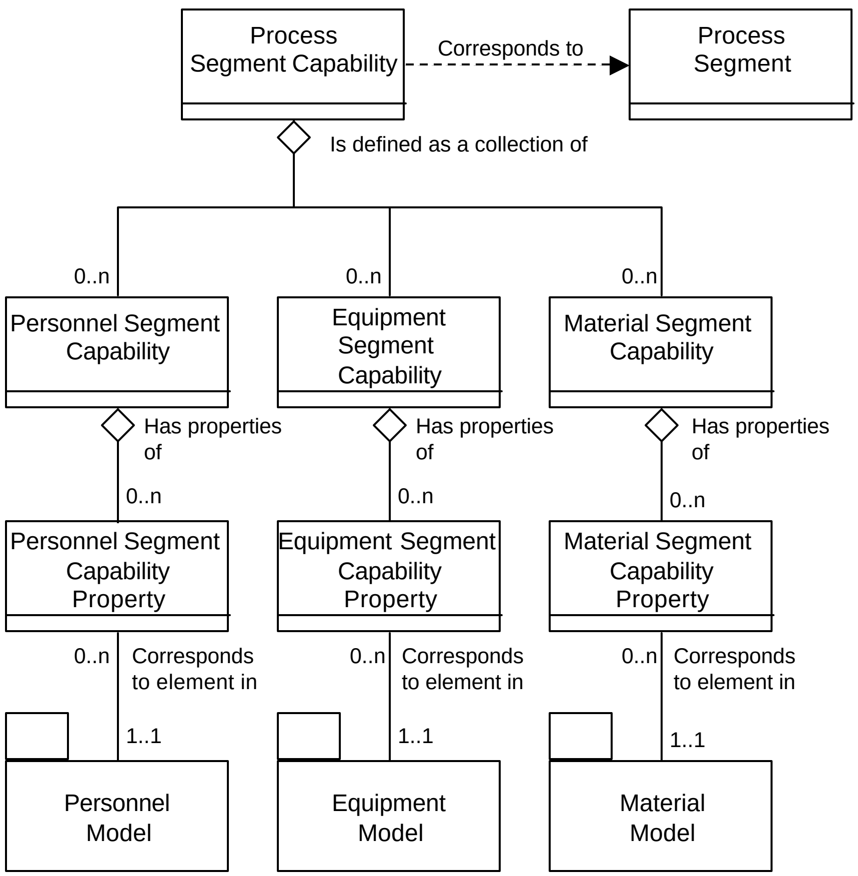


Figure 16 - Process segment capability model

7.3.2 Personnel Model

The personnel model contains the information about specific personnel, classes of personnel, and qualifications of personnel. Figure 17 illustrates the personnel model.

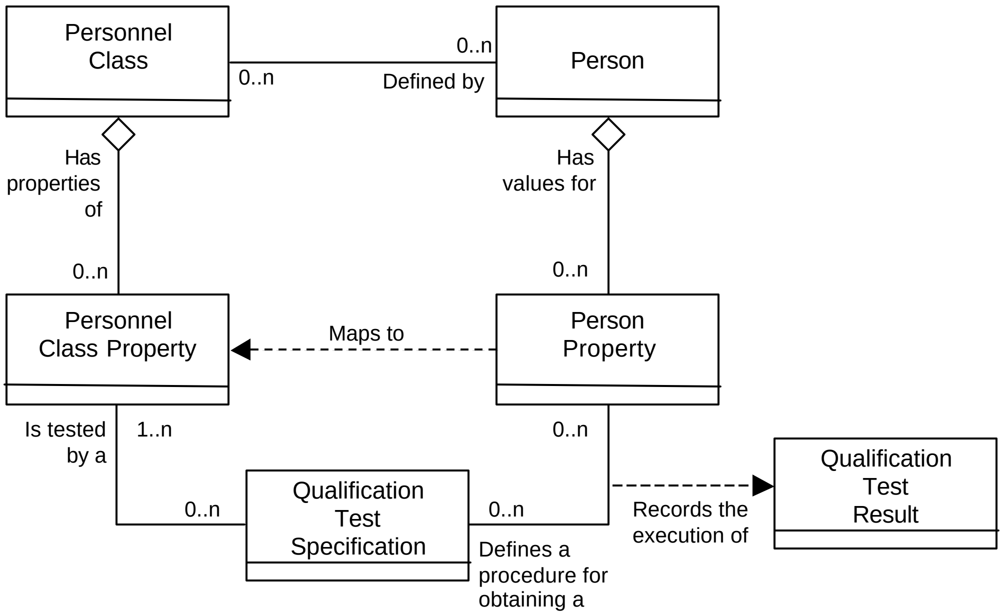


Figure 17 - Personnel model

7.3.2.1 Personnel class

A *personnel class* is a means to describe a grouping of persons with similar characteristics for purposes of scheduling and planning. Any person may be a member of zero or more *personnel classes*.

Examples of *personnel classes* are "Cook Machine Mechanics", "Slicing Machine Operators", "Cat-Cracker Operator", and "Zipper Line Inspectors".

7.3.2.2 Personnel class property

Each *personnel class* may have zero or more recognized properties. Examples of *personnel class properties* for the *personnel class* "Operators" may be "Class 1 Certified", "Class 2 Certified", "Night Shift", and "Exposure hours". *Production requests* may specify required *personnel class property* requirements for a *product segment*.

7.3.2.3 Person

A *person* represents a specifically identified individual. A *person* may be a member of zero or more *personnel classes*.

— *Person* will include a unique identification of the individual.

7.3.2.4 Person property

Each *person* may have zero or more *person properties*. These specify the current property values of the person for the associated personnel property. For example: a *person property* may be "Night Shift" and its value would be "available", and a *person property* may be "Exposure hours available" and its value would be "4".

Person properties may include the current availability of a person and other current information, such as location and assigned activity, and the unit of measure of the current information.

7.3.2.5 Qualification test specification

A *qualification test specification* may be associated with a *personnel class property* or *person property*. This is typically used where a qualification test is required to ensure that a *person* has the correct training and/or experience for specific operations. A *qualification test specification* may test for one or more properties.

A *qualification test specification* will usually include:

- an identification of the test,
- a version of the test,
- a description of the test.

7.3.2.6 Qualification test result

A *qualification test result* records the results from a qualification test for a specific person.

A *qualification test result* will usually include:

- the date of the test,
- the result of the test (passed, failed),
- the expiration date of the qualification.

7.3.3 Equipment Model

The equipment model contains the information about specific equipment, the classes of equipment, equipment capability tests, and maintenance information associated with equipment. Figure 18 illustrates the equipment model.

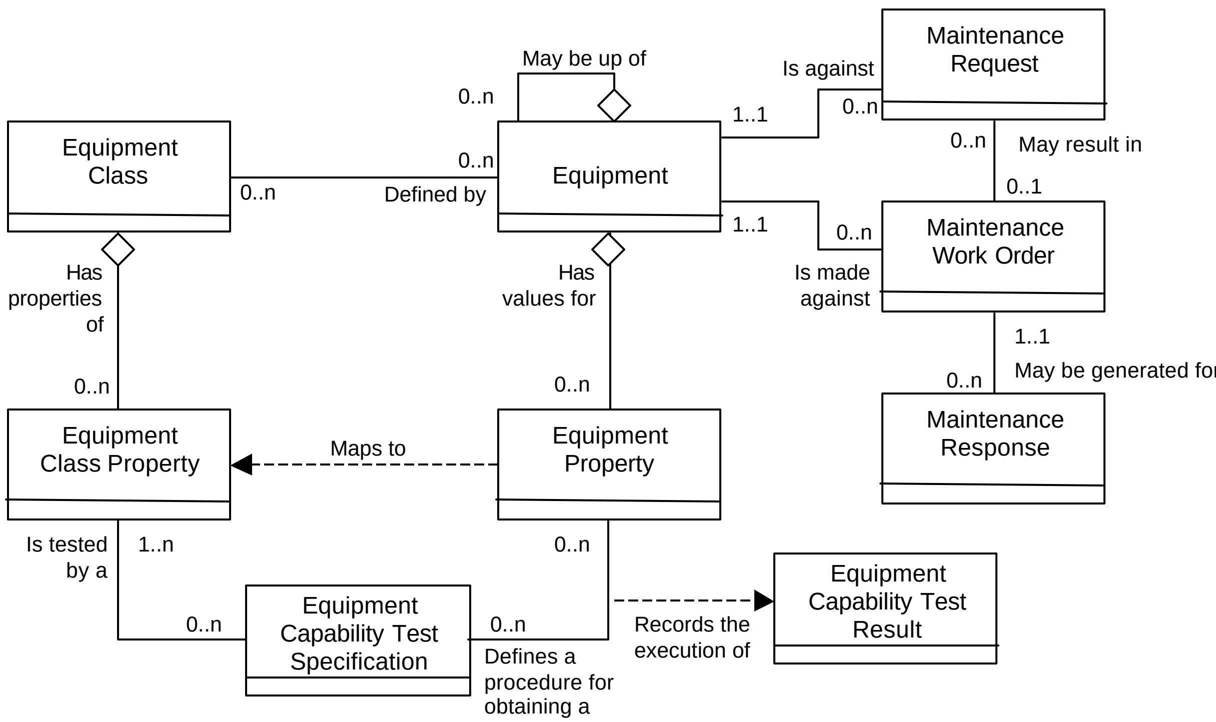


Figure 18 - Equipment model

7.3.3.1 Equipment class

An *equipment class* is a means to describe a grouping of equipment with similar characteristics for purposes of scheduling and planning. Any piece of equipment may be a member of zero or more *equipment classes*. Examples of *equipment classes* are "Reactor Unit", "Bottling Line", and "Horizontal Drill Press".

7.3.3.2 Equipment class property

Each *equipment class* may have zero or more recognized properties. Examples of *equipment class properties* for the *equipment class* "Reactor Unit" may be "Lining Material", "BTU Extraction Rate", and "Volume". *Production requests* may specify required *equipment property* requirements for a *product segment*.

7.3.3.3 Equipment

Equipment represents the elements of the equipment hierarchy model defined in Section 4.2. *Equipment* may be definitions of sites, areas, production units, production lines, work cells, process cells, or units.

Equipment may be made up of other equipment, as defined in equipment hierarchy model. For example, a production line may be made up of work cells.

Examples of *equipment* are “Reactor Unit #1”, “Bottling Line #1”, and “Horizontal Drill Press #4”

7.3.3.4 Equipment property

An *equipment* may have zero or more *equipment properties*. These specify the current property values of the *equipment* for the associated *equipment class property*. Equipment properties may include a unit of measure.

For example: an *equipment class property* may be “Volume” and its value would be “50000" with a unit of measure of "Liters", an *equipment property* may be “Lining Material” and its value would be “glass”.

Examples of *equipment properties* are:

- the current availability of equipment,
- other current information, such as when calibration is needed,
- maintenance status,
- the current state of the equipment,
- performance values.

7.3.3.5 Equipment capability test specification

An *equipment capability test specification* may be associated with an *equipment property*. This is typically used where a test is required to ensure that the equipment has the rated capability. An *equipment capability test specification* may test for one or more *equipment properties*.

An *equipment capability test specification* will usually include:

- an identification of the test,
- a version of the test,
- a description of the test.

7.3.3.6 Equipment capability test result

An *equipment capability test result* records the results from a qualification test for a specific piece of equipment.

An *equipment capability test result* will usually include:

- the date of the test,
- the result of the test (passed-failed or quantitative result),
- the expiration date of the test.

7.3.3.7 Maintenance information

The overlap of information between manufacturing control and maintenance is in the equipment area. This is represented as maintenance requests, maintenance responses, and work orders associated to specific equipment.

A *maintenance request* is made against specific *equipment*. There may be many outstanding *maintenance requests* against a piece of equipment. A *maintenance request* may result in a *maintenance work order* against the equipment. Zero or more *maintenance work orders* may be generated from a *maintenance request*. A *maintenance response* is made against a *maintenance work order*.

Maintenance requests will usually include:

- who made the request,
- the date and time of the request,
- the needed data and time of resolution,
- the equipment associated with the request,
- a description of the request,
- a priority.

Maintenance work order will usually include:

- the associated person or personnel class assigned,
- the assigned priority of the work order,
- the status of the work order (e.g. pending, in process).

Maintenance responses will usually include:

- the date and time of the response,
- who responded to the work order,
- a description of the response,
- the result of the work order.

7.3.4 Material model

The material model defines the actual materials, material definitions, and information about classes of material definitions. Material information includes the inventory of raw, finished, and intermediate materials. The current material information is contained in the *material lot* and *material sublot* information. Material classes are defined to organize materials. Figure 19 illustrates the material model.

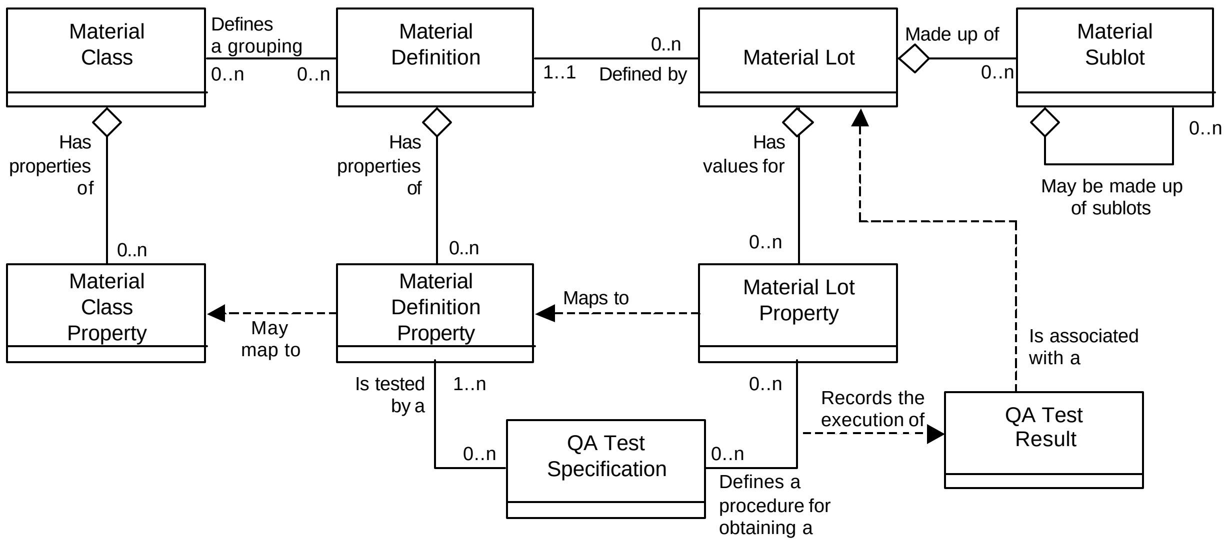


Figure 19 - Material model

7.3.4.1 Material definition

A *material definition* is a means to describe goods with similar characteristics for purposes of scheduling and planning. Examples of these may be “City Water”, “HCl”, and “Grade B Aluminum”. The materials may be identified as raw, intermediate, or final and may have other state information, such as availability of safety information.

Any material lot is defined by one *material definition*.

Material definitions may also be related to a production request. The same material may have different definitions for different production requests, depending on specific customer requirements.

7.3.4.2 Material definition property

A *material definition* may be further characterized through zero or more *material definition properties*. Examples of *material definition property* include density, pH factor, or material strength. These define the nominal or standard values for the material.

7.3.4.3 Material Class

A *material class* is means of defining groupings *material definitions* for use in production scheduling or processing. An example of a *material class* is "Sweetener", with members of "Fructose", "Corn Syrup", and "Sugar Cane Syrup". Another example of a material class is "Water", with members of "City Water", "Recycled Water", and "Spring Water".

A *material definition* may belong to zero or more *material classes*.

7.3.4.4 Material Class Property

A *material class* may be further characterized through zero or more *material class properties*. Examples of *material class property* include density, pH factor, or material strength. The *material class properties* usually define the nominal, or standard, values for the material. A material property does not have to match a material class property.

7.3.4.5 Material lot

A *material lot* object uniquely identifies a specific amount of material, countable or weighable. This describes the actual total quantity or amount of material available, its current state, and its specific property values.

Materials may be made up of other materials but that association is not described in this model.

A *material lot* may include:

— a unique identification of the lot,

— the amount of material (count or weight),

— the unit of measure of the material (e.g. parts, kg, tons),

— a location for the material,

— and any committed status of the lot.

Material lots and material sublots may be used for traceability when they contain unique identifications.

7.3.4.6 Material lot property

Each material may have unique values for zero or more *material lot properties*, such as a specific pH value for the specific lot of material, or a specific density for the lot of material.

7.3.4.7 Material sublot

A *material lot* may be stored as a separate identifiable quantity. Each separate identifiable quantity of the material is identified in a *material sublot* object. All *material sublots* must contain the same *material lot*, so they use the *material lot element's* property values. A *material sublot* may be just a single item.

Each *material sublot* also contains the location of the sublot and the quantity or amount of material available in the sublot.

Material sublots may contain other sublots. For example, a sublot may be a pallet, each box on the pallet may also be a sublot, and each material blister pack in the box may also be a sublot.

A *material sublot* may include:

— a unique identification of the sublot,

— the packing mode of the material,

— the unit of measure of the material (e.g. parts, kg, tons),

— and any committed status of the sublot.

7.3.4.8 QA test specification

A *QA test specification* may be associated with a *material class property.* This is typically used where a test is required to ensure that the material has the required property value. A *QA test specification* may identify a test for one or more *material class properties*. Not all properties need to have a defined QA test specification.

QA test specifications may also be related to a production request. The same material may have different specifications for different production requests, depending on specific customer requirements.

A *QA test specification* will usually include:

- an identification of the test,
- a version of the test,
- a description of the test.

7.3.4.9 QA test results

A *QA test result* records the results from a QA test for a specific piece of material lot. *QA test results* will usually have the following characteristics:

- They are related to a *material lot*.
- They may be related to a *production request*.
- They may be associated with a specific *production response*
- They may be related to a specific *process segment*.
- They generally include a pass/fail status of the test
- They may include quantitative information of the tests.
- The result may be the granting or refusing of an in-process or finished goods waiver request.
- They may be related to a product characteristic.

QA test results may be associated with a specific production response.

7.3.5 Process Segment Model

The process segment model contains information about the commonly defined process segments. Figure 20 illustrates the process segment model.

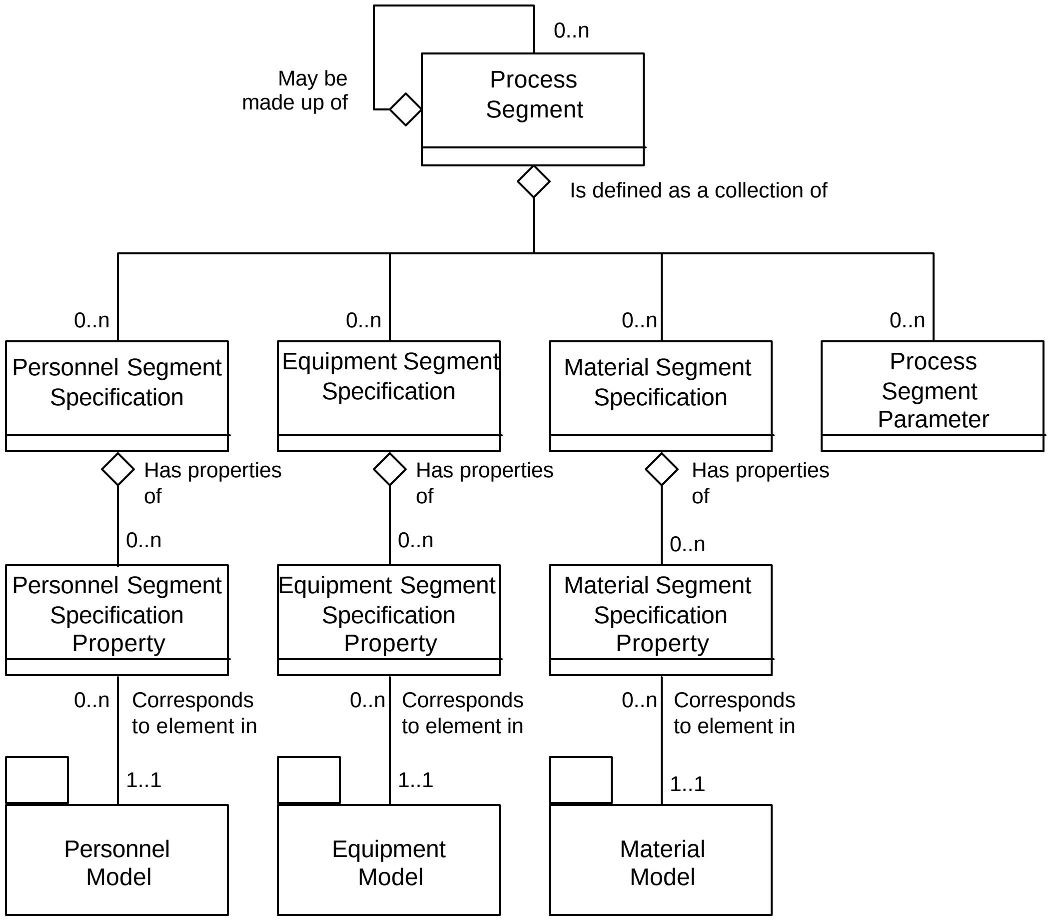


Figure 20- Process segment model

7.3.5.1 Process segment

A *process segment* is a logical grouping of personnel resources, equipment resources, and material required to carry out a production step. *Process segment* usually define the needed classes of personnel, equipment, and material, but it may define specific resources, such as specific equipment needed. *Process segment* usually define the quantity of the resource needed.

A *process segment* is related to a *product segment* that can occur during production, as defined in the Product Information Model in Section 7.4. A *process segment* may relate to one or more products.

Process segment will usually identify:

— the time duration associated with the capability (e.g. 5 hours, or 5 hours/100KG),

— and may include constraint rules associated with ordering or sequencing of segments

A *process segment* may be made up of other *process segment*, in a hierarchy of definitions. Figure 20 illustrates the elements of a process segment.

Process segments may contain specifications of specific resources required by the process segment. *Process segments* may contain parameters that can be defined in specific *production requests.*

7.3.5.2 Process segment parameter

*Process segment parameter*s define specific parameters required for the segment. Examples of parameters are product colors, quality requirements, assembly options, and packaging options,

7.3.5.3 Personnel segment specification

Personnel segment specifications define what personnel resources are required for the process segment, such as three lathe machine operators, or a certified inspector. Specific properties that are required are specified in *personnel segment specification properties*.

7.3.5.4 Equipment segment specification

Equipment segment specifications define what equipment resources are required for the process segment, such as three lathe operators, or a certified test chamber. Specific properties that are required are specified in *equipment segment specification properties*.

7.3.5.5 Material segment specification

Material segment specifications define what material resources are required for the process segment, such as distilled water, or HCl.. Specific properties that are required are specified in *material segment specification properties*.

7.4 Product definition information

The product definition information is information shared between production rules, bill of material, and bill of resources. These three external models are represented by packages in Figure 21, their definitions are outside the scope of this document. The model in this section defines the information shown in the shaded areas of Figure 8.

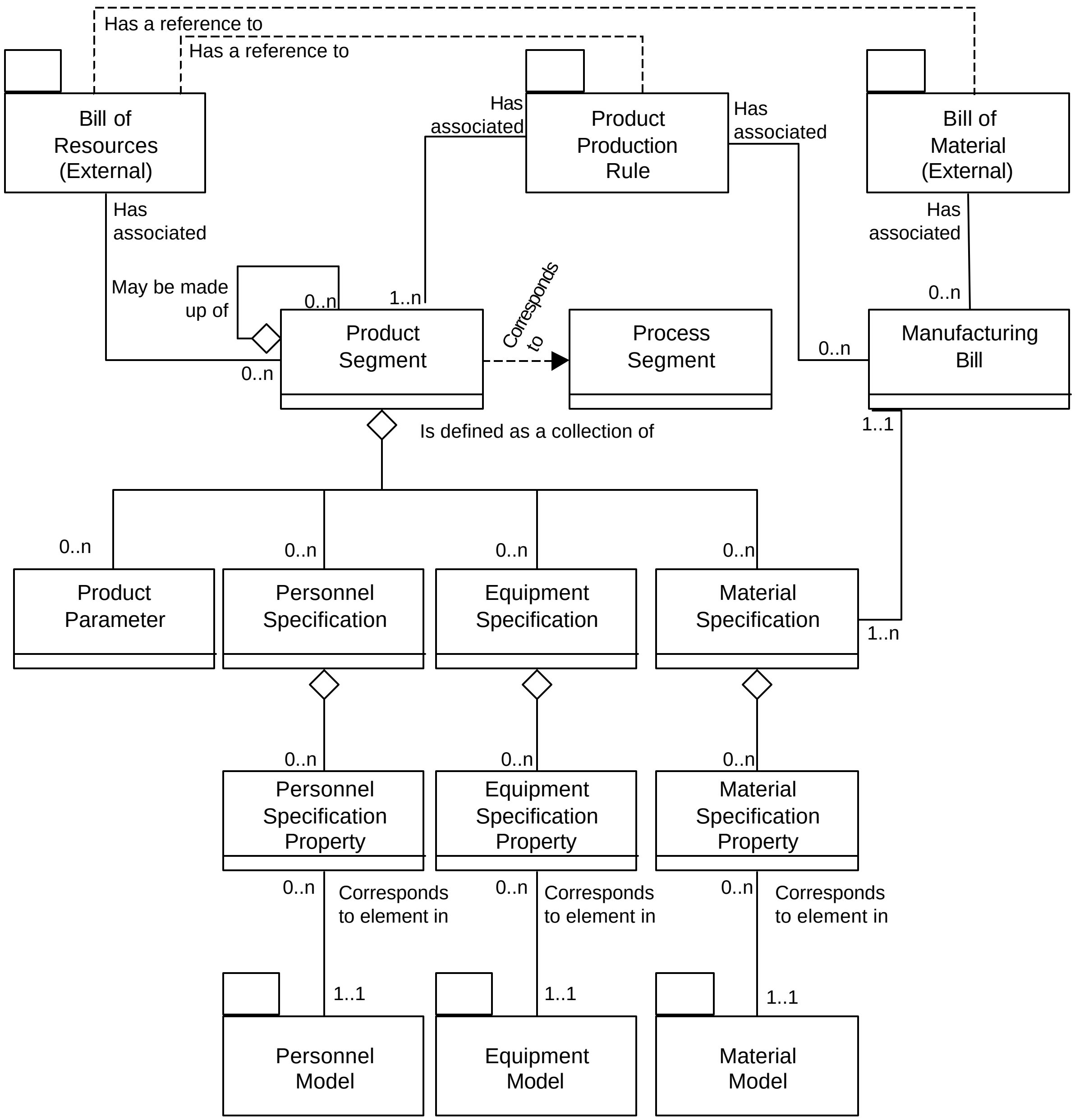


Figure 21 - Product definition model

7.4.1 Product segment

A *product segment* identifies, references, or corresponds to a *process segment*. A *product segment* is related to a specific product, while a *process segment* is product independent. The *product* *segment* specifies the values needed to quantify a segment for a specific product, such as specific number of operators with specific qualifications.

The collection of *product segments* for a product defines the sequence and ordering of segments required to manufacture a product in sufficient detail for production planning and scheduling. The corresponding production rule defines the additional detail required for actual production.

A *product segment* may use zero or more resources, which may correspond to an *equipment specification*, a *personnel specification* or a *material specification*. A *product segment* may have parameter values for parameters specified in the corresponding *process segment*.

7.4.1.1 Product parameter

The *production rule* definition is outside the scope of this document, but a *production rule* will have an associated set of zero or more *product parameters* per product segment for each product defined. The *product parameters* define the names and types of the values that may be sent to the control system to parameterize the product. Examples of product parameter specifications are “pH of 3.5”, “Pressure Limit of 35psi”, and “Flange Color = Orange”. *Product parameters* may include:

- An identification of the parameter.
- A default value for the parameter
- The units of measure of the parameter value.
- Possible ranges of the parameter value. May include alarm or quality ranges.
- Tolerances for acceptable parameter values.

7.4.1.2 Personnel specification

A *personnel specification* identifies, references, or corresponds to a *personnel capability* and usually specifies *personnel class* but may sometimes specify a *person*. This identifies the specific personnel capability that is associated with the identified product segment. A *personnel specification* may include

- An identification of the personnel capability needed.
- The quantity of the personnel capability needed.
- The unit of measure of the quantity.

Specific elements associated with a *personnel specification* may be included in one or more *personnel specification properties*. Examples of *personnel specification properties* are training level required, specific skill required, and exposure availability.

7.4.1.3 Equipment specification

An *equipment specification* identifies, references, or corresponds to an *equipment capability* and may specify either an *equipment class* or a piece of *equipment*. This identifies the specific equipment capability that is associated with the identified product segment. An *equipment specification* may include

An identification of the equipment capability needed either as the *equipment class* needed or specific *equipment*.

- The quantity of the equipment capability needed.
- The unit of measure of the quantity.
- The production performance target.

Specific elements associated with a *equipment specification* may be included in one or more *equipment specification properties*. Examples of *equipment specification properties* are material of construction, maximum material capacity, and minimum heat extraction amount.

7.4.1.4 Material specification

A *material specification* identifies or corresponds to a *material capability* and usually specifies a *material* or a *material class*. This identifies the specific *material specification* that is associated with the identified product segment. A *material specification* may include

- An identification of the material capability needed.
- The quantity of the material capability needed.
- The unit of measure of the quantity.
- Alternate materials or material classes that could be used in place of the primary material specified.
- The production performance target.

Specific elements associated with a *material specification* may be included in one or more *material specification properties*. Examples of *material specification properties* are color range, density tolerance, and maximum scrap content.

7.4.2 Manufacturing bill

A *manufacturing bill* identifies a *material* or *material class* that is needed for production of the product.

The *manufacturing bill* includes all uses of the material in production of the product, while the *product segment's material specification* defines just the amount used in a segment of production.

For example: a *manufacturing bill* may identify 55 Type C left threaded screws, where 20 are used in one product segment, 20 in another product segment, and 15 used in a third product segment.

7.5 Production information

Production information is defined in two models, shown in Figure 22 and Figure 23. These correspond too requests for production and responses to the requests.

A request for production is defined in a production schedule.

7.5.1 Production schedule

The *production schedule* shown in Figure 22 defines the shaded information shown in Figure 11. A *production schedule* is made up of one or more production requests.

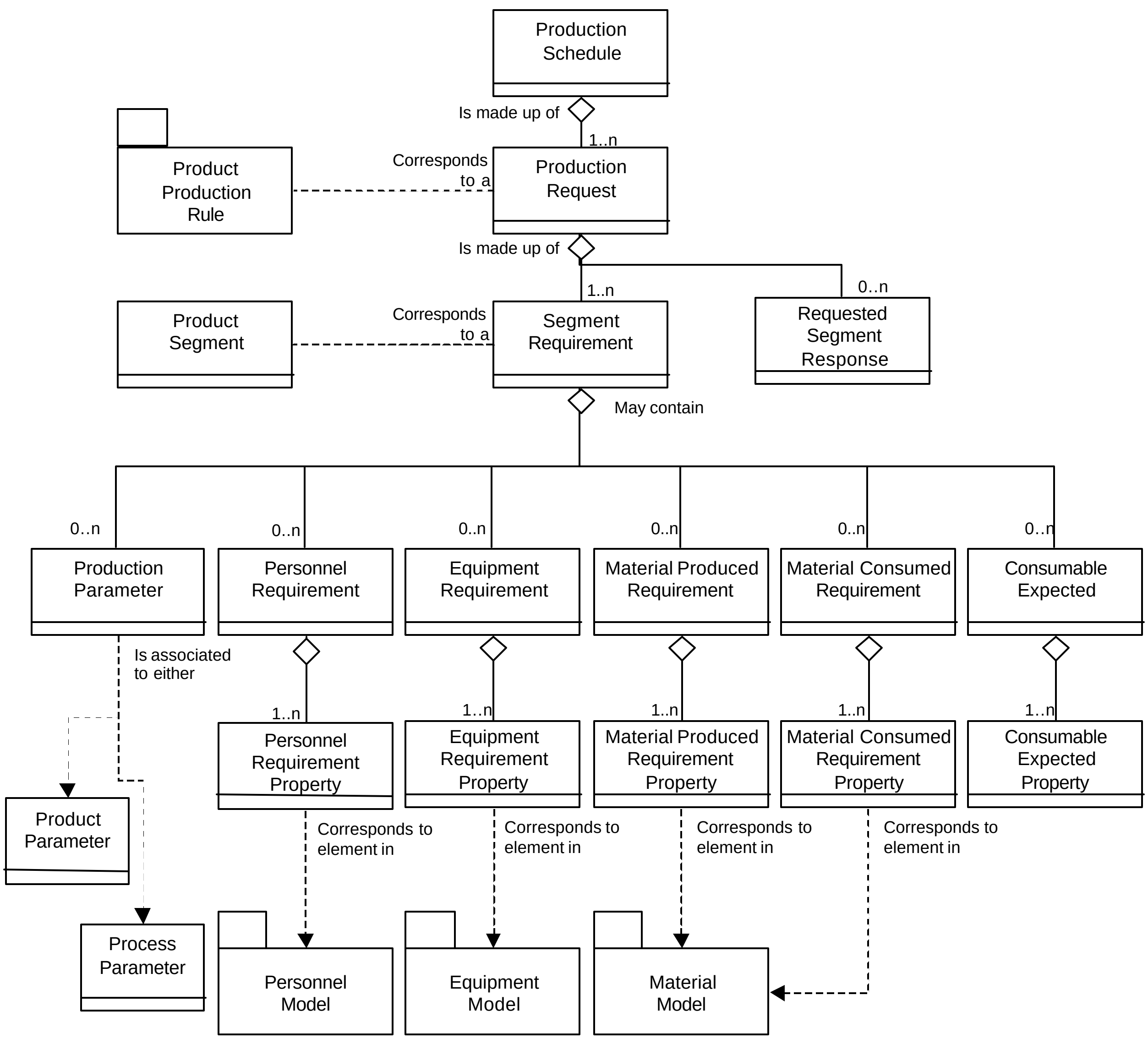


Figure 22 - Production schedule model

7.5.2 Production request

A *production request* defines a request for production for a single product identified by a *production rule*. A *production request* contains the information required by manufacturing to fulfill scheduled production. This may be a subset of the business production order information, or it may contain additional information not normally used by the business system.

A *production request* will identify or reference the associated *production rule*. A production request must contain at least one *segment requirement*, even it spans all production of the product. If not uniquely defined by the production rule, then a segment requirement will contain at least one *material produced requirement* with the identification, quantity, and units of measure of the material to be produced.

A *production request* may also include:

- When to start production, typically used if a scheduling system controls the schedule.
- When the production is to be finished, typically used if the manufacturing system controls its internal schedule too meet deadlines.
- The priority of the request, typically used if exact ordering of production is not externally scheduled.
- A pack out schedule.
- A pre-assigned lot identification for the produced material.

A production request may be reported on by one or more production responses. In some situations, the material identification, production rule identification, and material quantity may be all that is needed for the manufacturing. Other situations may require additional information. The additional information may be described in the *production parameters*, *personnel requirements*, *equipment requirements*, and *material requirements.*

7.5.2.1 Segment requirement

A *production request* is made up of one or more *segment requirements.* Each *segment requirement* must correspond to, or reference, an identified *product segment*. The *segment requirement* identifies or references the segment capability to which the associated personnel, equipment, materials, and production parameters correspond.

The *personnel requirement property, equipment requirement property* and *product parameter* must align with the *personnel property*, *equipment property*, and *product parameters* sent as part of a *production request*. If the scheduling function sends information that is not understood by the receiving control function, then that information can not be used within the control function. Likewise the scheduling function must be able to determine what information can be accepted by the control function.

7.5.2.2 Personnel requirement

A *personnel requirement* and the associated *personnel requirement property* elements refer to the number, type, duration, and scheduling of specific certifications and job classifications needed to support the current production request. Examples of job classification types include: "mechanics", "operators", "health & protection", or "inspectors".

For example, there may be a requirement for one operator with a specified level of certification available two hours after production starts. There would be one *personnel requirement* for the requirement for the operator and two *personnel requirement properties*, one for the certification level and one for the time requirement.

A *personnel requirement* typically includes:

- The identification of the personnel capability needed, such as “Milling machine operator”
- The quantity of personnel capability needed.

Specific elements associated with each *personnel requirement* may be included in one or more *personnel requirement properties*.

Examples of *personal requirement property* elements are: training and certification, specific skill, physical location, seniority level, exposure level, training certification, security level, experience level, physical requirements, and overtime limitations and restrictions.

7.5.2.3 Equipment requirement

The *production request* may include one or more requirements for, or constraints upon, the equipment that the facility shall use in the production process for the scheduled item. Requirements can be as generic as materials of construction, or it can as specific as a particular piece of equipment. Each of these requirements is an instance of the *equipment requirement* class.

Each *equipment requirement* identifies a general class of equipment (such as “Reactor Vessels”), a specific class of equipment (such as “Isothermal Reactors”), or a specific piece or set of equipment (such as “Isothermal Reactor #7”). The specific requirements on the equipment, or equipment class are defined in *equipment requirement property* objects.

An *equipment requirement* typically includes:

- The identification of the equipment capability needed, such as “Milling machine”
- The quantity of equipment capability needed.
- The *product segment* the *equipment requirement* is needed in, such as “First Step Rough Shaping”.

Specific elements associated with each *equipment requirement* may be included in one or more *equipment requirement properties*.

Examples of equipment requirement properties are: material of construction and minimum equipment capacity.

7.5.2.4 Material produced requirement

A *material produced requirement* is an identification of a material to be produced from the production request. A *material produced requirement* may include:

- The total quantity of the material to be produced and unit of measure, such as 5000 Lbs.
- An acceptable range for the quantity of material.

Specific elements associated with each *material produced requirement* may be included in one or more *material produced requirement properties*.

Examples of *material produced requirement properties* are:

- fat content,
- octane rating,
- delivery locations,
- *material lot* identification (such as “Starch Lot #45663”) to be assigned to the material,
- identification of sublots.

7.5.2.5 Material consumed requirement

A *material consumed requirement* is an identification of a material to be used in the production request. A *material consumed requirement* may include:

- The total quantity of the material to be used and unit of measure, such as 5000 Lbs.
- An acceptable range for the quantity of material.

Specific elements associated with each *material consumed requirement* may be included in one or more *material consumed requirement properties*.

Examples of *material produced requirement properties* may include:

- *Material lot* (such as “Starch Lot #45663”)
- A list of possible *material lots* that can be used in production, where the production system or operators may select the lot from the list, as described in Section 7.3.4.5.
- A *material definition*, such as “Starch”, where the actual lot of material is not specified.
- A *material class*, such as "Starch Alternates", so that any *material lot* of that class can be used for production.

7.5.2.6 Consumable expected

Consumable expected include resources that are not normally included in bills of materials or are not individually accounted for in specific production requests. Depending on the industry these may include water, catalysts, common chemicals, and utilities, such as electricity and steam. These items will often result in direct charges that will usually be considered in costing the product segment. Consumables are often materials that do have an inventory balance.

In some industries *consumable expected* are not used and the information is included in *material consumed requirement*.

Consumables do not have lot identifications. Consumables with lot identifications are typically treated as *material consumed requirements.*

Consumable expected usually include the following information:

- the identification of the resource expected to be consumed,
- the total quantity of the resource consumed expected to be consumed and the unit of measure of the quantity.

Specific elements associated with each *consumable expected* may be included in one or more *consumable expected properties*.

Examples of *consumable expected properties* may include:

- A unique identification of the consumable, such as "River water 01-01-2001"
- A definition of the consumable, such as "Rubber Gloves" or "Cotton balls"

7.5.2.7 Production parameter

A *production parameter* is information contained in the enterprise system that is required by the operation system for correct production.

Examples of *production parameters* are:

- quality limits,
- setpoints,
- targets,
- specific customer requirements (such as "Purity = 99.95%"),
- final disposition of the produced product,
- transportation information,
- other information not directly related to control (such as a customer order number required for labeling or language for labels).

A *production parameter* may include:

- An identification of the parameter, that matches the *product parameter* of the product's production rule, such as "target acidity".
- A value for the parameter, such as 3.4.
- The type of the parameter, such as "ph".
- A set of limits that apply to any change to the value, such as quality limits and safety limits.

Production parameters may be either product parameters that define some characteristics of the product (such as paint color), or process parameters that define some characteristics of the production process (such as bake time).

7.5.2.8 Requested segment response

A *requested segment response* is the definition of the information that must be sent back as a result of the *production request*. This information is of the same form as a *segment response*, but without containing actual values.

A *requested segment response* may include required information, which defines information that must be reported on from production, such as the actual amount of material consumed.

A *requested segment response* may include optional information, which defines information that may be reported on from production, such as operator entered comments.

7.5.3 Production performance

The performance of the requested manufacturing requests is the *production performance*. *Production performance* is a collection of *production responses*.

7.5.4 Production response

Production responses are the response from manufacturing that is associated with a *production Request*. There may be one or more *production responses* for a single *production request* if the production facility needs to split the *production request* into smaller elements of work. For example a single *production request* for the production of “200 gears” may be reported on by 10 *production response* objects of “20 gears” each because of manufacturing restrictions.

A *production result* may include the status of the request, such as the percentage complete, completed, or aborted.

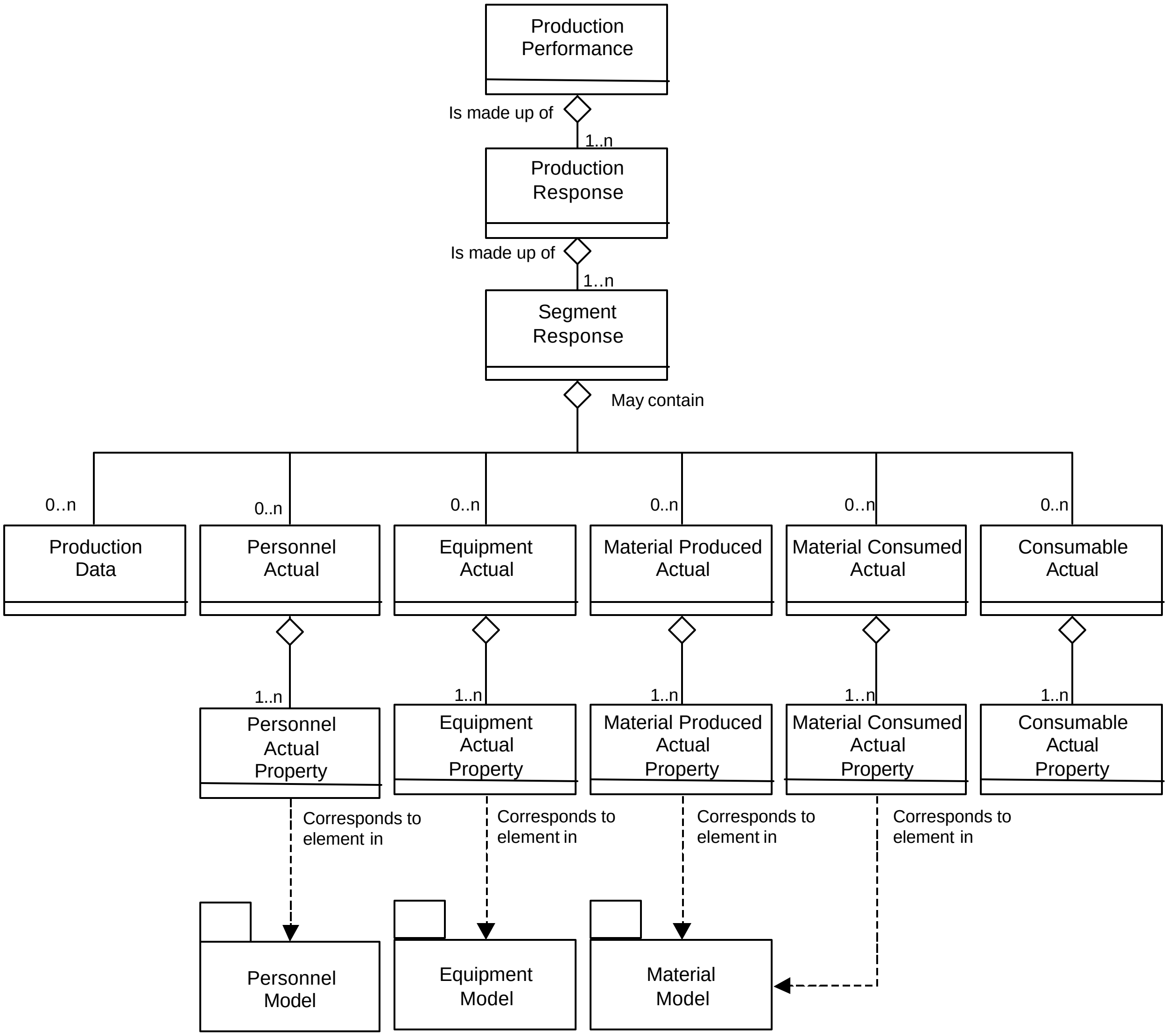


Figure 23 - Production performance model

Production responses contain the items reported back to the business system, at the end of production or during production. The business system may need to know intermediate *production response* statuses, rather than waiting for the final *production response* status, because of cost accounting of material produced or intermediate materials.

7.5.4.1 Segment response

The *production response* for a specific segment of production is defined as a *segment response*. A *segment response* may be made up of zero or more sets of information on *product data*, *personnel actual*, *equipment actual*, *utilities actual*, *materials consumed actual*, *materials produced actual*, and *consumables actual*. A *segment response* may include:

— An identification of the associated product segment.

— The actual starting and stopping time of the segment.

— The duration of the segment.

The response actuals may contain attributes that define if the response was required or optional.

7.5.4.2 Production data

Production data is information related to the actual products made. Examples of *production data* are:

— A customer order number associated with the production request.

— Specific commercial notes from operations related to the customer order. Such as “order complete”, “order incomplete”, or an anticipated completion date and time.

— Quality information.

— Certification of Analysis.

— Procedural deviations, such as an identification of an event defined in another system and alarm information.

— Process behavior, such as temperature profiles.

— Operator behavior, such as interventions, actions, and comments.

7.5.4.3 Personnel Actual

The *personnel actuals* in a production response identifies a personnel capability used during a specified product segment. Production functions often require people as a resource to carry out tasks. *Personnel actuals* may include the following information:

— The identification of each resource used, usually identifying a specific personnel capability or personnel class, such as "End Point Transmission Assembly Operators", or a personnel IDs such as “Jean Smith” or “SS# 999-123-4567”.

Specific information about *personnel actuals* is defined in *personnel actual properties*. Examples of *personnel actual properties* are:

— The actual duration of use of the personnel during the product segment, such as “2 hours”. This information is often needed for actual costing analysis.

— Actual monitored exposure times by the personnel during the product segment.

— The location of the personnel after use in the product segment, such as “Area 51”. This information is often used for short term scheduling of personnel resources.

7.5.4.4 Equipment actual

The *equipment actual* in a production response identifies an equipment capability used during a specified product segment. Production functions often require equipment as a resource to carry out tasks. *Equipment actual* may include the following information:

— The identification of the equipment used, usually identifying a specific piece if equipment

Specific information about *equipment actuals* is defined in *equipment actual properties*. Examples of *equipment actual properties* are:

- The actual duration of use of the equipment during the product segment. This information is often needed for actual costing analysis.
- The equipment condition, after use in the product segment, such as a status of available, out-of-service, or cleaning. This information is often used for short term scheduling of equipment resources.
- The equipment setup procedures used for the product segment. This information is often needed for actual costing analysis and scheduling feedback.
- Other equipment attributes, such as percentage of available capability used.

7.5.4.5 Material produced actual

The *material produced actual* in a production response identifies the material produced during a defined product segment. The material may be the final product, an intermediate product that must be identified for costing or scheduling purposes, or a scrapped product or material. *Material produced actuals* may include the following information:

- The identification of the material produced, usually identifying the material. Examples include "Resin-89-B", "Motherboard MP667a".
- The quantity of the material produced and the unit of measure of the quantity produced, such as "500 Parts", "50000 Liters"

Specific information about *material produced actuals* is defined in *material produced actual properties*. Examples of *material produced actual properties* are:

- An identification of the *material lot* or *material sublot* produced.
- Type of material, such as final, intermediate, or co-product.

7.5.4.6 Material consumed actual

The *material consumed actual* in a production response identifies the material used during a specified product segment. This material may be identified in the *Bill of material* and may be a raw material or purchased material. *Material consumed* usually include the following information:

- the identification of the material consumed,
- the quantity of the material consumed and the unit of measure of the quantity.

Specific information about *material consumed actuals* is defined in *material consumed actual properties*. Examples of *material consumed actual properties* are:

- the *material lot* or *material sublot* consumed,
- comments about the use from operations.

7.5.4.7 Consumable actual

Consumable actuals include resources that are not normally included in bills of materials or are not individually accounted for in specific production requests. These include water, catalysts, common chemicals, and utilities, such as electricity and steam. These items will often result in direct charges that will usually be considered in costing the product segment. Consumables are often materials that do have an inventory balance.

Consumable actuals usually include the following information:

- the identification of the resource consumed,
- the quantity of the resource consumed and the unit of measure of the quantity.
- Specific information about *consumable actuals* is defined in *consumable actual properties.*

7.6 Model cross reference

Figure 24 provides an informative illustration of how the object models inter-relate. The production information defines what was made and what was used. Its elements correspond to information in production scheduling that defined what to make and what to use. The production scheduling elements correspond to information in the product definition that defines what must be specified to make a product. The produce definition elements correspond to information in the process segment definitions that define what can be done with the production resources.

The slanted rectangles in Figure 24 represent any of the resources (personnel, equipment, or material) or properties.

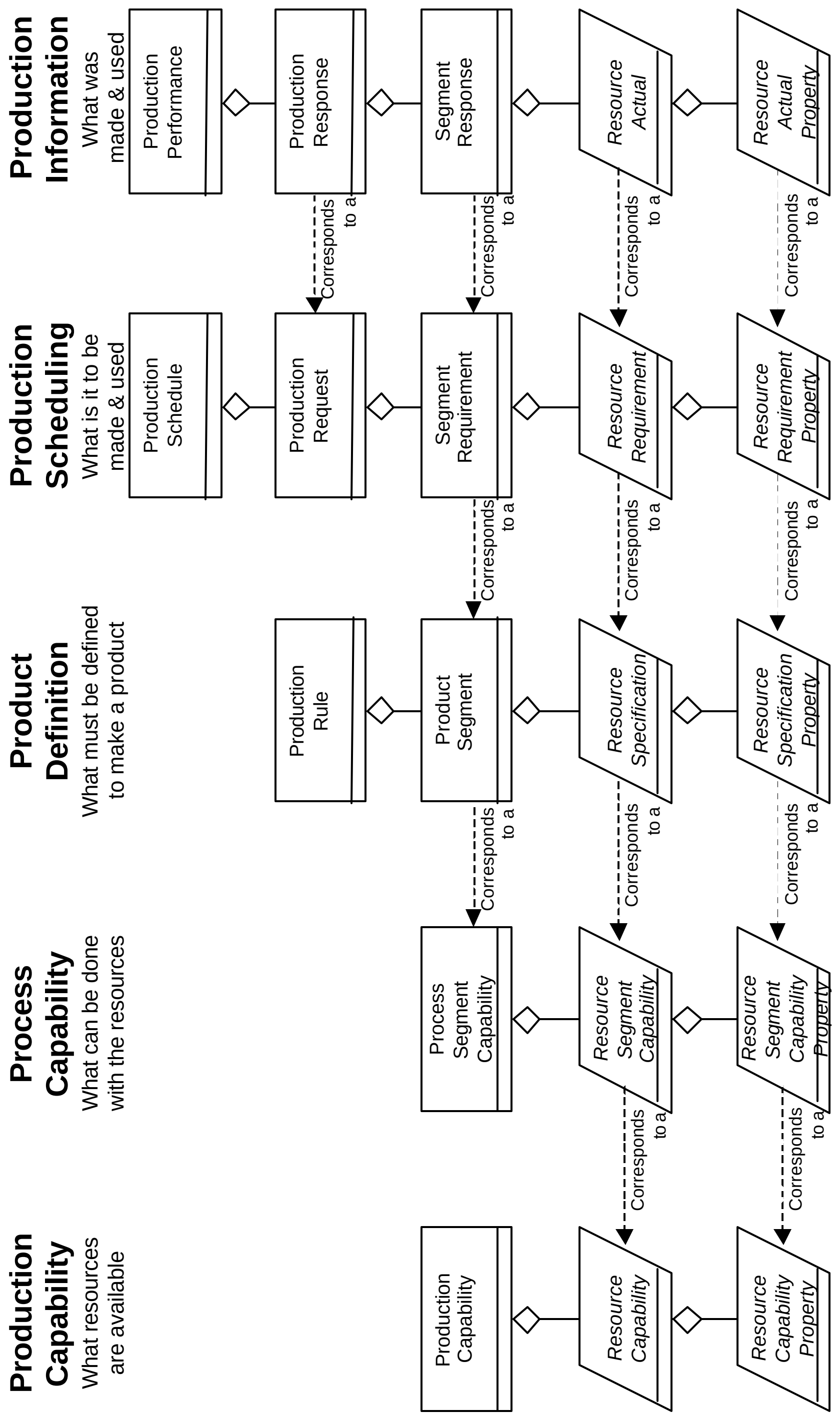


Figure 24 - Object model inter-relations

Table 3 provides a cross-reference between the elements of the information flows in the data flow model and the corresponding section describing the object model.

Table 3- Model cross reference

Data Flow Model Information	From Function	To Function	Object Model Section
6.2.1 Schedule	Production scheduling (2.0)	Production control (3.0)	7.5.1 and 7.5.2
6.2.2 Production from plan	Production control (3.0)	Production scheduling (2.0)	7.5.3 and 7.5.4
6.2.3 Production capability	Production control (3.0)	Production scheduling (2.0)	7.3
6.2.4 Material and energy order requirements	Production control (3.0)		Defined in terms of the Material Model, 7.3.4
6.2.5 Incoming order confirmation	Material and energy control (4.0)	Procurement (5.0)	Defined in terms of the Material Model, 7.3.4
6.2.6 Long term material and energy requirements	Production scheduling (2.0)	Material and energy control (4.0)	Defined in terms of the Material Model, 7.3.4
6.2.7 Short term material and energy requirements	Production control (3.0)	Material and energy control (4.0)	Defined in terms of the Material Model, 7.3.4
6.2.8 Material and energy inventory	Material and energy control (4.0)	Production control (3.0)	7.3.4
6.2.9 Production cost objectives	Product cost accounting (8.0)	Production control (3.0)	7.4
6.2.10 Production performance and costs	Production control (3.0)	Product cost accounting (8.0)	7.5.3 and 7.5.4
6.2.11 Incoming Material and energy receipt	Material and energy control (4.0)	Product inventory control (7.0)	<Not detailed in object model>
6.2.12 Quality assurance results	Quality assurance (6.0)	Production control (3.0)	7.3.4.9 and 7.5.4
6.2.13 Standards and customer requirements	Marketing and sales	Quality assurance (6.0)	7.3 and 7.5.2
	Quality assurance (6.0)	Production control (3.0)	
6.2.14 Product and process requirements	Research, development, and engineering	Quality assurance (6.0)	7.4
6.2.15 Finished goods waiver	Functions Order processing (1.0)	Quality assurance (6.0)	<Not detailed in object model> Typically unstructured information handled on an ad-hoc basis
6.2.16 In-process waiver request	Production control (3.0)	Quality assurance (6.0)	Defined in terms of the Material Model, 7.3.4
6.2.17 Finished goods inventory	Product inventory control (7.0)	Production scheduling (2.0)	7.3.4 and 7.5.4
6.2.18 Process data	Production control (3.0)	Quality assurance (6.0)	7.5.3and 7.5.4
6.2.19 Pack out schedule	Production scheduling (2.0)	Product inventory control (7.0)	7.5.2

6.2.20 Product and process know how	Research, development, and engineering	Production control (3.0)	7.4
6.2.21 Product and process information request	Production control (3.0)	Research, development, and engineering	<Not detailed in object model>
6.2.22 Maintenance requests	Production control (3.0)	Maintenance management (10.0)	7.3.3
6.2.23 Maintenance responses	Maintenance management (10.0)	Production control (3.0)	7.3.3
6.2.24 Maintenance standards and methods	Production control (3.0)	Maintenance management (10.0)	<Not detailed in object model>
6.2.25 Maintenance technical feedback	Maintenance management (10.0)	Production control (3.0)	7.1.1 and 7.3
6.2.26 Product and process technical feedback	Production control (3.0)	Research, development, and engineering	<Not detailed in object model>
6.2.27 Maintenance Purchase Order Requirements	Maintenance management (10.0)	Procurement (5.0)	<Not detailed in object model>
6.2.28 Production Order	Functions Order processing (1.0)	Production scheduling (2.0)	<Not detailed in object model>
6.2.29 Availability	Production scheduling (2.0)	Functions Order processing (1.0)	<Not detailed in object model>
6.2.30 Release to Ship	Product shipping administration (9.0)	Product inventory control (7.0)	<Not detailed in object model>
6.2.31 Confirm to Ship	Product inventory control (7.0)	Product shipping administration (9.0)	<Not detailed in object model>

Annex A – Bibliography and Abbreviations

A.1 Bibliography

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A.2 Abbreviations

CIM – Computer Integrated Manufacturing

CGMP – Current Good Manufacturing Practices – Defined in the United States Code of Federal Regulations 21 CFR.

COA – Certificate Of Analysis

ERP – Enterprise Resource Planning

LIMS – Laboratory Information Management System

MRP – Materials Requirements Planning

MRP II – Manufacturing Resource Planning

MSDS – Material Safety Data Sheet

PRM – Purdue Reference Model

QA – Quality Assurance

RD&E – Research Development & Engineering

SCM – Supply Chain Management

SKU – Stock Keeping Unit

SOC – Standard Operations Conditions

SOP – Standard Operating Procedure or Standardized Operational Procedure

SPC – Statistical Process Control – A set of techniques based on statistical principles and methods used to regulate the quality of products and processes. Also call SQC

SQC – Statistical Quality Control – A set of techniques based on statistical principles and methods used to regulate the quality of products and processes.

UML – Unified Modeling Language

WIP – Work In Process

Annex B – Business drivers and key performance indicators

This section contains a collection of business drivers and KPI (key performance indicators) or issues that have been defined, and used as the potential touch points into the business processes of the users of the standard. These are also called Critical Success Factors. The drivers were used to test the informational content included within the standards. They determined if the communications model adequately addressed the business issue associated with integration.

These business drivers are identified as being critical to the success of the operation of manufacturing companies across a variety of industries. The drivers have been clarified and validated with operating companies and vendors companies. The drivers provide users with the basis from which to determine the usage of the standard based on their particular industry and information system needs.

B.1 History

Key business drivers are the areas of performance that are most critical to the organization's success. Key business driver is a term used in connection with strategic planning and related goal setting. Key business drivers refer to principal organization-level requirements (similar to Mission Essential Task List (METL) in tactical units), derived from short- and long-term strategic planning. They include customer-driven quality requirements and operational requirements such as productivity, cycle time, deployment of new technology, strategic alliances, supplier development, and research and development. In simplest terms, key business drivers are those things the organization must do well for its strategy to succeed. (Sources: How to Interpret the Malcolm Baldrige 1995 Award Criteria by Mark Graham Brown and Malcolm Baldrige, National Quality Award 1995 & 1996 Award Criteria)

B.2 Drivers and Issues

Business drivers, in a manufacturing facility, generate the need for information to flow between the executive offices and the process or manufacturing floor. Enterprises focus on these business drivers to meet competitive requirements in the marketplace. Business drivers subsequently influence information sent to the production floor or are influenced by information gathered from the production floor.

Business drivers and some information demands have been identified. Additional research and work may be required to clarify the scope and definition of the drivers and information demands for particular users requirements.

There is always some business process that needs information from production, or needs to exercise control of production that drives the need for integration. Integration requires that the production information can be mapped back to the business information.

B.3 Value of Standard to the Business

Manufacturing enterprises are typically dynamic entities. There are continual changes in business processes to meet changing the business and legal environments. There are also usually continual changes in production processes, as new technologies and advances in production capabilities emerge. The purpose of this standard is to aid in the separation of the business processes from the production processes. The standard describes information in a way that is business process independent and production process independent. Figure B-1 below illustrates this concept of a common model that bridges the different business and production processes.

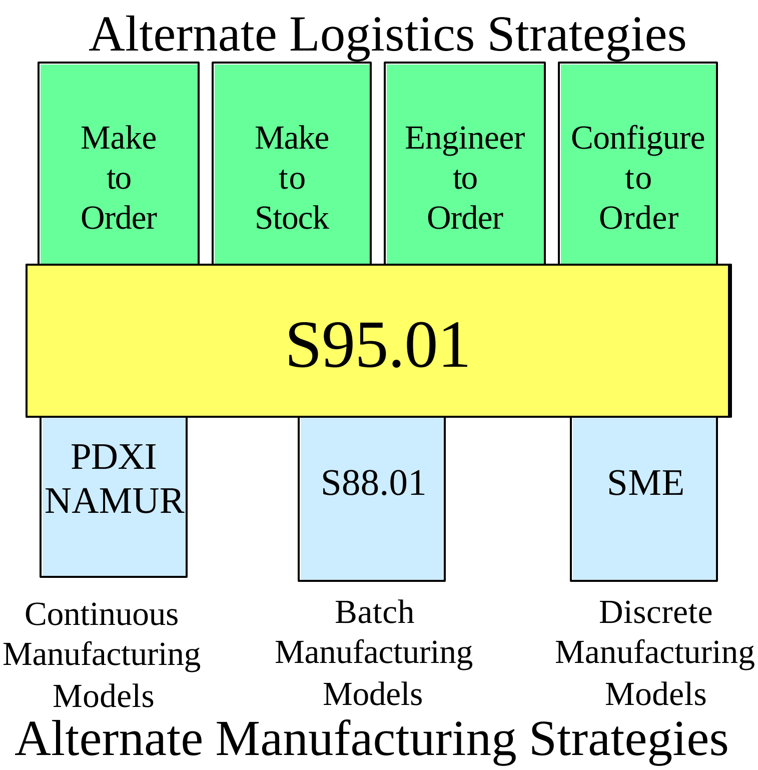

Figure B-1 - Multiple business and production processes

B.4 Vendor independent exchange

Another value of the standard to the business is the separation of exchanged information from specific implementations of manufacturing control systems and specific implementations of business management systems. Manufacturing control systems change when the production processes change, when factories are bought or sold, or when control equipment is updated or replaced. Likewise business management systems change due to corporate mergers, sell-off, technology changes, or business or legal changes.

This standard provides vendor independent methods of describing the information exchanged, that can be consistent across changes to manufacturing systems and IT business systems.

B.5 Business drivers

Some terms or labels that describe such business drivers include:

B.5.1 Available to Promise

Automated available-to-promise is achieved by giving order takers access to inventory and capacity information, and in some cases even vendor information, so that they are able to commit to reliable delivery dates while the customer is still on the phone.

Information needed for automated available-to-promise

- current finished goods inventory,
- current production plan for that product,
- realistic capacities of the production facility of that product,
- raw material inventories,
- raw material purchasing capability.

B.5.2 Reduced cycle time

Cycle Time is defined as the time it takes to produce a product from the time the order is placed.

Cycle time refers to responsiveness and completion time measures - the time required to fulfill commitments or to complete tasks. (Source: Malcolm Baldrige 1996 Award Criteria)

The reason that businesses concentrate on minimizing the total cycle time is generally to increase inventory turns. This has the net result of increasing a business's ROA (Return On Assets).

To reduce cycle time a business must identify areas where most of the delay and waiting occurs and address them appropriately. In most cases, the time needed to plan and react to changes is much longer than the time to build. Response time improvement requires all aspects of the planning, scheduling and execution to be taken into account. Reducing the time to plan allows more frequent analysis of forecasts and less dependence on forecasting data. (By K. Cyrus Hadavi , CEO, Paragon Management Systems)

B.5.3 Asset efficiency

Asset efficiency is a focus on maximizing the effective and cost effective use of the assets in the production of the products. The information obtained from the production environment will deliver to the enterprise realistic information on the production capabilities of the plant, train, unit, work cell, etc. Asset efficiency is the desire to better utilize the assets of the company. It usually involves all assets of the company, production, service, administration, support, sales, and marketing. Asset efficiency improves a company's ROA.

May imply:

- operating to capacity, with timely maintenance.
- operating equipment efficiently in terms of its operating parameters and its maintenance.
- measurements such as counter readings per operating hours.

— time, temperature, pressure/vibration, status or other detailed data.

— maintenance schedules, operating/maintenance specs, procedure times.

B.5.4 Agile Manufacturing

Agile manufacturing is the ability to reconfigure production assets to quickly meet market demand. This requires the ability to change production using existing plants and equipment.

Agility in manufacturing is the ability to thrive in a manufacturing environment of continuous and often unanticipated change and to be fast to market with customized products. Agile manufacturing uses concepts geared toward making everything "re-configurable."

Agile enterprises may be supported by a networked infrastructure that can link multi-company teams into an integrated virtual corporation.

Agile manufacturing requires that production can quickly respond to changes in product definition, and sometime even change product production processes in mid stream.

B.5.6 Supply Chain Optimization

The aim of supply chain management (SCM) is for each player in the supply chain to conduct business with the latest and best information from everyone else in the chain, guiding supply and demand into a more perfect balance. The purpose is to move product from the point of origin to that of consumption in the least amount of time and at the smallest cost.

Supply-chain management helps managers do such things as integrate retail channels with manufacturing, drive demand from the point of sale, or eliminate inventory buffers in the distribution chain. SCM extends beyond the walls of the enterprise to suppliers and distributors

Supply chain management moves to supply chain optimization when the supply chain is used to maximize the effectiveness of the whole, as well as maximizing the effectiveness of the individual parts.

Supply chain optimization involves making complex tradeoffs to satisfy business objectives of reducing operational costs and inventory, improving delivery reliability and response time, and service to the customer.

B.5.7 Quality & Traceability

Quality and traceability can be a business driver in some businesses. This may be required by factors such as regulatory rules, service cost measurement per product improvement, reliability to customers, and Human Resources tracking of exposure to hazardous items.

Quality and trace-ability requires that information, that is typically kept within the manufacturing system, be made available to other parts of the enterprise. This often requires integration of production control and quality assurance, with a corporate quality system.

B.5.8 Operator Empowerment

Moving more decision making to operations sometimes provides a competitive advantage, where operator decisions can have directly measurable financial impact. The operations floor thus requires a significant increase in information that was only accessible from the business offices in the past.

Empowerment: A condition whereby employees have the authority to make decisions and take action in their work areas without prior approval. The act of vesting appropriate authority in the hands of the people nearest the problems to be solved. (Source: Leadership for Total Army Quality)

B.5.9 Improved Planning

Improved planning is a key business driver for companies with expensive inventory, time consuming production but fast customer changes, and variable demand. Improved planning requires access and use of information from throughout the corporation to move planning output from production requests and closer to production schedules.

Improved planning requires continual feedback on actual production and material consumption, as well as continual feedback on demand and inventories.

B.5.10 Summary

The business driver list is not all inclusive. Any business driver that impacts Cost, Capacity, Compliance, Time, or Analysis could be added to the list. Additionally, informational components of one business driver will also often be required when addressing other business drivers. The example in section B.7 is a basic situation that may provide a starting point for various business drivers.

B.6 Example Business Driver and Information Flow

An example of how business drivers and associated production functions generate the need for information flow throughout the business enterprise is described as follows.

The first business driver, Available to Promise, is a basic business driver. We assume a manufacturing business. In this business, there are certain functional steps that generate information flow between the business enterprise (office) and the production floor (control systems).

We will consider this business to be a general manufacturing facility. In a typical business day, we have customers who are requesting to buy our product. Armed with information from our sales personnel, we progress to the manufacturing floor. Here, information generation may be outlined in the following steps:

- **Current State:** Where are we right now? Every business requires knowledge of current manufacturing and business situation. This information is defined as *production from plan* and *production performance and costs* in the standard's data flow model.
- **Target State:** Where do we want to go? In the normal course of business, new orders may be received, legal requirements change, even the weather may have an informational impact through the business. So, there is information that flows between the business practices and manufacturing practices. This information is defined as *schedule* and *pack out schedule* in the standard's data flow model.
- **Transition State:** Prior to a change, there is a significant amount of information generated to anticipate how the changes will be managed. And when things actually change, there is history gathering of how the changes actually occur. This information is defined as production performance in the standard's object model.
- **Planning/Scheduling:** For this business, the need for information regarding current state, target state and transition environment may occur may times per week, day or operations shift. The frequency of schedule update and the frequency of information uploads will depend on industry needs. A grouping or series of steps A, B, and C may be described as a schedule for the manufacturing floor. Or, the business offices may regard this as a plan. Either way, there is information that must flow between the two to reconcile issues. This information is defined as *production schedule* in the standard's object model.
- **Planned vs. Actual:** At certain times, a typical business must review the actions in steps A through C and see if the business requires adjustments.

This is one method of describing steps that generate information flow between the business offices and the production floor in an Available to Promise Enterprise.

Regardless of the specific business driver and associated functions identified, some of the steps described in the Make to Order example above are required to meet all business drivers. For example, many business drivers require the business to know what the current state of its business is.

B.7 Definitions

This section defines terms sometimes used in describing key business drivers.

B.7.1 Current state reporting

Current state reporting is a collection of information that characterizes the current activity and conditions that exist in the manufacturing environment. This information is collected for the purpose of decision support. This information allows you to understand where you are in relationship to current commitments. This information is described in the standard in the current production capability information. Some other terms often used in current state reporting include:

- Production Request: Information on the current production schedule with respect to the actual product that has been requested for production

- Production Quantity: How much of the current production request has been completed (Cumulative versus Request)
- Current Rate: What is the instantaneous rate of production of the product requested.
- Quality: Measure of the effectiveness of production - this measurement of product quality, yields data, waste, loss, Yield, Material and Energy Balance…)
- Physical Equipment Status: information on the maintenance state of the equipment, work cells, trains, etc. to determine the current and future availability of that equipment for the production of the next product.
- Predictive maintenance: a predictive determination of when equipment will need maintenance, and a mechanism to perform maintenance on the equipment at or before its expected error or failure time.
- Preventative maintenance: performing maintenance before an error or failure occurs, and a mechanism to perform maintenance, usually on a fixed time or run-time schedule.
- Inventory Status: Data on materials that will impact the decision to proceed with the next product's production.

B.7.2 Turn-around time

Turn around time is the time required to change a production mechanism for the purpose of producing a different product or the same product with different characteristics. The information that will determine the *turn around time* include:

- The current state of all items and current state of the production facility
- Historical transition times, given the current state of the production facility
- Standard operating procedures required for switch over
- Resource requirements versus available (Labor, Material, Equipment)

B.7.3 Campaigning

Campaigning is the planning of the execution of production based on the existing capacity, raw material, resources and production request. A campaign is usually a limited run of product through the production process. Campaigns can last from days to months depending on the products, processes, and production requirements. Control strategy and physical process changes may accompany campaign.

One important aspect of *campaigning* is letting production know the sequence of events or scheduled runs ahead of time.

Campaigns generally deal with a single product, or a set of products with compatible processing or product requirements. Campaign planning must also address previous product characteristics to maximize the agility of the change.

Campaigning is addressed in the standard through *production schedules* and *production requests.*

B.7.4 New Targets

New targets define what to make in the next time sequence and when to start it. Mainly an information demand that the control system places on the enterprise for a production order.   *New targets* are handled in the standard through the *production parameters* in a *production request*.

The type of information required for new targets depends on the industry. New targets can be fixed numbers in a discrete environments and can be variable values, such as tables or functions, in continuous environments.

New targets may include the product quality characteristics

B.8 Data reconciliation

Data reconciliation is a serious issue for enterprise/control integration. The data has to be valid to be useful for the enterprise system. The data must often be determined from physical measurements that have associated error factors. This must usually be converted into exact values for the enterprise system. This conversion may require manual, or intelligent reconciliation of the converted values. Additional problems occur when the type of physical measurement, such as volume, must be used to calculate information based on a related value, such as weight. For example in the refining industry, the operations floor changes the density of products, but measure by volume, then use inference to calculate density and weight.

Systems must be setup to ensure that accurate data is sent to production and from production. Inadvertent operator or clerical errors may result in too much production, too little production, the wrong production, incorrect inventory, or missing inventory.

Annex C - Discussion on Models

As noted in the Introduction to this standard, it has long been the goal of the industrial systems engineer to integrate the operating units of the plant in order to be able to produce that plant's products at minimum unit cost and at maximum overall profit for the company involved. Early work in this field was based on plant design techniques that:

(1) closely coupled production units,

(2) minimized in-process inventories and work in progress, and

(3) made maximum use of in-plant energy sources to supply plant energy needs.

While excellent in initial concept, these techniques floundered because of lack of :

(1) unit coordination,

(2) dynamic response, and

(3) market sensitivity.

Lack of unit coordination is exemplified by the presence of unpredictable plant interruptions and breakdowns in plant production processes that occur randomly in time and location thus wreaking havoc with the productivity of such a close-coupled, low-inventory plant. Unforeseen changes in customer requirements, often making obsolete an inflexible manufacturing system, characterize the lack of dynamic response. A lack of market sensitivity is exhibited through limited flexibility in responding to changes in competition, in production cost items (such as energy and raw materials), and in regulatory requirements, any of which can invalidate the initial optimization criteria of the plant's design.

More recently, the trend in systems integration has been toward the use of automatic control in its broadest sense (including dynamic control, scheduling and the closure of information loops) to integrate all aspects of the plant's operations including closing the information loops within the plant. This latter trend then allowed the plant to compensate for the unforeseen interruptions and breakdowns in its production processes and also allowed it to modify its product mix and its production rate as its customer's needs and desires changed. All of this must be done while continually minimizing overall production costs to match the current plant condition. Thus we have the substitution of control and management techniques for initial design procedures in an attempt to counteract the forces that invalidated the original concept and therefore to still accomplish the original goals.

It has long been known what tasks that such a system had to be able to carry out to accomplish these goals. It has only been since the advent of the advanced computer technology that it has been possible to handle the enormous computational load involved in carrying out these functions in *real time* and thus hoping to compensate for all of the factors affecting plant productivity and economic return.

Current technology is providing the technical capability to greatly facilitate the development of integrated automated systems. These trends include: (1) distributed, digital, microcomputer based, first level dynamic control systems; (2) standard real-time programming languages and configurable programming systems; (3) standard high speed communications; and (4) corresponding major developments in database management techniques. These have resulted in computer systems that are able to integrate the plant management, plant production scheduling, inventory management, individual process optimization, and unit process control for all the plant's operating units treated as a whole.

However, to accomplish the design and development of such large-scale systems, the aid of overall design and operational standards and accompanying models of such systems are vitally necessary as also pointed out in the Introduction.

Requirements for the Models

It is necessary in such a model to be able to show clearly all of the major operational characteristics of the relationships of the functions involved in the plant management and control system. These include the following, among others:

1. *Subordination and Aggregation*: Which of the functions are (a) dependent upon others for direction (instructions) in carrying out their assigned tasks; which of them (b) have the major function of supplying information necessary for other functions to help carry out the other's assigned tasks?

   A prime example of subordination in Item 1(a) is those of

   a. Customer Order Processing

   b. Overall Production Scheduling

   c. Detailed Production Scheduling

   d. Production Planning

   e. Process Control of Production Unit

   A prime example of aggregation in Item 1(b) is the continued collection, averaging and smoothing of process control operational data to achieve the information which management needs for overall operational management of the plant and the company.

2. *Connectivity and Progression*: How does data flow in the plant production system? Where does each item of data originate; through what intermediate functions does it flow; and where does the resulting information have its ultimate use?

3. *Automatability and Innovation*: Can the function be automated or mechanized through electronic devices, i.e., can the function be mathematically described? Or, does the function require innovation by a human for its ultimate successful completion?

4. *Genericity*: To the extent possible, the model developed to explain the scheduling and control system necessary for enterprise integration studies should be generic, i.e., it should be able to be used to model the control system of any factory or plant, in any industry, anywhere, if at all possible. Each of the models presented here will be generic to the extent possible.

5. *Semantics*: It is also extremely important that the semantics or meaning of the various terms used in describing the concepts of the model(s) used be interpreted by all readers in exactly the same way. A powerful way to accomplish this is to use an *object model* to accomplish the required concept definition. Section 7.0 of this standard presents such a capability.

A popular and effective way of illustrating Item 1(a) above in a model is through the use of a hierarchical layered model, with each of the items of Item 1(a) being subordinate, or below that above it in the list, in the model. At the same time, the aggregation of Item 1(b) occurs naturally, going upward in the same layered fashion.

Unfortunately, it has not been possible to date to show all of the required capabilities listed above in one graphical representation of the system. Particularly difficult has been the representation of subordination and aggregation (hierarchical layers) and connectivity and progression (data flow) together. Thus two separate representations are necessary and the coordination of the resulting two forms has been difficult.

Annex D presents a major table (Table D-XII) that points out the coordinate between both models in the PRM. Such a procedure appears to be necessary whenever a system is modeled from widely different aspects or views as occurs here.

The concepts of Automatability vs. Innovation (i.e., human input required) was handled in the PRM by the concept of *external entities*. External entities are those functions that are not included in the automated scheduling and control system but for which a complete data transfer interface is provided. Thus there are enterprise functions which require human input but cannot be part of the model since the functions involved cannot be modeled. However, they can take part in the plant integration since all needed communications are established.

Figure C-1 illustrates the concept for the PRM. All those functions which are at the top of the dashed line in this diagram require human involvement. Hence, they are considered external, but contributing, entities in the PRM. All of those to the bottom are part of the management and control system which can be automated.

All parts of the Purdue Reference Model for CIM that are concerned with the scope of this standard are presented in Annex D of this standard.

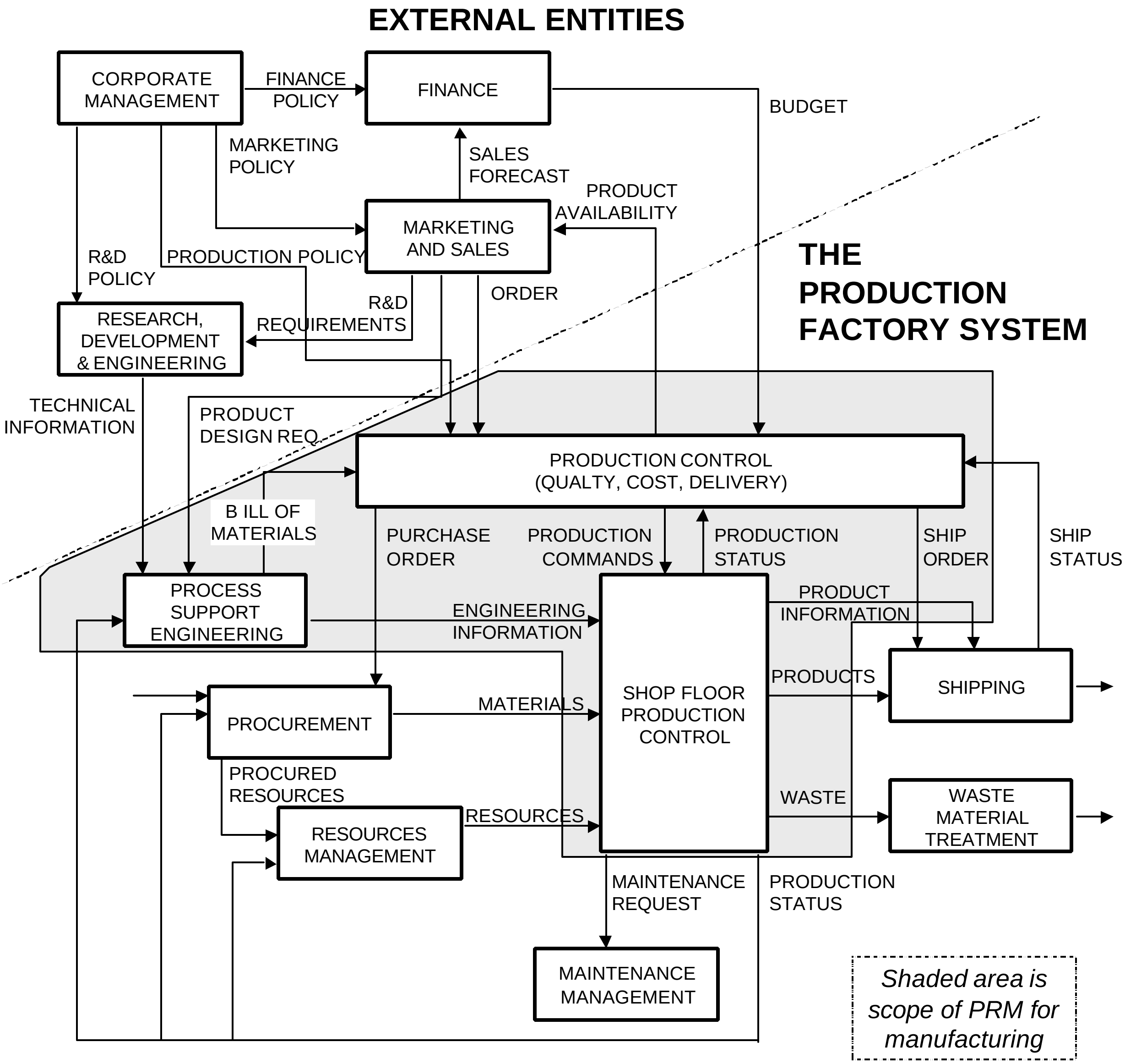

Figure C-1 - Scope for Purdue Reference Model (PRM) for Manufacturing

Annex D – Selected elements of the Purdue Reference Model

This section contains selected portions the complete published version of the Purdue Reference Model[1]. This annex gives a brief description of the Purdue Reference Model. This section is included so that the models in the standard may be better understood in the context of the complete plant reference model. Some non-pertinent sections and tables have been removed. References in the original document have been replaced with footnotes. The figures and tables have also been consecutively numbered.

Figure D-4 has been modified to show a different split between the production scheduling & management information systems and the control computation and control enforcement than in the original publication. The split is now shown between level 3 and 4, based on planned changes to the Purdue model as a result of the SP95 analysis rather than between levels 2 and 3 of the original.

Generic List of Macro-Functions

The overall applicability of the concepts of enterprise integration depends to a great extent on the development of a set of generic tasks, functions and macro functions to describe an enterprise integration system or indeed any enterprise. The Purdue Reference Model for CIM developed two such lists, one based on the Scheduling and Control Hierarchy View and another based on the Data Flow Diagram View of the Reference Model. It then proceeded to show the correlation of these two apparently widely different lists by cross-referencing the task titles used and their point of application in each view. For the sake of completeness, that material will be reproduced here, along with considerable related material on the architecture.

One of the most important graphical representations is the Scheduling and Control Hierarchy View from the Reference Model as mentioned above. The hierarchy view that is shown in Figure D-1 categorizes the tasks carried out by the industrial control system for a complete plant or company. Figure D-2 shows that this same diagram with modifications only for the names of the functions involved will characterize the control tasks of either a continuous or discrete manufacturing industry plant. Figure D-3 expands the earlier diagrams to cover a company with multiple plants.

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1 Williams, T.J. Editor, *A Reference Model for Computer Integrated Manufacturing (CIM), A Description From the Viewpoint of Industrial Automation*, Minutes, CIM Reference Model Committee, International Purdue Workshop on Industrial Computer Systems, Purdue University, West Lafayette, IN (1988) Instrument Society of American, Research Triangle Park, NC (1989). While out of print at ISA, the complete document is available on the World Wide Web under the following URL:

http://www.pera.net/Pera/PeraReferenceModel/ReferenceModel.html

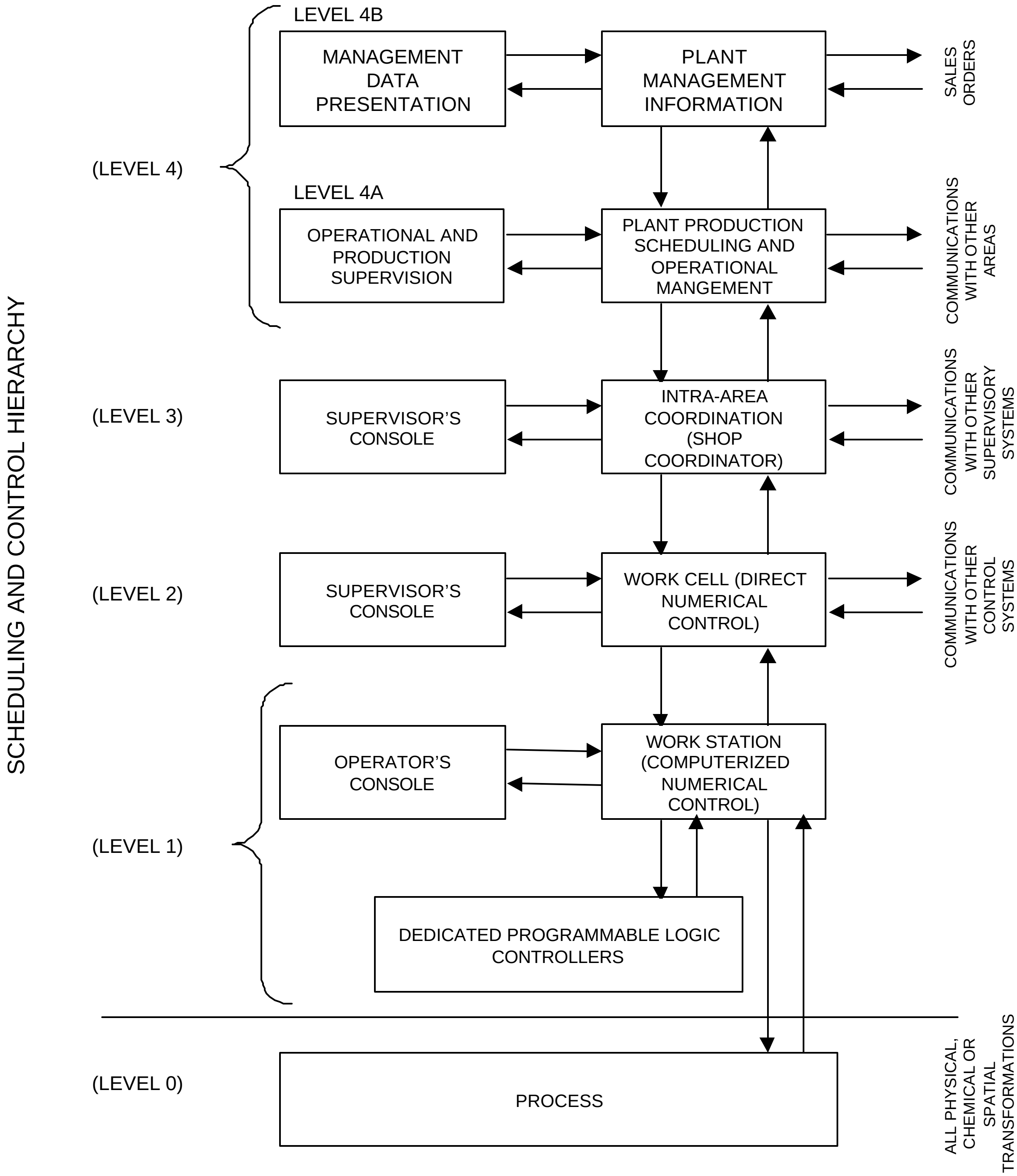

FIGURE D-1 ASSUMED HIERARCHICAL COMPUTER CONTROL STRUCTURE FOR A LARGE MANUFACTURING COMPLEX (COMPUTER INTEGRATED MANUFACTURING [CIM])

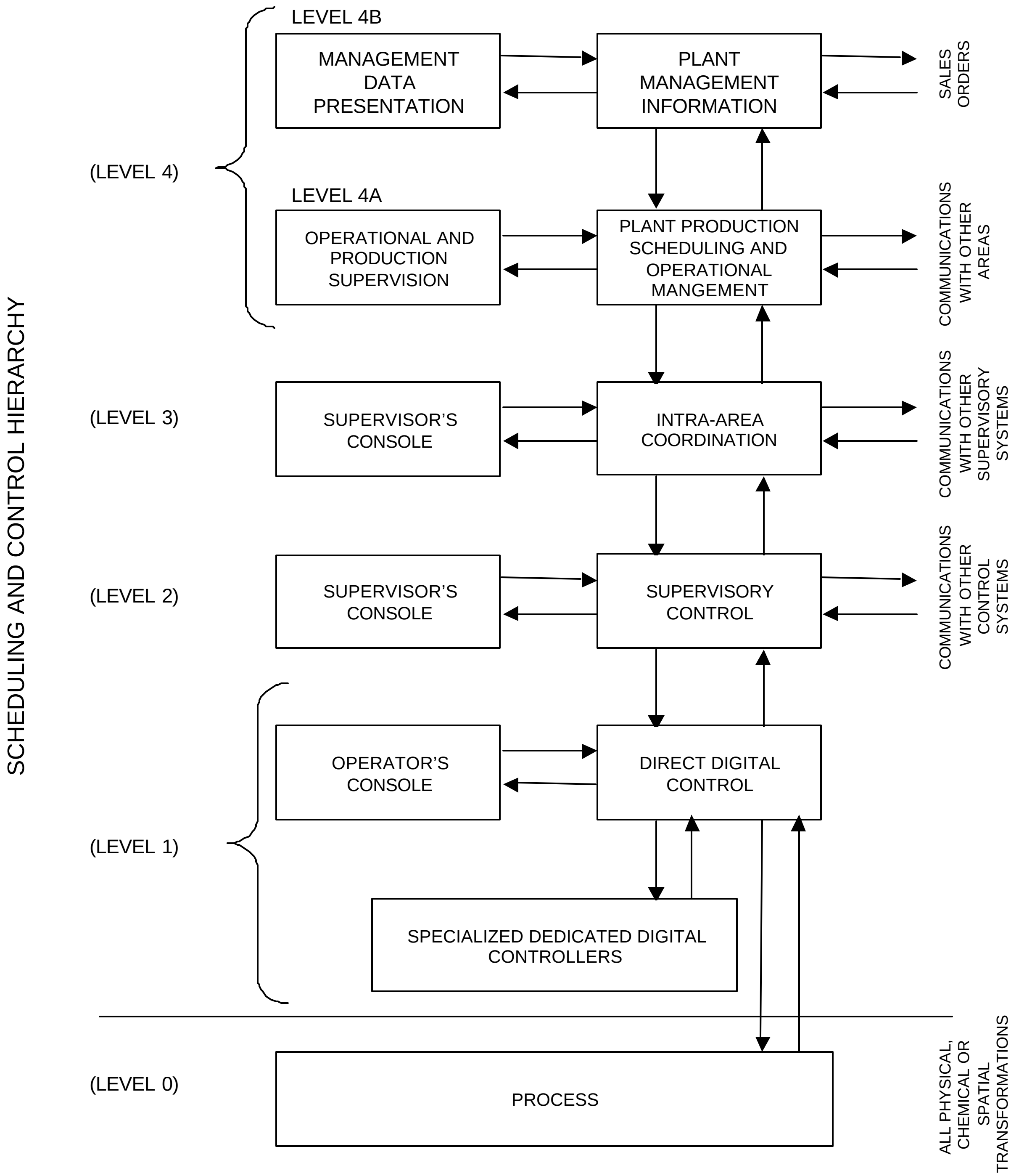

FIGURE D-2 ASSUMED HIERARCHICAL COMPUTER CONTROL SYSTEM STRUCTURE FOR AN INDUSTRIAL PLANT
(CONTINUOUS PROCESS SUCH AS PETROCHEMICALS)

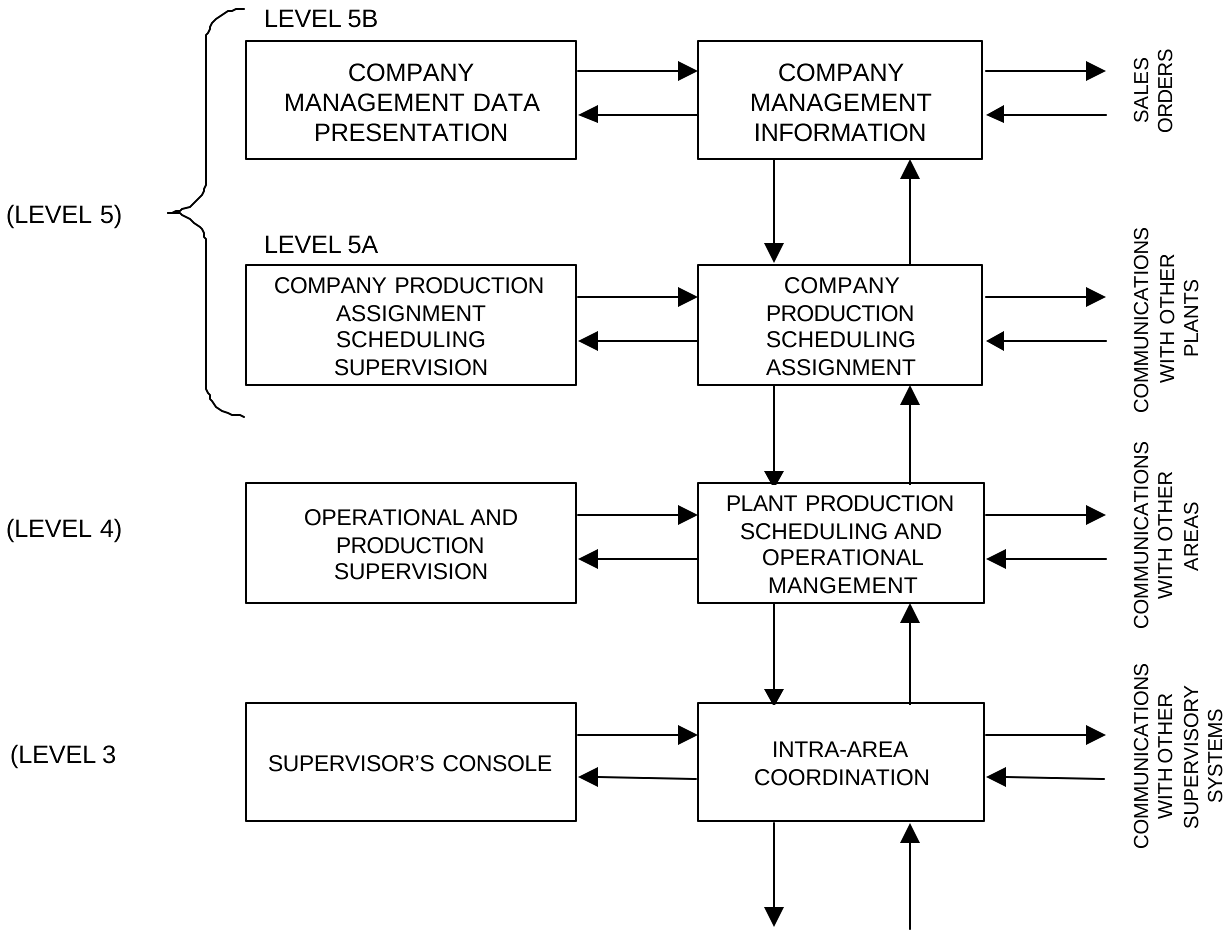

FIGURE D-3 ASSUMED HIERARCHICAL COMPUTER CONTROL STRUCTURE FOR AN INDUSTRIAL COMPANY (MULTI-PLANT) TO SHOW LEVEL 5 AND ITS RELATIONSHIP TO THE REVISED LEVEL 4

One form of generic tasks in a plant wide hierarchy

Overall automatic control of any large modern industrial plant regardless of the industry concerned involves each of the requirements listed in Table D-I.

Thus the automation of any such industrial plant becomes the managing of the plants' information systems to assure that the necessary information is collected and used wherever it can enhance the plants' operation - true information systems technology in its broadest sense.

Another major factor should also be called to our attention here. It has been repeatedly shown that one of the major benefits of the use of digital computer control systems in the automation of industrial plants has been in the role of a control systems enforcer. In this mode, one of the control computer's main tasks is to continually assure that the control system equipment is actually carrying out the job that it was designed to do in keeping the units of the plant production system operating at some best (near optimal) level. That is, to be sure that in the continuous process plant, for instance, the controllers have not been set on manual, that the optimal set points are being maintained, etc. Likewise, it is the task of dynamic control to assure that the plant's production schedule is carried out, i.e., to enforce the task set by the production scheduling function.

Often the tasks carried out by these control systems have been ones that a skilled and attentive operator could have readily done. The difference is the degree of attentiveness to the task at hand that can be achieved over the long run.

As stated earlier, all of this must be factored into the design and operation of the control system that will operate the plant, including the requirements for maximum productivity and minimum raw material and energy usage. As the overall requirements, both energy and productivity based, become more complex, more sophisticated and capable control systems are necessary.

While the above tasking list is truly generic for any manufacturing plant - continuous or discrete - it is necessary to rearrange it in order to come up with a more compact set of tasks for further discussion.

Therefore, what is needed is an overall system for any manufacturing plant which has the capabilities shown in Table D-II.

In view of Item 2 of Table D-II, Table D-III presents some observations of the differences in process improvement technologies (i.e., near optimization) for continuous versus discrete optimization.

Because of the ever-widening scope of authority of each of the first three requirements in turn, they effectively become the distinct and separate levels of a superimposed control structure, one on top of the other. Also in view of the amount of information which must be passed back and forth among the above four "tasks" of control, a distributed computational capability organized in a hierarchical fashion would seem to be the logical structure for the required control system. This must be true of any plant regardless of the industry involved.

As just noted, a hierarchical arrangement of the elements of a distributed, computer-based, control system seems an ideal arrangement for carrying out the automation of the industrial plant just described. Figures D-1, D-2 and D-3 lay out one possible form of this distributed, hierarchical computer control system for overall plant automation.

In the context of large industrial plants or of a complete industrial company based in one location, the detailed tasks that would be carried out at each level of the hierarchy can be readily described. These tasks are easily subdivided into those related to production scheduling, control enforcement, systems coordination and reporting, and reliability assurance (Table D-IV).

TABLE D-I

DUTIES (FUNCTIONAL REQUIREMENTS) OF ALL INTEGRATED INFORMATION AND AUTOMATION SYSTEMS, A GENERIC LIST

1	An extensive system for the automatic monitoring of a large number of different plant variables operating over a very wide range of process operations and of process dynamic behavior. Such monitoring will detect and compensate for current or impending plant emergencies or production problems.
2	The development of a large number of quite complex, usually nonlinear, relationships for the translation of some of the above plant variable values into control correction commands.
3	The transmission of these control correction commands to another very large set of widely scattered actuation mechanisms of various types.
4	Improvement of all aspects of the manufacturing operations of the plant by guiding them toward likely optima of the appropriate economic or operational criteria. Results may be applied to the control correction commands of Item 2 above and/or to the plant scheduling functions of Item 8 below.
5	Reconfiguration of the plant production system and/or of the control system as necessary and possible to assure the applicable production and/or control system for the manufacturing situation at hand.
6	Keeping plant personnel, both operating and management, aware of the current status of the plant and of each of its processes and their products including suggestions for alternate actions where necessary.
7	Reduction of plant operational and production data and product quality data to form a historical database for reference by Plant Engineering, other staff functions and Marketing.
8	Adjusting the plant's production schedule and product mix to match its customers' needs, as expressed by the new order stream being continually received, while maintaining a high plant productivity and the lowest practical production costs. This function must also provide for appropriate plant preventive or corrective maintenance functions.
9	Determination of and provision for appropriate inventory and use levels for raw materials, energy, spares, goods in process and products to maintain desired production and economics for the plant.
10	Assuring the overall availability of the control system for carrying out its assigned tasks through the appropriate combination of fault detection and fault tolerance, redundancy, and fail-safe techniques.
11	Maintaining interfaces with the external entities which interact with the plant production system such as Corporate Management; Marketing; Accounting; Corporate Research, Development and Engineering; External Transportation; Suppliers and Vendors; Purchasing; Customers; and Contractors.

TABLE D-II

AN OVERALL PLANT AUTOMATION SYSTEM MUST PROVIDE

1	An effective dynamic control of each operating unit of the plant to assure that it is operating at its maximum efficiency of production capability, product quality and/or of energy and materials utilization based upon the production level set by the scheduling and supervisory functions listed below. This thus becomes the Control Enforcement component of the system. This control reacts directly to compensate for any emergencies which may occur in its own unit.
2	A supervisory and coordinating system which determines and sets the local production level of all units working together between inventory locations in order to continually improve (i.e., optimize) their operation. This system assures that no unit is exceeding the general area level of production and thus using excess raw materials or energy. This system also responds to the existence of emergencies or upsets in any of the units under its control in cooperation with those units' dynamic control systems to shut down or systematically reduce the output in these and related units as necessary to compensate for the emergency. In addition, this system is responsible for the efficient reduction of plant operational data from the dynamic control units, described just above, to assure its availability for use by any plant entity requiring access to it as well as its use for the historical database of the plant.
3	An overall production control system capable of carrying out the scheduling functions for the plant from customer orders or management decisions so as to produce the required products for these orders at the best (near optimum) combination of customer service and of the use of time, energy, inventory, manpower and raw materials suitably expressed as cost functions.
4	A method of assuring the overall reliability and availability of the total control system through fault detection, fault tolerance, redundancy, uninterruptible power supplies, maintenance planning, and other applicable techniques built into the system's specification and operation.

TABLE D-III

SOME NOTES REGARDING OPTIMIZATION (IMPROVEMENT)
OF MANUFACTURING EFFICIENCY

In discrete manufacturing optimization (improvement) is generally carried out in scheduling.
In continuous manufacturing optimization (improvement) is generally carried out both in control and scheduling.

TABLE D-IV

SUMMARY OF DUTIES OF CONTROL COMPUTER SYSTEMS

I. Production Scheduling

II. Control Enforcement

III. Plant Coordination and Operational Data Reporting

IV. System Reliability and Availability Assurance

Item I of the above list (Production Scheduling) corresponds to Item 3 of the list of Table D-II.

Item II of the above list corresponds to much of Items 1 and 2 of the list of Table D-II.

Items III and IV of the above list require the cooperative operation of all items of the list of Table D-II. The Plant Coordination part comprises the detailed interpretation and expansion of the overall Production Schedule of Item 3 of Table D-II.

It is our contention that such lists can outline the tasks that must be carried out in any industrial plant, particularly at the upper levels of the hierarchy. Details of how these operations are actually carried out may vary drastically, particularly at the lowest levels, because of the nature of the actual process being controlled. We all recognize that a distillation column will never look like or respond like an automobile production line. But the operations themselves remain the same in concept, particularly at the upper levels of the hierarchy.

Thus it is our further contention that despite the different nomenclature in different industries the major differences in the control systems involved is concentrated in the details of the dynamic control technologies used at Level 1 and the details of the mathematical models used for optimization at Level 2.

The differences are thus concentrated in the details of the control and operation of the individual production units (the application entities) of the factory. Commonality is in the support functional entities (computational services, communications, database technology, management structure, etc.). Sensing and communication techniques are exactly the same in both systems. The same optimization algorithms can be used. Computer systems technology and programming techniques should be the same and production scheduling technology should be identical to name only a few.

Thus the duties of the hierarchical computer system can be established as outlined in Table D-IV and in Figure D-4. Therefore Levels 1 and 2 will concentrate on performing Task II of Table D-IV, Levels 3 and 4 will carry out Task I and all will be involved in assuring the implementation of Task III and the integrity of Task IV, overall reliability and availability.

Possibilities of major reduction in the costs, development manpower effort, and time required to produce an integrated industrial control system then devolves upon the factors listed in Table D-V.

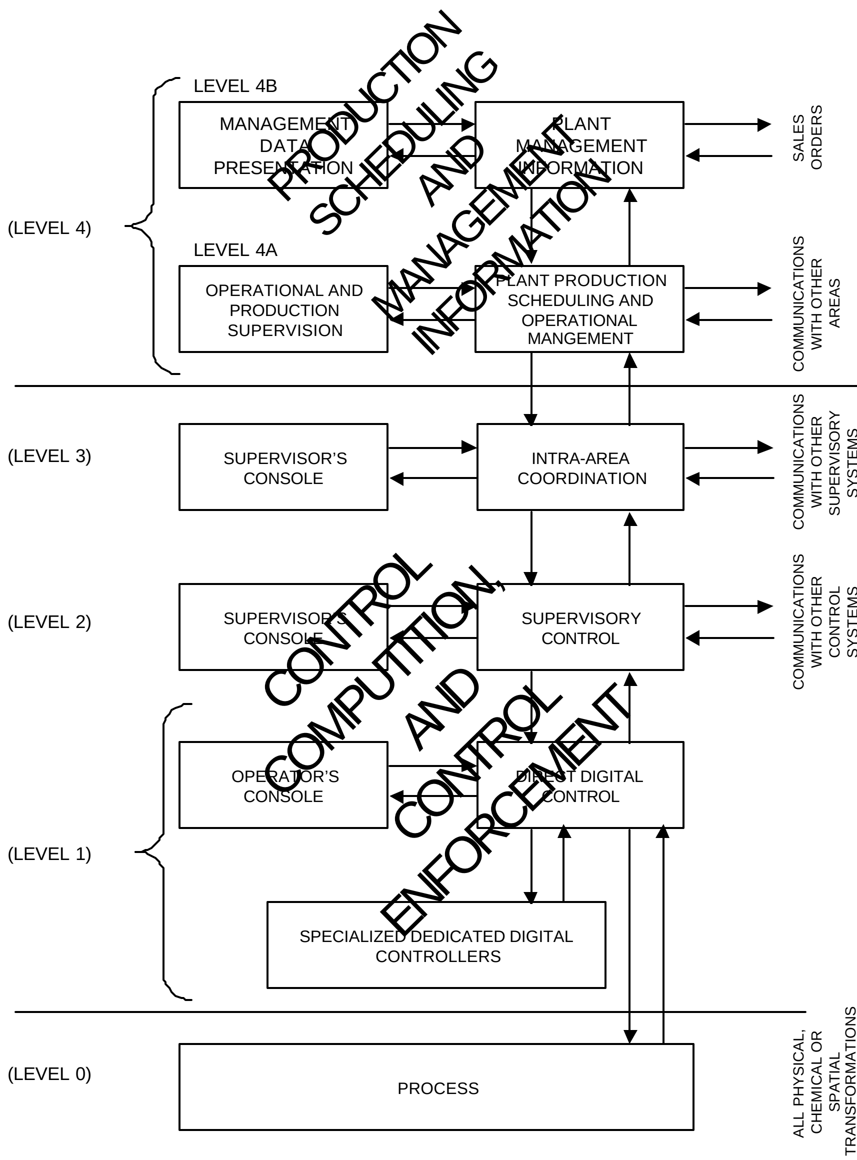

FIGURE D-4 DEFINITION OF THE REAL TASKS OF THE HIERARCHICAL COMPUTER CONTROL SYSTEM (AS MODIFIED IN S95.01)

TABLE D-V

POTENTIAL FACTORS FOR FACILITATING INTEGRATED

CONTROL SYSTEM DEVELOPMENT AND USE

1. Potential commonality of control system structure in terms of the:
   A. Computer systems,
   B. Communications systems,
   C. Database organization,
   D. Relationship to plant management and operational structure (personnel).
2. Commonality of the techniques of application of:
   A. Software engineering and programming,
   B. Communications
   C. Database management,
   D. Control systems engineering
   E. Production scheduling
   F. Operations research and optimization

TABLE D-VI

REQUIRED TASKS OF THE INTRACOMPANY MANAGEMENT INFORMATION SYSTEM

(LEVEL 4B OF FIGURE D-1 OR 2 OR LEVEL 5 OF FIGURE D-3)

III. System Coordination and Reporting

1. Maintain interfaces with:
   - A) Plant and company management
   - B) Sales and shipping personnel
   - C) Accounting, personnel and purchasing departments
   - D) Production scheduling level (Level 4A)
2. Supply production and status information as needed to:
   - A) Plant and company management
   - B) Sales and shipping personnel
   - C) Accounting, personnel and purchasing departments
   - D) This information will be supplied in the form of:
     - 1) Regular production and status reports
     - 2) On-line inquiries
3. Supply order status information as needed to sales personnel

IV. Reliability Assurance

4. Perform self-check and diagnostic checks on itself

Note: 1. There are no production scheduling or control actions required at this level. This level is solely for use as an upper management and staff level interface.

2. Roman numeral subdivisions of Tables D-VI to D-X correspond to the same headings in Table D-IV.

TABLE D-VII

DUTIES OF THE PRODUCTION SCHEDULING

AND OPERATIONAL MANAGEMENT LEVEL (LEVELS 4A OR 5A)

I. Production Scheduling

1. Establish basic production schedule
2. Modify the production scheduling for all units per order stream received, energy constraints, power demand levels, and maintenance requirements.
3. In coordination with required production schedule develop optimum preventive maintenance and production unit renovation schedule.
4. Determine the optimum inventory levels of raw materials, energy sources, spare parts, etc., and of goods in process at each storage point. The criteria to be used will be the trade-off between customer service (i.e., short delivery time) versus the capital cost of the inventory itself, as well as the trade-offs in operating costs versus costs of carrying the inventory level. This function will also include the necessary material requirements planning (MRP) and spare parts procurement to satisfy the production schedule planned. (This is an off-line function.)
5. Modify production schedule as necessary whenever major production interruptions occur in downstream units, where such interruptions will affect prior or succeeding units.

III. Plant Coordination and Operational Data Reporting

6. Collect and maintain raw material and spare parts use and available inventory and provide data for purchasing for raw material and spare parts order entry and for transfer to accounting.
7. Collect and maintain overall energy use and available inventory and provide data for purchasing for energy source order entry and for transfer to accounting.
8. Collect and maintain overall goods in process and production inventory files.
9. Collect and maintain the quality control file.
10. Collect and maintain machinery and equipment use and life history files necessary for preventive and predictive maintenance planning.
11. Collect and maintain manpower use data for transmittal to personnel and accounting departments.
12. Maintain interfaces with management interface level function and with area level systems.

IV. Reliability Assurance

13. Run self-check and diagnostic routines on self and lower level machines.

Note: There are no control functions as such required at this level. This level is for the production scheduling and overall plant data functions.

TABLE D-VIII

DUTIES OF THE AREA LEVEL (LEVEL 3)

I. Production Scheduling

1. Establish the immediate production schedule for its own area including maintenance, transportation and other production related needs.

2. Locally optimize the costs for its individual production area while carrying out the production schedule established by the production control computer system (Level 4A) (i.e., minimize energy usage or maximize production for example).

3. Along with Level 4A modify production schedules to compensate for plant production interruptions which may occur in its area of responsibility.

III. System Coordination and Operational Data Reporting

4. Make area production reports including variable manufacturing costs.

5. Use and maintain area practice files

6. Collect and maintain area data queues for production, inventory, and manpower, raw materials, spare parts and energy usage.

7. Maintain communications with higher and lower levels of the hierarchy.

8. Operations data collection and off-line analysis as required by engineering functions including statistical quality analysis and control functions.

9. Service the man/machine interface for the area.

10. Carry out needed personnel functions such as:

    A) Work period statistics (time, task, etc.)

    B) Vacation schedule

    C) Work force schedules

    D) Union line of progression

    E) In-house training and personnel qualification

IV. Reliability Assurance

11. Diagnostics of self and lower level functions

Note: No control actions are required here. This level handles detailed production scheduling and area coordination for the major plant subdivisions.

TABLE D-IX

DUTIES OF THE SUPERVISORY LEVEL (LEVEL 2)

II. Control Enforcement

1. Respond to any emergency condition which may exist in its region of plant cognizance.
2. Optimize the operation of units under its control within limits of established production schedule. Carry out all established process operational schemes or operating practices in connection with these processes.

III. System Coordination and Operational Data Reporting

3. Collect and maintain data queues of production, inventory, and raw material, spare parts and energy usage for the units under its control.
4. Maintain communications with higher and lower levels
5. Service the man/machine interfaces for the units involved

IV. Reliability Assurance

6. Perform diagnostics on itself and lower level machines
7. Update all standby systems

Note: This level and those below it carry out the necessary control and optimization functions for the individual production units to enforce the production schedule set by Levels 4A and 3.

TABLE D-X

DUTIES OF THE CONTROL LEVEL (LEVEL 1)

II. Control Enforcement

1. Maintain direct control of the plant units under its cognizance.
2. Detect and respond to any emergency condition which may exist in these plant units.

III. System Coordination and Reporting

3. Collect information on unit production, raw material and energy use and transmit to higher levels.
4. Service the operator's man/machine interface.

IV. Reliability Assurance

5. Perform diagnostics on itself
6. Update any standby systems

Notes: It has repeatedly been shown that one of the major benefits of the use of digital computer control systems in the automation of industrial plants has been in the role of a Control Systems Enforcer. In this mode, one of the control computer's main tasks is to continually assure that the control system equipment is actually carrying out the job that it was designed to do in keeping the units of the plant production system operating at some best (near optimal) level.

That is, to be sure that in the continuous process plant, for instance, the controllers have not been set on manual, that the optimal set points are being maintained, etc. Likewise, it is the task of dynamic control to assure that the plant's production schedule is carried out, i.e., to enforce the task set by the production scheduling function.

In the Purdue Reference Model definition there are no Informational Transformations at Level 0.

Sensors determine the state of the physical equipment or the material being transformed therein. All operations on the resulting data are informational. Sensor outputs are considered part of Level 1.

Actuators are considered part of Level 0 - commands to them are considered Level 1.

Tasks of each level of the hierarchy

In the context of any large industrial plant, or of a complete industrial company based in one location, the tasks that would be carried out at each level of the hierarchy are as described in Tables D-VI to D-X. Note that these tasks are subdivided within each table into those related to production scheduling, control enforcement, systems coordination and reporting, and reliability assurance (Table D-IV). As was mentioned above, these tables outline the tasks which must be carried out in any industrial plant, particularly at the upper levels of the hierarchy.

Figures D-5 to D-10 show the application of the Scheduling and Hierarchy View to a variety of industries showing also that the computer control system discussed here is pyramidal as well as hierarchical. Figure D-10 is an entirely different appearing diagram as originally developed by the Cincinnati-Milacron Company. However with the current CIM hierarchy levels imposed it can be readily seen that this diagram converts directly to the others.

Figures D-5 to D-10 also bring out an important aspect of this model in relation to those proposed by some other developers, that is, inventories and associated material handling equipment in relation to the manufacturing processes themselves are treated just like any other process. Thus they are considered to have process control inputs and outputs and their dynamic behavior can be modeled mathematically in order to develop the appropriate overall control system for the functions served by the inventory and its associated material handling equipment.

The Data-flow graph, a Functional Network View of the CIM Reference Model

There is need in the Reference Architecture to have a mechanism to show the interconnection and precedence of the several tasks assigned to the overall mill-wide control system which is not shown by the Scheduling and Control Hierarchy view. An excellent method for showing this is the so-called Data-Flow Graph or Information-Flow Graph using a technique known as Structured Analysis[1], also known as the Yourdon-DeMarco technique.

This section will develop such a representation as derived from the CIM Reference Model. The basis for this work will be a Data-Flow Model entitled, Information Flow Model of Generic Production Facility, contributed to the Purdue Reference Model for CIM project by The Foxboro Company in August 1986[2]. The original document has been considerably modified by the Workshop CIM Committee to match the nomenclature, etc., of other parts of the model's documentation.

As noted above this method diagrams the interconnection of the several tasks carried out by the control system and allows the potential for an ever greater detailing of these tasks in the form of sub-tasks and the resulting interconnections of these sub-tasks with each other and the main tasks. These diagrams are restricted to the model as defined in the Purdue Reference Model for CIM (i.e., the definable scheduling and control system for the manufacturing facility and including only interfaces to the external

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[1] DeMarco, T., *Structured Analysis and System Specification*, Yourdon Press – Prentice Hall, Englewood Cliffs, NJ (1979)

[2] Pampel, Albert, *Information Flow Model of a Generic Production Facility*, The Foxboro Company, Foxboro, MA (1986)

influences), i.e., the Integrated Information Management and Control System of Figure D-11 and the Information Systems Architecture of this text.

The set of diagrams begins with the interconnection of the influencing external entities on the factory itself (Figure D-12). In the present model one very important external influence on the factory is the company management itself. As noted in Figure D-13 management interfaces through the staff departments who provide services to the factory itself or express management's policies in sets of requirements to be fulfilled by the factory.

It will be immediately noticed by the reader that the two lists of tasks and functions we are developing here look entirely different even though each is a complete listing within itself. This is because these two different models of the Information Architecture show different ones of the task and function relationships. The Scheduling and Control Hierarchy shows subordination, precedence, time horizon and span of control, while the Data Flow Diagram shows connectivity and precedence. Thus since there is no layering in the Data Flow diagram (subordination) and no connectivity in the Scheduling and Control hierarchy their views of the tasks and functions are greatly different. This results in a different definition of each task in many cases particularly because of a difference in span of concern. Therefore the description and labels may be (and are) different between the two models.

Table D-XI presents the functions and tasks listed on the diagrams of Figures D-16 to D-28. Table D-XII makes a comparison of the tasks listed in Tables D-VI to D-X versus those on Figures D-16 to D-28 as discussed just above.

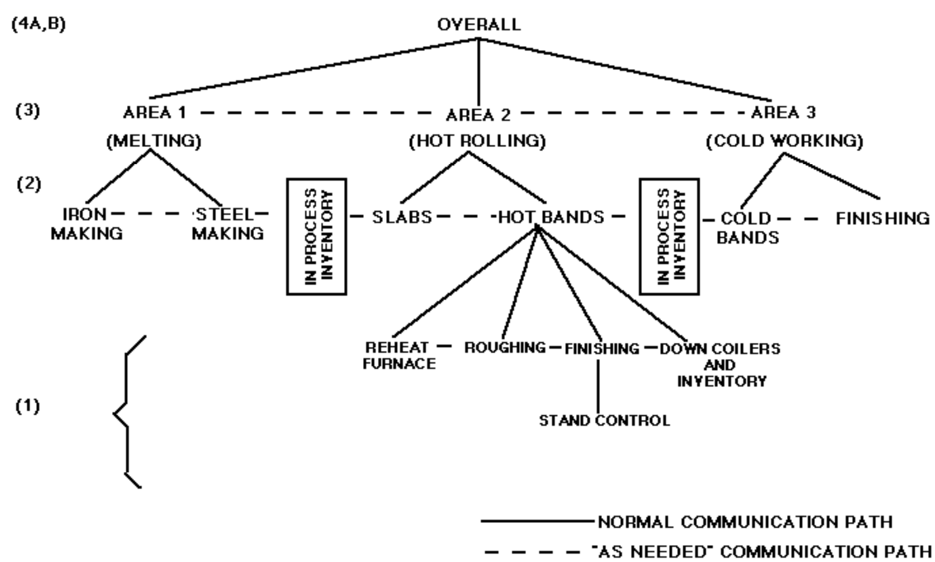

FIGURE D-5 HIERARCHY ARRANGEMENT OF THE STEEL PLANT CONTROL TO SHOW RELATIONSHIP OF HIERARCHY TO PLANT STRUCTURE

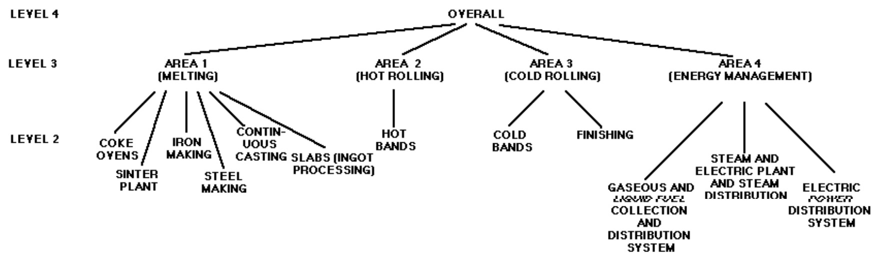

FIGURE D-6 HIERARCHY ARRANGEMENT OF THE STEEL PLANT CONTROL SYSTEM AS STUDIED FOR ENERGY OPTIMIZATION

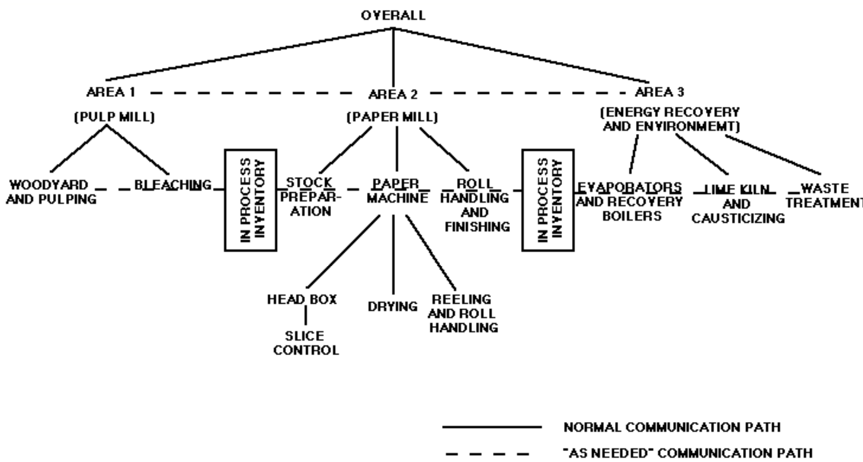

FIGURE D-7 HIERARCHY ARRANGEMENT OF THE PAPER MILL CONTROL TO SHOW RELATIONSHIP OF HIERARCHY TO PLANT STRUCTURE

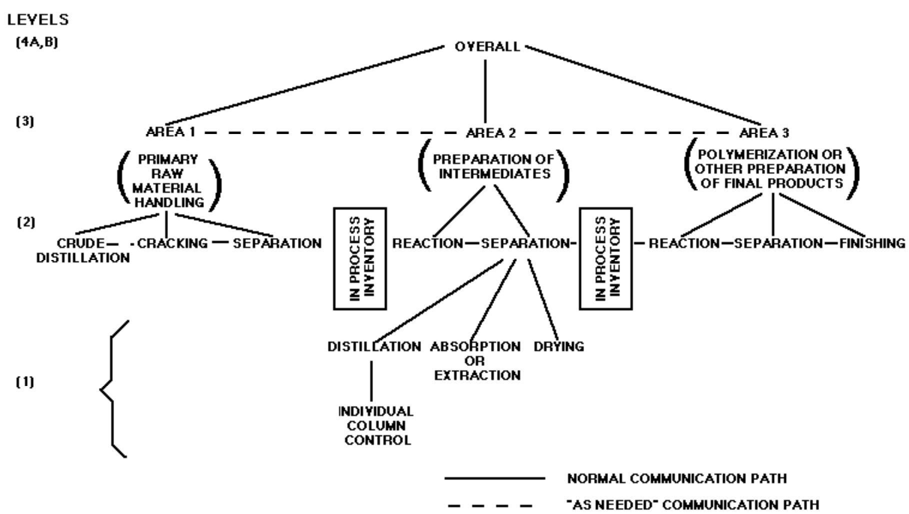

FIGURE D-8 THE HIERARCHY CONTROL SCHEME AS APPLIED TO A PETROCHEMICAL PLANT

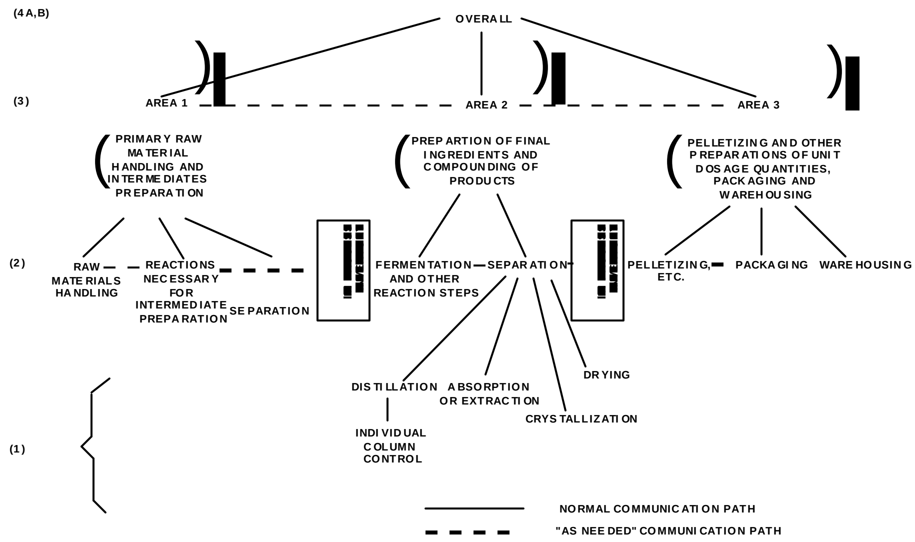

FIGURE D-9 THE HIERARCHY CONTROL SCHEME AS APPLIED TO A PHARMACEUTICALS PLANT

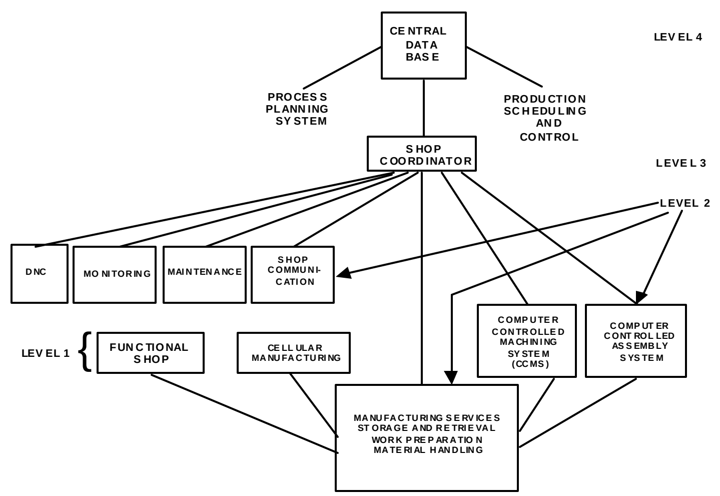

FIGURE D-10 COMPUTER INTEGRATED MANUFACTURING SYSTEM (CIMS) (CINCINNATI-MILICRON PROPOSAL)

TABLE D-XI

INFORMATION FLOW MODEL OF GENERIC PRODUCTION FACILITY MINI-SPECS (DEFINITION OF FUNCTIONS)

FIRST ORDER ENTITY DIVISIONS

0. FACILITY MODEL CONTEXT - Figure D-16
   External Entities
   Marketing and Sales
   Corporate R. D. & E.
   Supplier
   Vendor
   Customer
   Transport Company
   Accounting
   Purchasing

1. ORDER PROCESSING - Bubble 1 of Figure D-16 and Figure D-17
   Customer order handling, acceptance and confirmation
   Sales forecasting
   Waiver and reservation handling
   Gross margin reporting
   Determine production orders

2. PRODUCTION SCHEDULING - Bubble 2 and Figure D-18
   Determine production schedule
   Identify long term raw material requirements
   Determine packout schedule for end products
   Determine available product for sales

3. PRODUCTION CONTROL - Bubble 3 and Figure D-19
   Control of transformation of raw materials into end product in accordance with production schedule and production standards
   Maintenance of processing equipment
   Plant engineering and updating of process plans, etc.
   Issue requirements for raw materials
   Produce reports of performance and costs
   Evaluate constraints to capacity and quality
   Self test and diagnostics of production and control equipment

4. MATERIALS AND ENERGY CONTROL - Bubble 4 and Figure D-23
   Keep stock of raw materials
   Reorder raw materials according to production Requirements
   Accept delivery of raw materials, request QA tests and release for utilization after approval
   Reporting on RM and energy utilization
   Reporting on RM inventory to production

5. PROCUREMENT - Bubble 5 and Figure D-24
   Place orders with suppliers for RM supplies, spare parts, tools, equipment and other required materials
   Monitor progress of purchases and report to requisitioners
   Release incoming invoices for payment after arrival and approval of goods

6. QUALITY ASSURANCE - Bubble 6 and Figure D-25
   Testing and classification of incoming material and end products
   Set standard for production QA in accordance with market and technology requirements
   Assist production with exceptional and effective QA tests

7. PRODUCT INVENTORY - Bubble 7 and Figure D-26
   Keep stock of produced end products
   Make reservation for specific product on list in accordance with product selling directives

Pack-out end product in accordance with schedule Report on inventory to production scheduling Report on balance and losses to product cost accounting Arrange physical loading/shipment of goods in coordination with product shipping administration

TABLE D-XI (Continued)

8. COST ACCOUNTING - Bubble 8 and Figure D-27
   Calculate and report on total product cost
   Report cost results to production for adjustment
   Set cost objectives for production

9. PRODUCT SHIPPING ADMINISTRATION - Bubble 9 and Figure D-28
   Organize transport for product shipment in accordance with accepted orders requirements
   Negotiate and place orders with transport companies
   Accept freight items on site and release material for shipment
   Prepare accompanying documents for shipment (BOL, customs clearance)
   Confirm shipment and release for invoicing to general accounting
   Report on shipping costs to product cost accounting

(10.0 MAINTENANCE (Defined as a FIRST ORDER ENTITY in the S95 model)

SECOND-ORDER ENTITY SUBDIVISIONS

1.1 PRODUCTION FORECASTING (LONG RANGE) - Bubble 1.1, Figure D-17
   The orders expected within the next period of time are predicted
   The prediction is based on the sales history and function of the market expectation
   Forecasting makes use of the traditional statistical techniques (smoothing, seasonal indices, etc.)
   The forecasting period is set by the confidence of market expectations
   Market expectations are influenced by outside factors, e.g., economical or political situation, or by inside factors, e.g., long term contracts, production problems

1.2 HISTORIAN - Bubble 1.2 , Figure D-17
   Create and update a sales history file with clarification of product, customer, shipping method

1.3 ORDER ENTRY - Bubble 1.3, Figure D-17
   Main interface with customer for inquiries and orders
   Supply product price and availability
   Handle order entry and amendments
   Give confirmation and progress of entered orders

1.4 PRODUCTION ORDER - Bubble 1.4, Figure D-17
   Based on active and forecasted orders determine the required production

1.5 ORDER ACCEPTANCE - Bubble 1.5, Figure D-17
   Handle the acceptance for delivery of entered orders
   Acceptance is based on ability to manufacture and availability of product customer credibility is checked
   In specific cases the product specifications can be waived in accordance with marketing policies to ratify a particular customer or market need

2.1 PROCESS PRODUCTION ORDERS - Bubble 2.1, Figure D-18
   Produce detailed production requirements from sales production orders
   Highlight specification requirements for non-standard requests
   Produce production order entry in scheduling file and append shipment requirements

2.2 BALANCE IN PROCESS AND PRODUCTION INVENTORY - Bubble 2.2, Figure D-18
   Identify ordered quantities against produced products and initiate packout of specific shipments
   Identify availability of on-hand product
   Highlight variance in production schedule
   Maintain capacity estimates for production facility in terms of products

2.3 PRODUCTION FORECASTING (SHORT TERM) - Bubble 2.3, Figure D-18
   From existing production orders and known capacity, produce specific schedule entries for production rates and specifications
   Set long term raw material order rates to meet production schedule
   Produce a long term forecast report

TABLE D-XI (Continued)

2.4 PRODUCTION SCHEDULING - Bubble 2.4, Figure D-18
Produce formal production schedule
Modify production schedule to account for production variances and interruptions
Modify production schedule to account for inventory and shipments

3.1 PROCESS SUPPORT ENGINEERING - Bubble 3.1, Figure D-19; Figure D-20
Issue request for modification or maintenance
Coordinate maintenance and engineering activities
Provide technical standards and methods to maintenance function
Follow-up on equipment and process performance
Provide technical support to operators
Follow-up on technological developments
Provide specifications for purchase order requests

3.2 MAINTENANCE - Bubble 3.2, Figure D-19; Figure D-21 *(10.0 in the S95 Model)*
Provide maintenance for existing installations
Provide preventative maintenance program
Provide equipment monitoring program to anticipate Failure including self-check and diagnostic programs
Place purchase order request for materials and spare parts
Develop maintenance cost reports
Coordinate outside contract work effort

3.3 OPERATIONS CONTROL - Bubble 3.3, Figure D-19; Figure D-22
Supervise the operations of production process
Keep track and report on production costs and performance
Interpret the production plan in terms of the setpoints to individual units
Diagnostics and self-check of production and control equipment

3.4 OPERATIONS PLANNING - Bubble 3.4, Figure D-19
Set up a daily production plan as function of the production schedule
Check schedule against raw material availability and product storage capacity
Determine percent of capacity status
Modify production plan hourly to account for equipment outage, manpower and raw materials availability

4.1 MATERIAL AND ENERGY REQUIREMENT CONTROL - Bubble 4.1, Figure D-23
Determine supplier of new materials based on short and/or long term requirements from planning or manufacturing taking existing inventory into account
Set up transfers of materials and energy to manufacturing
Issue purchase request for new material and energy supplies
Notify incoming material and energy control on expected incoming orders

4.2 OPTIMUM MATERIAL AND ENERGY INVENTORY LEVELS - Bubble 4.2, Figure D-23
Continuously calculate and report inventory balance and losses of RM and energy utilization

4.3 INCOMING RAW MATERIAL AND ENERGY CONTROL - Bubble 4.3, Figure D-23
Receive incoming material and energy supplies and request QA tests
Transfer material and energy to storage and/or classify for use after QA approval
Notify purchasing of accepted material and energy supplies to release payment

4.4 RAW MATERIAL AND ENERGY ROUTING - Bubble 4.4, Figure D-23
Set up and monitor the movement of material and energy in storage
Update inventory of all movements and changes

4.5 RAW MATERIAL AND ENERGY INVENTORY REPORTING - Bubble 4.5, Figure D-23
Reporting of inventory to production

4.6 RAW MATERIAL AND ENERGY MOVEMENT CONTROL - Bubble 4.6, Figure D-23
Control and monitor transfer of materials

4.7 DRAW MATERIALS AND ENERGY MEASUREMENT VALIDATION - Bubble 4.7, Figure D-23
See 3.3.4

TABLE D-XI (Continued)

5.1 ORDER PLACEMENT - Bubble 5.1, Figure D-24
Order preparation for raw materials, spare parts, etc., for presentation to the vendors based on procurement contracts negotiated by company purchasing
Updating of vendor library and purchasing files of vendors performance on orders

5.2 PROCESS REQUESTS - Bubble 5.2, Figure D-24
Collection and processing of unit requests for raw materials, spare parts, etc., for order placement to vendors
Checking of requests for those materials versus historical files and budgets to assure correctness of requests

5.3 COST CONTROL - Bubble 5.3, Figure D-24
Certification of invoices on raw materials and spare parts based on satisfactory receipt of requested materials or parts

6.1 SET STANDARDS AND METHODS - Bubble 6.1, Figure D-25
Issue standards to manufacturing and testing laboratories in accordance with requirements from technology, marketing and customer services

6.2 RAW MATERIALS EVALUATION - Bubble 6.2, Figure D-25
Testing of incoming raw materials and approval for use if in accordance with set standards
Collect and maintain quality control file for data for quality control analysis

6.3 EVALUATION OF PRODUCT - Bubble 6.3, Figure D-25
Test of final product and report results to classification
Collect and maintain quality control file for data for quality control analysis

6.4 CLASSIFICATION AND CERTIFICATION - Bubble 6.4, Figure D-25
Classify quality and properties of end product in accordance with set marketing standards
Waiver classification on exceptional basis as per request from product selling
Report QA results and classification to finished product inventory control
Certify that product was produced according to standard process conditions
Report process data and certification to finished product inventory control

6.5 QA MEASUREMENT VALIDATION - Bubble 6.5, Figure D-25
Checking of product data versus customer's requirements and statistical quality control routines to assure adequate quality before shipment
Maintenance of quality statistics on each item checked for continuing quality control studies.

6.6 LABORATORY AND AUTOMATIC ANALYSIS - Bubble 6.6, Figure D-25
Conduct of metric, chemical and physical tests on sample product items to obtain data for on-going quality control tests
Transmission of this data to analysis facilities and quality control systems to assure future quality of product

6.7 ANALYZE PROCESS CAPABILITY - Bubble 6.7, Figure D-25
Use SQC methodology to examine product data to determine process capability of meeting product specifications
Relay process deviations to process engineering for reevaluation to upgrade process
Relay methods deviation to standards and methods group for corrective action

7.1 INVENTORY SUPERVISION - Bubble 7.1, Figure D-26
Coordinate all activities in product inventory control
Set up transfers of material to packing unit in accordance to packout schedule
Request replenishment of packing materials
Handle reservations and update inventory accordingly

7.2 LOSS CONTROL - Bubble 7.2, Figure D-26
Continuously calculate and report on inventory balance and losses

7.3 INVENTORY REPORTING - Bubble 7.3, Figure D-26
Generate daily, weekly ... reports on actual amounts of materials in storage

TABLE D-XI (Continued)

7.4	PRODUCT SHIPPING - Bubble 7.4, Figure D-26 Set-up and monitor transfers of products to customer in accordance with requirements from shipping administration Report confirmation of shipment for release of invoicing
7.5	PRODUCT ROUTING - Bubble 7.5, Figure D-26 Set-up and monitor the routes of product transfer and update inventory on changes
7.6	PHYSICAL PRODUCT MOVEMENT CONTROL - Bubble 7.6, Figure D-26 See 4.6
7.7	INVENTORY MEASUREMENT VALIDATION - Bubble 7.7, Figure D-26 See 3.3.4
8.1	COSTS BALANCING AND BUDGET - Bubble 8.1, Figure D-27 Establishment of criteria and tests to assure that operational budget is being followed Collection of raw material, labor, energy and other costs for transmission to accounting
8.2	RAW MATERIAL AND PARTS COSTS (ACCOUNTS PAYABLE) - Bubble 8.2, Figure D-27 Collection of cost data on all raw materials and spare parts in inventory or procured for the plant
8.3	PRODUCT INCOME (ACCOUNTS RECEIVED) - Bubble 8.3, Figure D-27 Collection of data of product shipped or in inventory Release invoice data to cost accounting at standard cost
8.4	PRODUCTION COSTS - Bubble 8.4, Figure D-27 Collection of data on costs of production in the plant - labor, energy, raw material usage, spare parts usage, etc.
9.1	SHIPMENT SCHEDULING - Bubble 9.1, Figure D-28 Classify accepted order and produce shipping schedule
9.2	SHIPPING COSTS - Bubble 9.2, Figure D-28 Calculate and report cost of shipping
9.3	SHIPMENT CONFIRMATION - Bubble 9.3, Figure D-28 Update shipping schedule to indicate that shipping has been done and configuration of shipments
9.4	RELEASE FOR INVOICING - Bubble 9.4, Figure D-28 Notify accounting of shipment in order to release invoice
9.5	RELEASE SHIPMENT - Bubble 9.5, Figure D-28 Send information for shipment to product shipping
9.6	PREPARE SHIPPING DOCUMENTS - Bubble 9.6, Figure D-28 Issue bill of lading, customer clearance, documents that are required with shipment

TABLE D-XI (Continued)

THIRD-ORDER ENTITY SUBDIVISIONS

3.1.1 PROJECT MANAGEMENT - Bubble 3.1.1, Figure D-20
Management of engineering function
Coordination of equipment and process modification
Cost and progress reporting
Project planning
Design follow-up with corrective action

3.1.2 EQUIPMENT AND PROCESS DESIGN MODIFICATION - Bubble 3.1.2, Figure D-20
Establish design basis of new project
Supply necessary information to allow cost estimating
Report and Coordinate Specialists' Assistance
Provide Technical Information to Operators

3.1.3 ENGINEERING SPECIALISTS - Bubble 3.1.3, Figure D-20
Provide support and advice in special area
Follow-up on state of the art in technology
Assess plant process and equipment performance
Adjust standards and methods to needs and progress
Monitor the interpretation of design basis during detailed engineering

3.1.4 STANDARDS AND METHODS - Bubble 3.1.4, Figure D-20
Establish standards for process equipment, design techniques and process operational methods (practice files)
Promulgate such standards within the process support engineering functions and within the operational groups of the factory

3.1.5 PROJECT COST CONTROL - Bubble 3.1.5, Figure D-20
Provide cost estimates of planned projects
Follow-up and report on costs of projects in execution

3.1.6 PROCESS ANALYSIS AND PROJECT DETAILED ENGINEERING - Bubble 3.1.6, Figure D-20
Conduct plant performance studies
Provide details for the construction of equipment or process modification project in accordance to design basis
Issue report for ordering of new equipment
Issue specifications to vendor
Report on engineering and committed equipment costs

3.1.7 EQUIPMENT MODIFICATION CONSTRUCTION - Bubble 3.1.7, Figure D-20
Provide for construction of project
Report on cost and labor

3.1.8 DRAFTING DOCUMENTATION - Bubble 3.1.8, Figure D-20
Maintain master copies of all plant drawings for units under its cognizance
Responsible for updating drawings and associated documentation as units are modified
Supply copies as needed

3.2.1 MAINTENANCE PLANNING - Bubble 3.2.1, Figure D-21
Organization and supervision of requested maintenance
Reporting on performed maintenance
Coordinate planned work with operators and plant supervision
Monitor and update maintenance history file

3.2.2 MAINTENANCE COST CONTROL - Bubble 3.2.2, Figure D-21
Follow-up on used spare parts, report maintenance labor and report on maintenance costs

TABLE D-XI (Continued)

3.2.3	SPARE PARTS - Bubble 3.2.3, Figure D-21 Supervise spare parts warehouse Supply necessary parts to maintenance crews Report on inventory to planning for reordering Report to cost control on used parts Accept and control new delivered parts from vendors
3.2.4	MAINTENANCE CREW SUPERVISION - Bubble 3.2.4, Figure D-21 Perform requested maintenance work Supervise and coordinate with outside contractors Report on technical activities to files Report on installation and equipment performance to engineering
3.2.5	DOCUMENTATION - Bubble 3.2.5, Figure D-21 See Item 3.1.8
3.3.1	OPERATIONS SUPERVISION - Bubble 3.3.1, Figure D-22 Set objectives for process operation Supervise people in operation of the process and equipment Deal directly in the resolution of exception conditions Issue modification or maintenance requests Set and report production capacity limits Monitor and report on production cost and performance
3.3.2	OPERATIONS COST CONTROL - Bubble 3.3.2, Figure D-22 Calculate total operating costs Maintain short term economic balances of energy and materials Capture maintenance and engineering costs chargeable to operations
3.3.3	PHYSICAL PROCESS CONTROL - Bubble 3.3.3, Figure D-22 Stabilize process variables to defined operating setpoints Alarming of operating variables for exceptional conditions Maintain operation against constraints or at specifications Response to operators and process engineers requests Response to emergencies
3.3.4	OPERATIONAL MEASUREMENT VALIDATION - Bubble 3.3.4, Figure D-22 Assess the validity of the measurements for further use within their limits of confidence Tag measurement data with quality and time
3.3.5	EQUIPMENT MONITORING - Bubble 3.3.5, Figure D-22 Assess the operating performance and limits of process equipment Alarming of equipment status variables against constraints Indicate performance against expected equipment life cycles
3.3.6	PRODUCTION BALANCING AND OPTIMIZATION - Bubble 3.3.6, Figure D-22 Optimization of production process to set objectives within equipment constraints Maintain material and energy balance to indicate exceptional conditions Perform performance tests where necessary to determine capacity Monitor product quality against specifications and standards

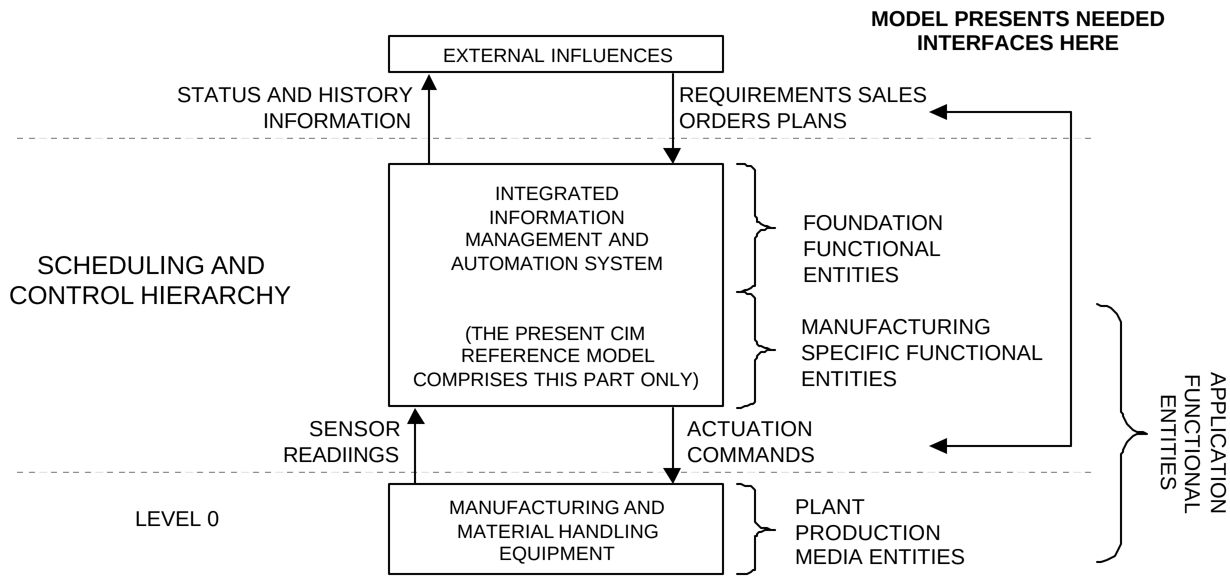

FIGURE D-11 RELATIONSHIP OF THE SEVERAL CLASSES OF FUNCTIONAL ENTITIES WHICH COMPROMISE THE CIM REFERENCE MODEL AND COMPUTER INTEGRATED MANUFACTURING ITSELF

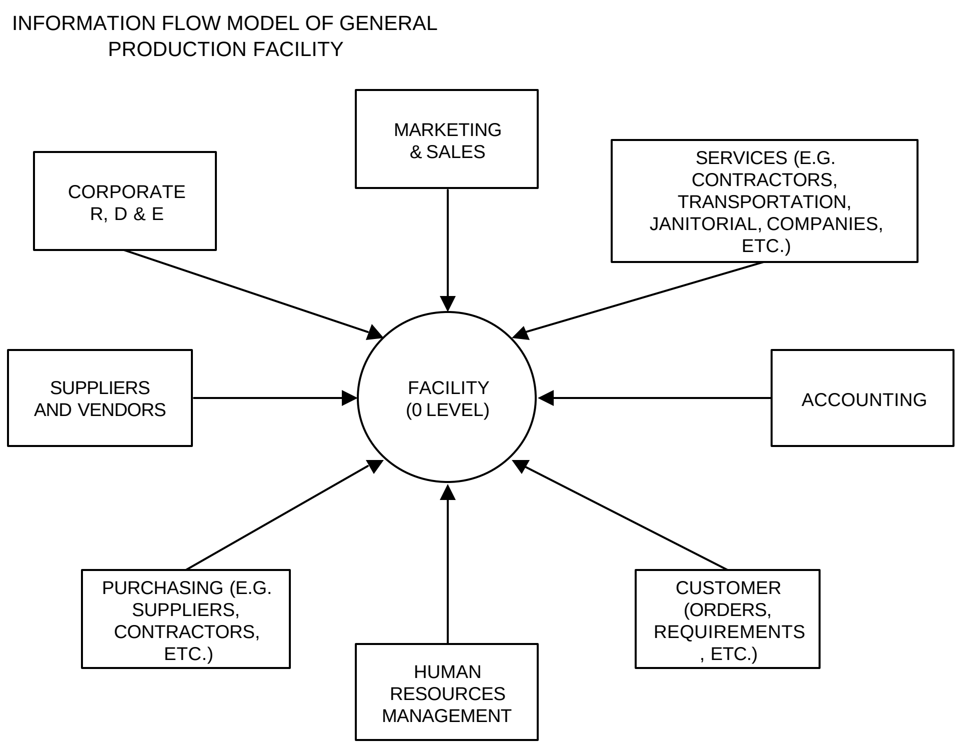

FIGURE D-12 MAJOR EXTERNAL INFLUENCES AS USED IN THE DATA FLOW MODEL

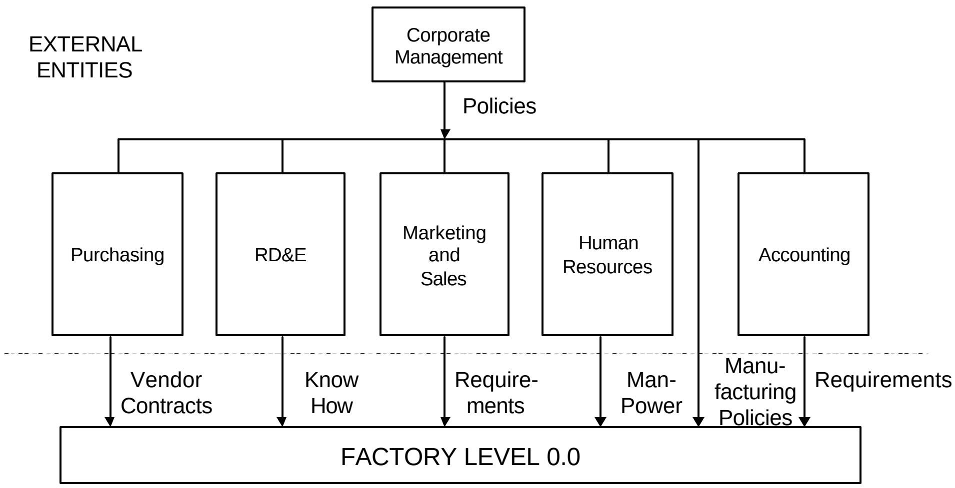

FIGURE D-13 REQUIREMENTS INTERFACING OF CORPORATE MANAGEMENT AND STAFF FUNCTIONAL ENTITIES TO THE FACTORY

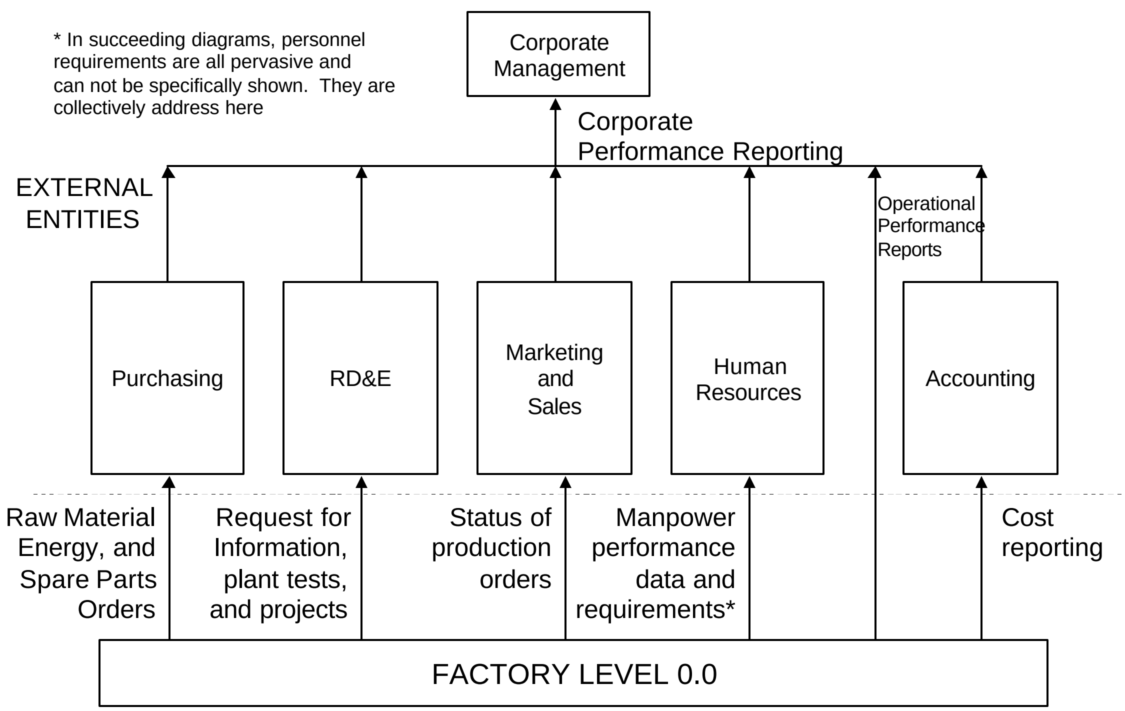

FIGURE D-14 REPORT INTERFACING TO CORPORATE MANAGEMENT AND STAFF FUNCTIONAL ENTITIES FROM THE FACTORY

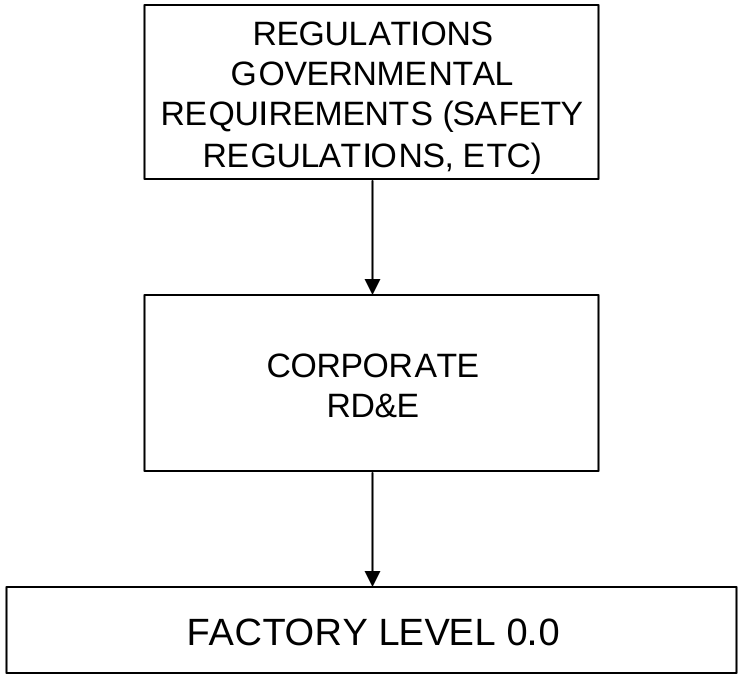

FIGURE D-15 INTERFACE OF GOVERNMENT REGULATIONS, ETC., TO THE FACTORY

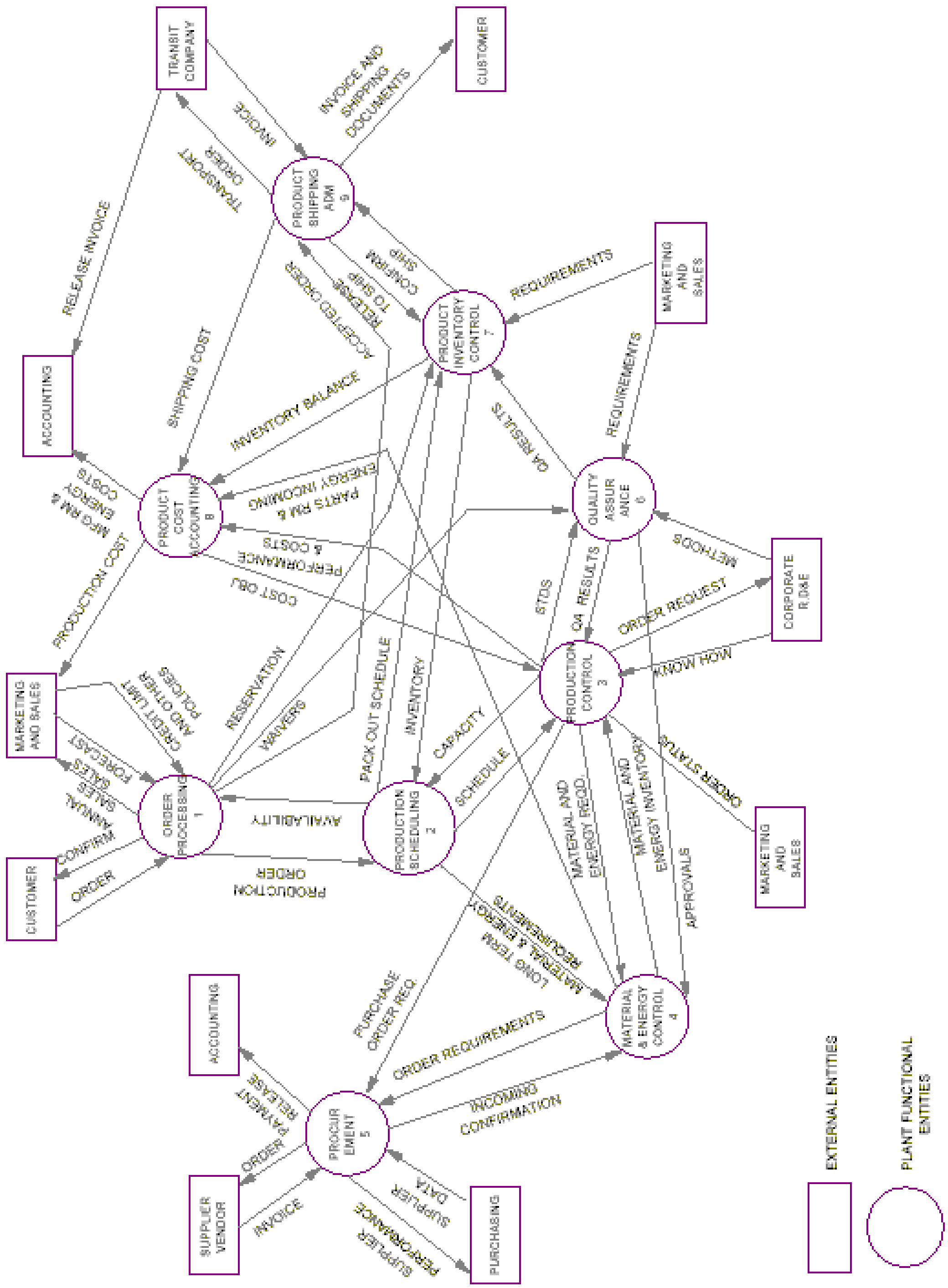

FIGURE D-16 0.0 FACILITY MODEL

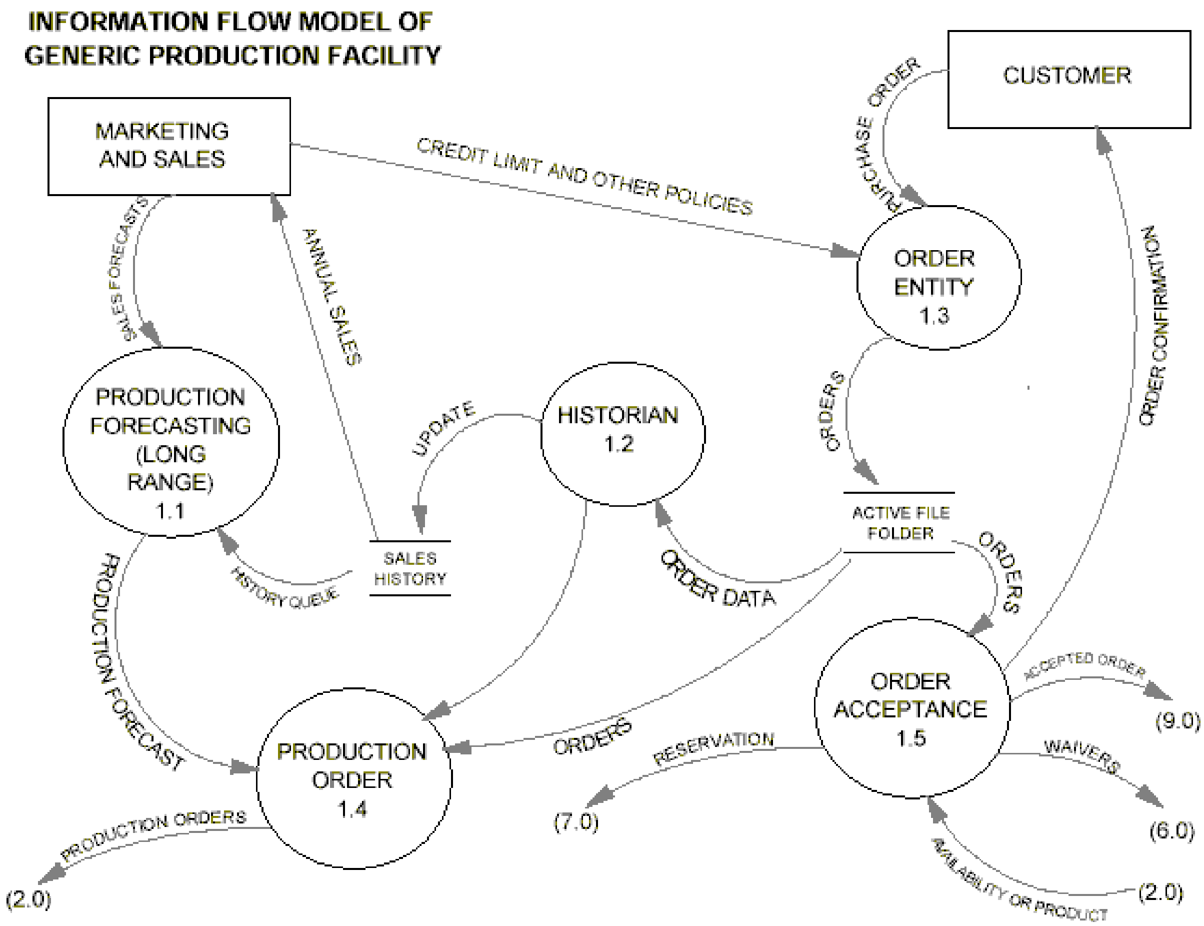

FIGURE D-17 1.0 ORDER PROCESSING

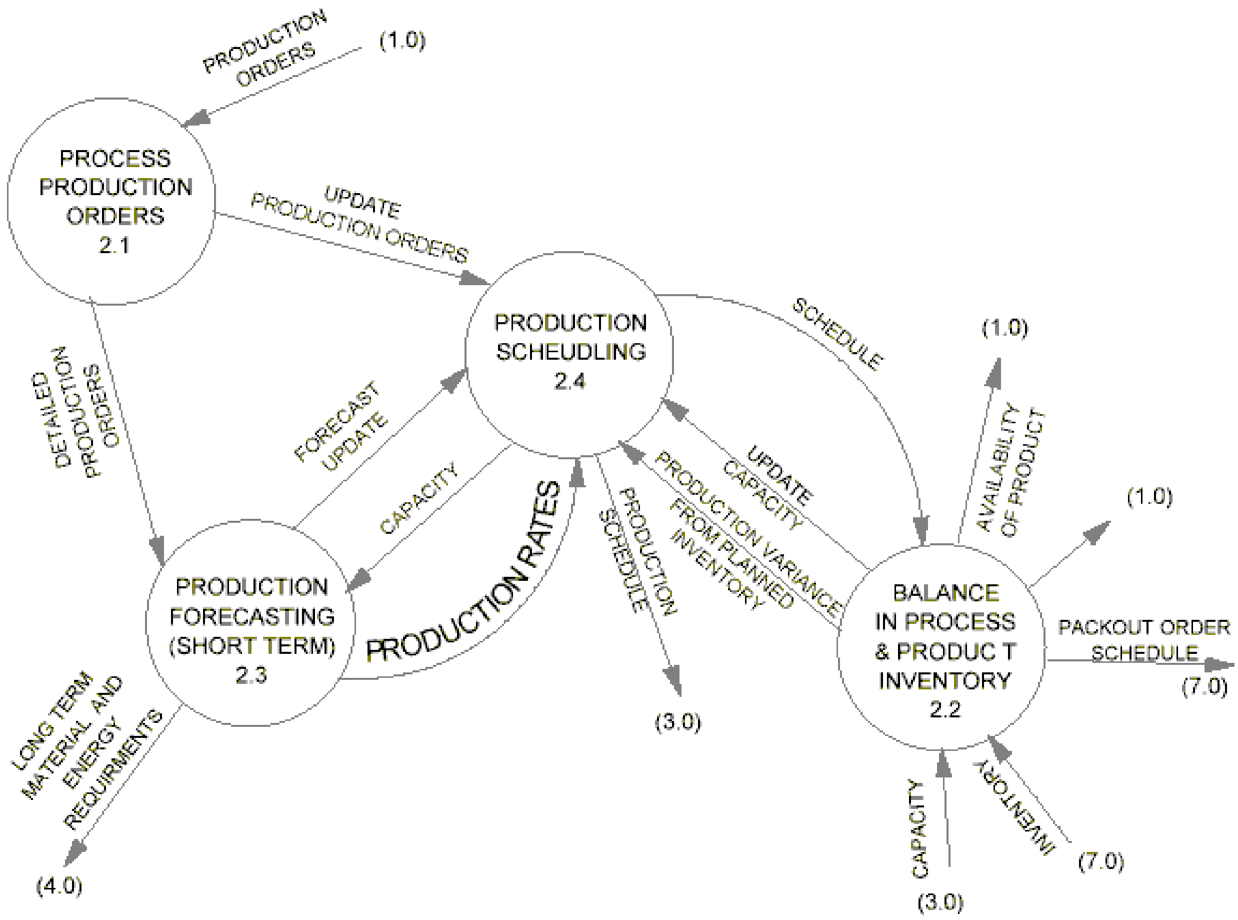

FIGURE D-18   2.0 PRODUCTION SCHEDULING

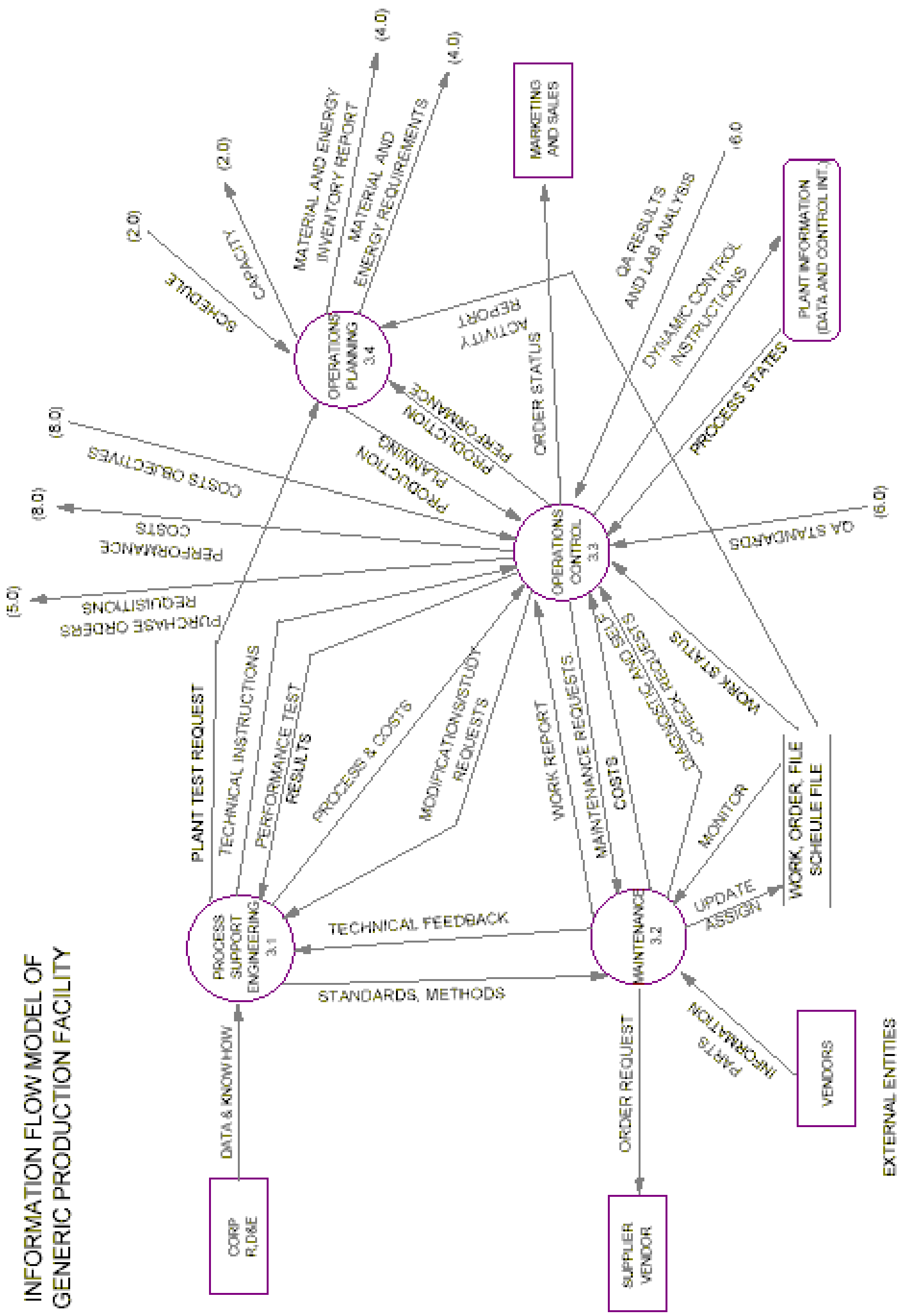

FIGURE D-19   3.0 PRODUCTION CONTROL

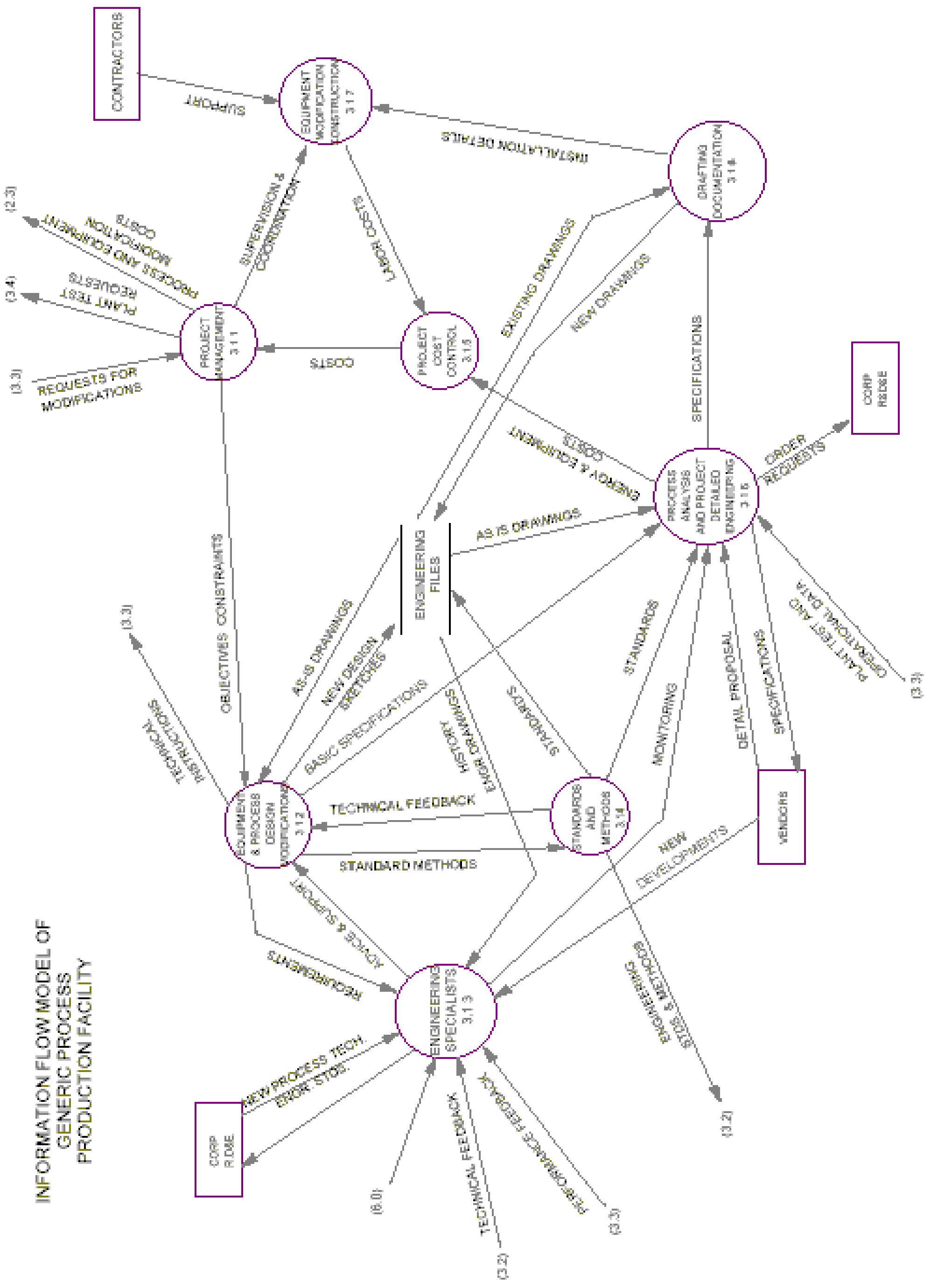

FIGURE D-20 3.1 PROCESS SUPPORT ENGINEERING

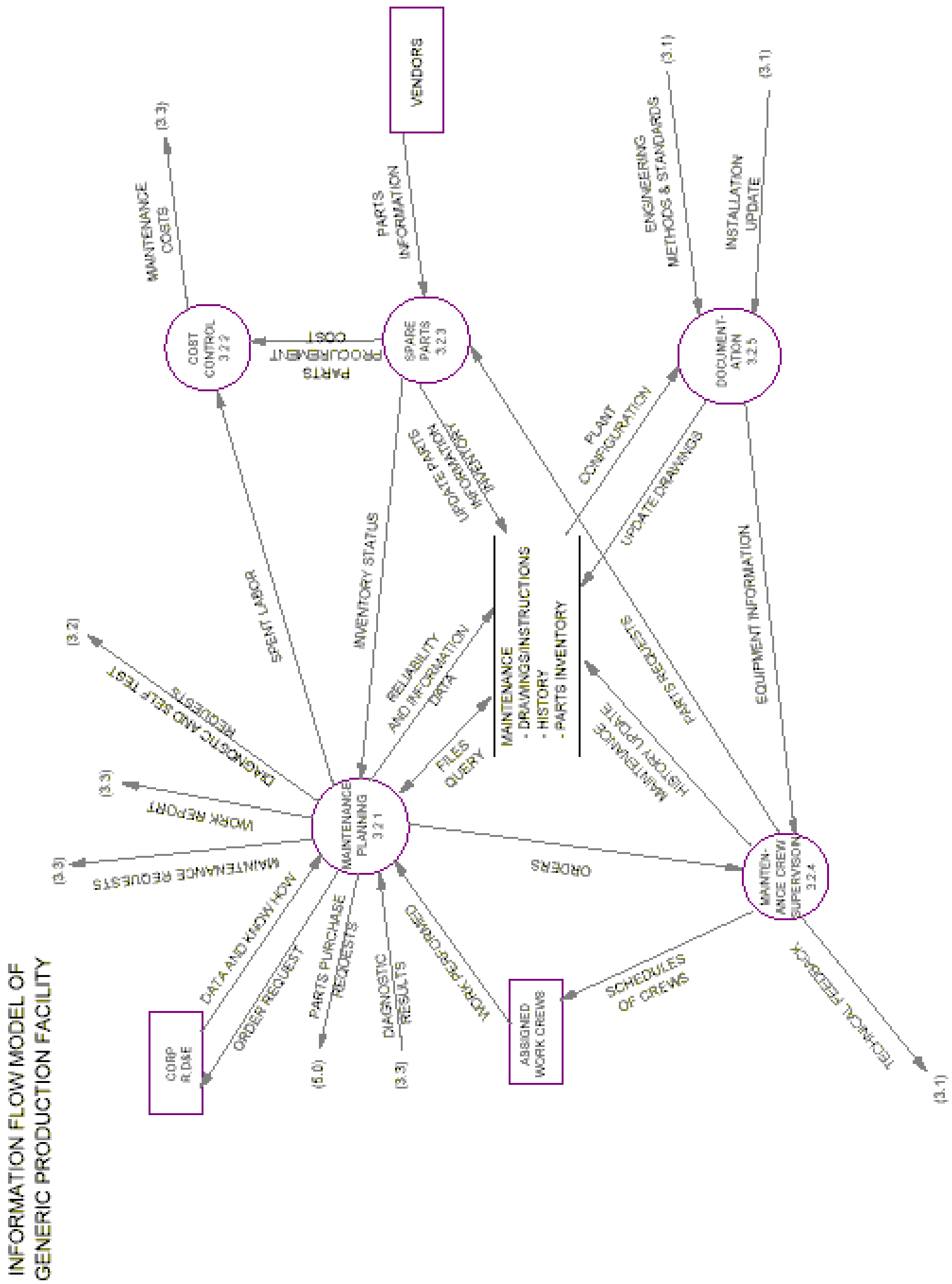

FIGURE D-21   3.2 MAINTENANCE

* Sub-Function 3.2, Maintenance, is defined as a separate major function (10.0, Maintenance) in the S95 model. This was to simplify the representation of the Level 3-4 split in the discussion and associated figures.

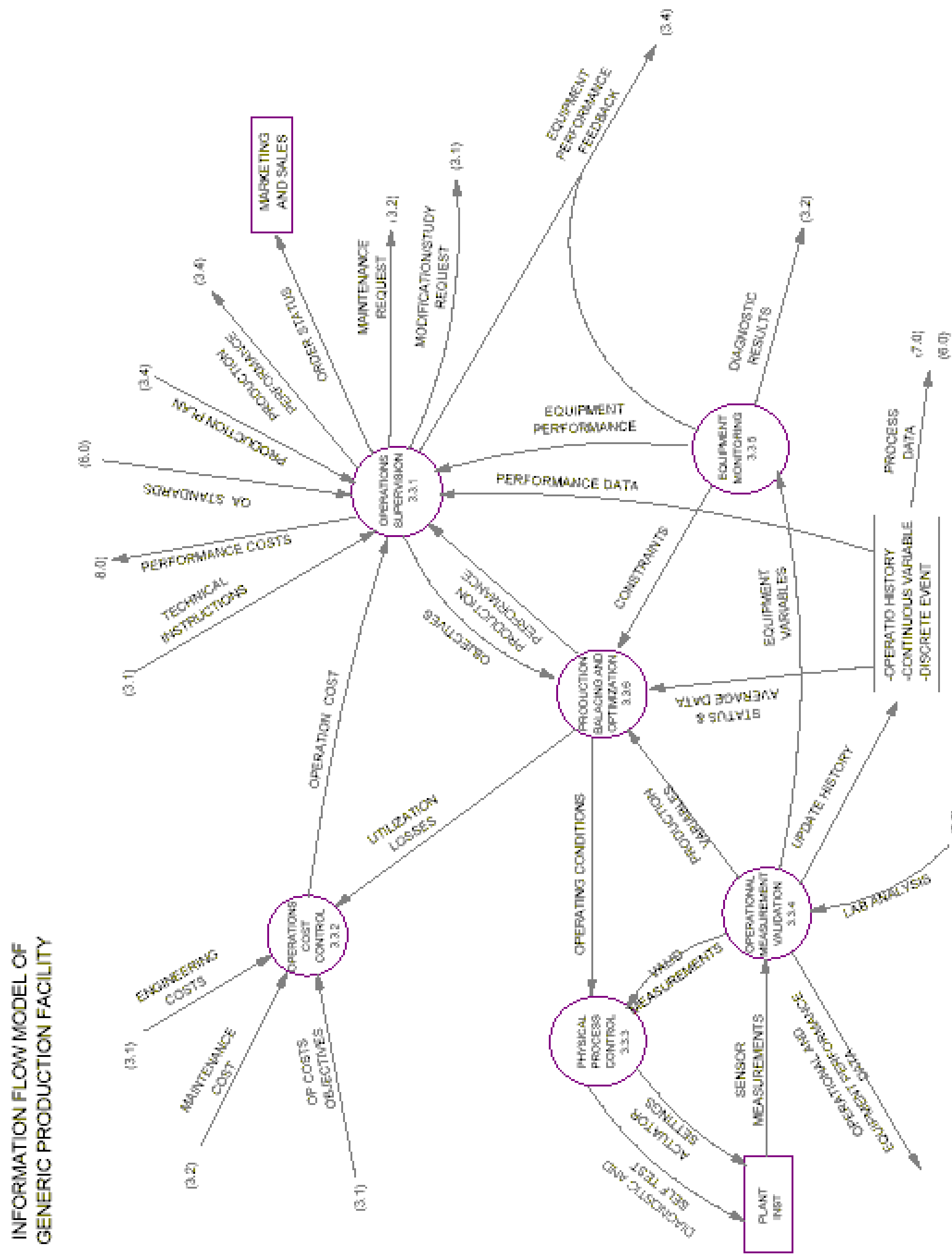

FIGURE D-22 3.3 OPERATIONS CONTROL

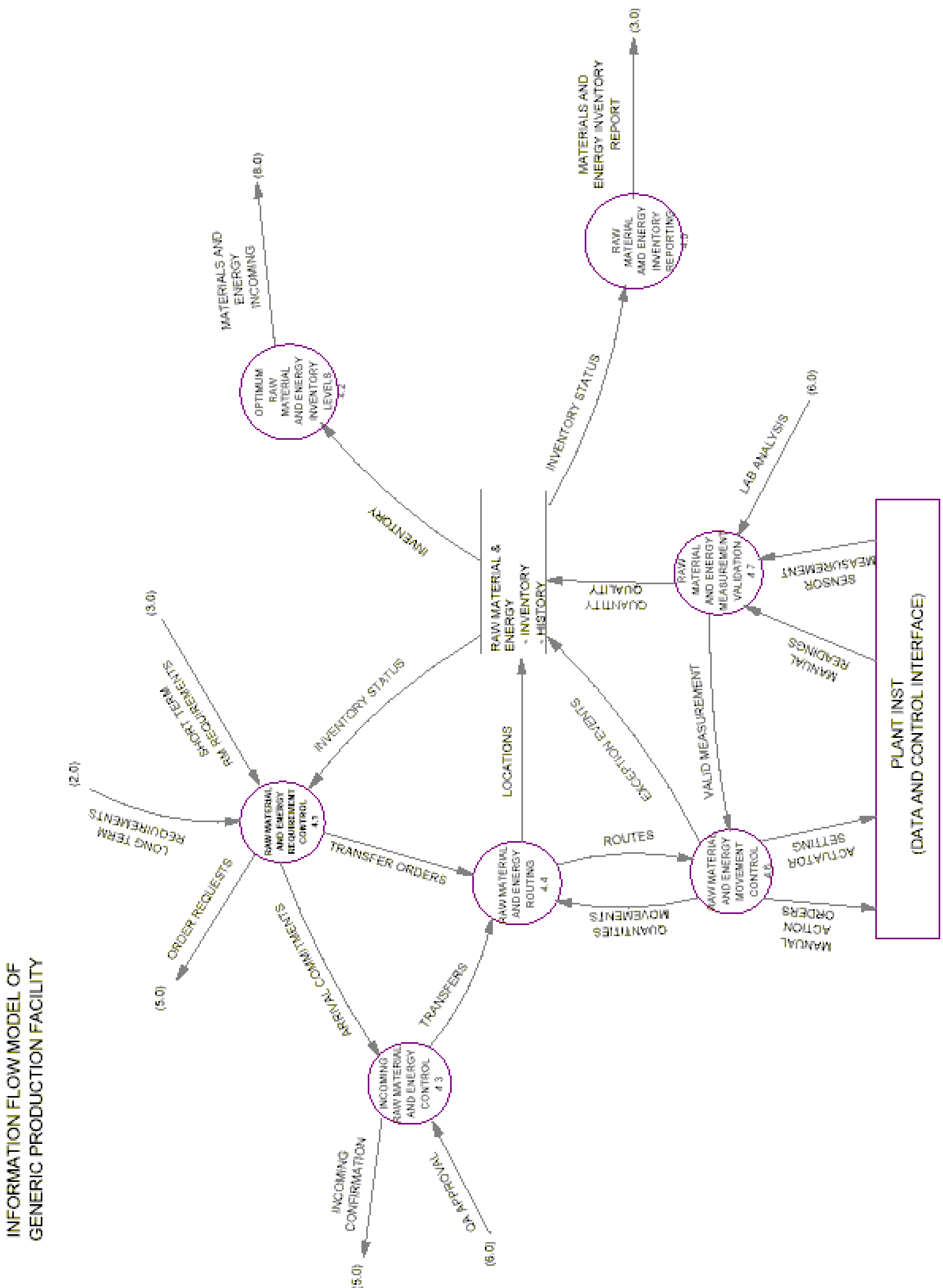

FIGURE D-23   4.0 MATERIALS AND ENERGY CONTROL

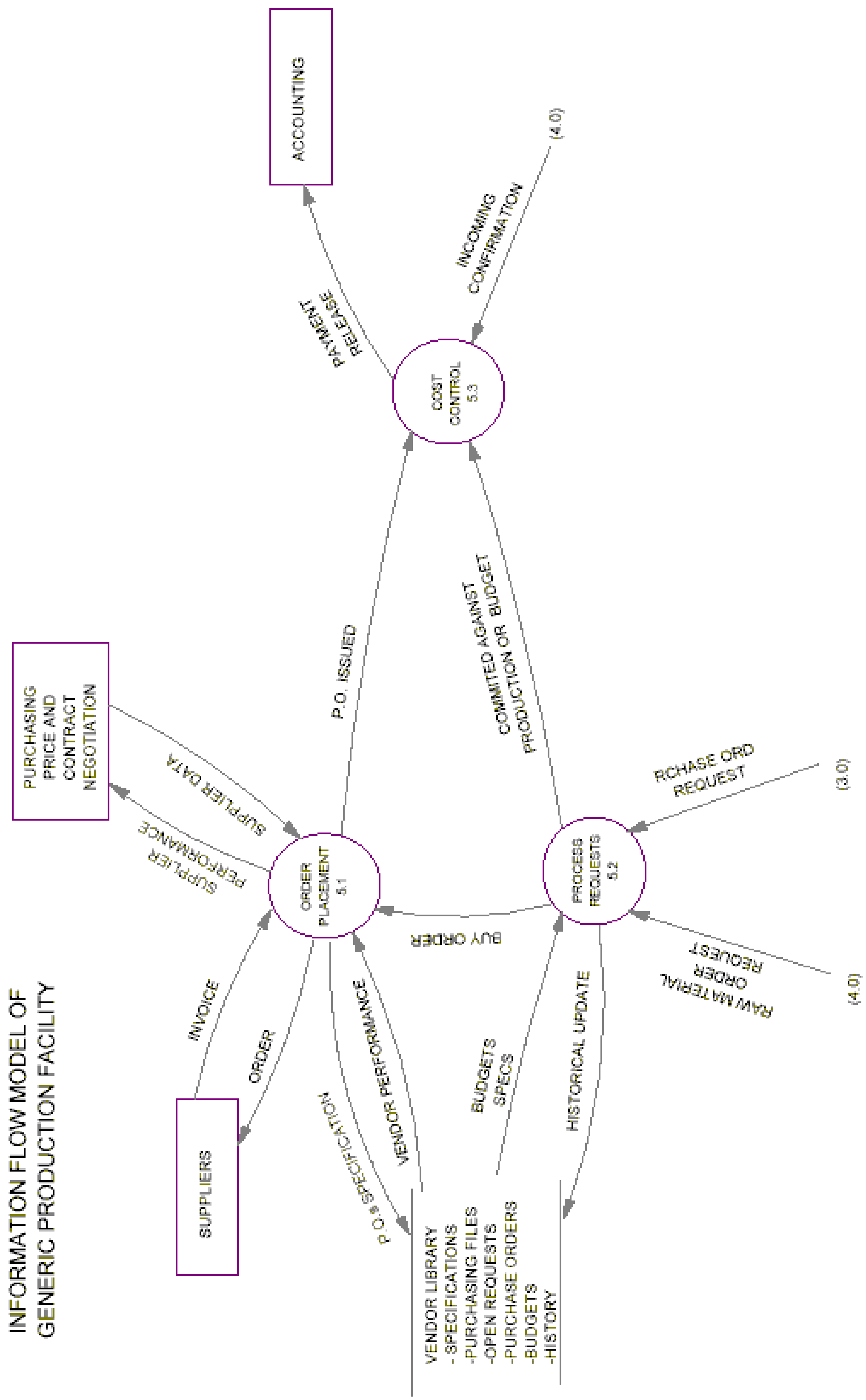

FIGURE D-24 5.0 PROCUREMENT

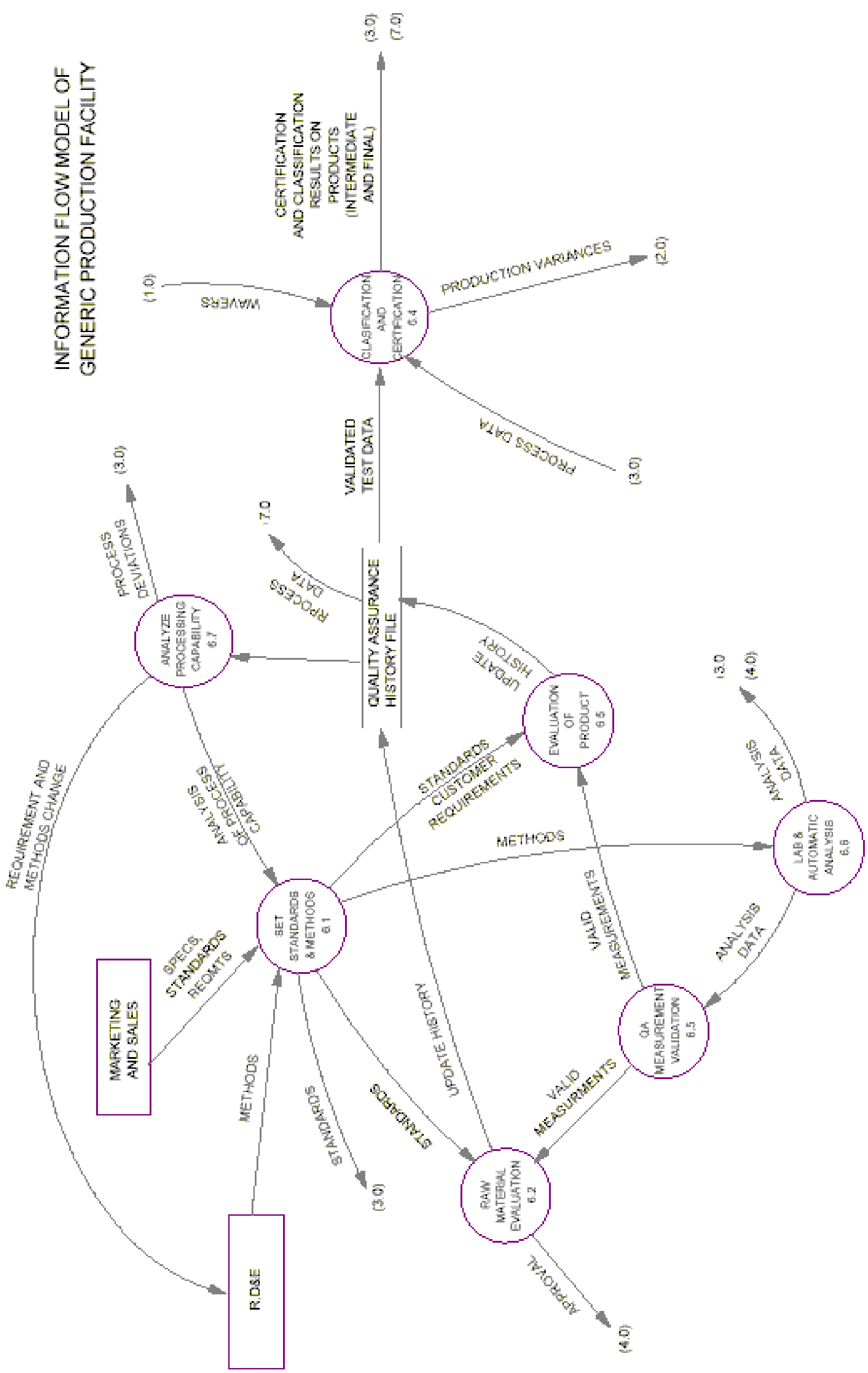

FIGURE D-25 6.0 QUALITY ASSURANCE

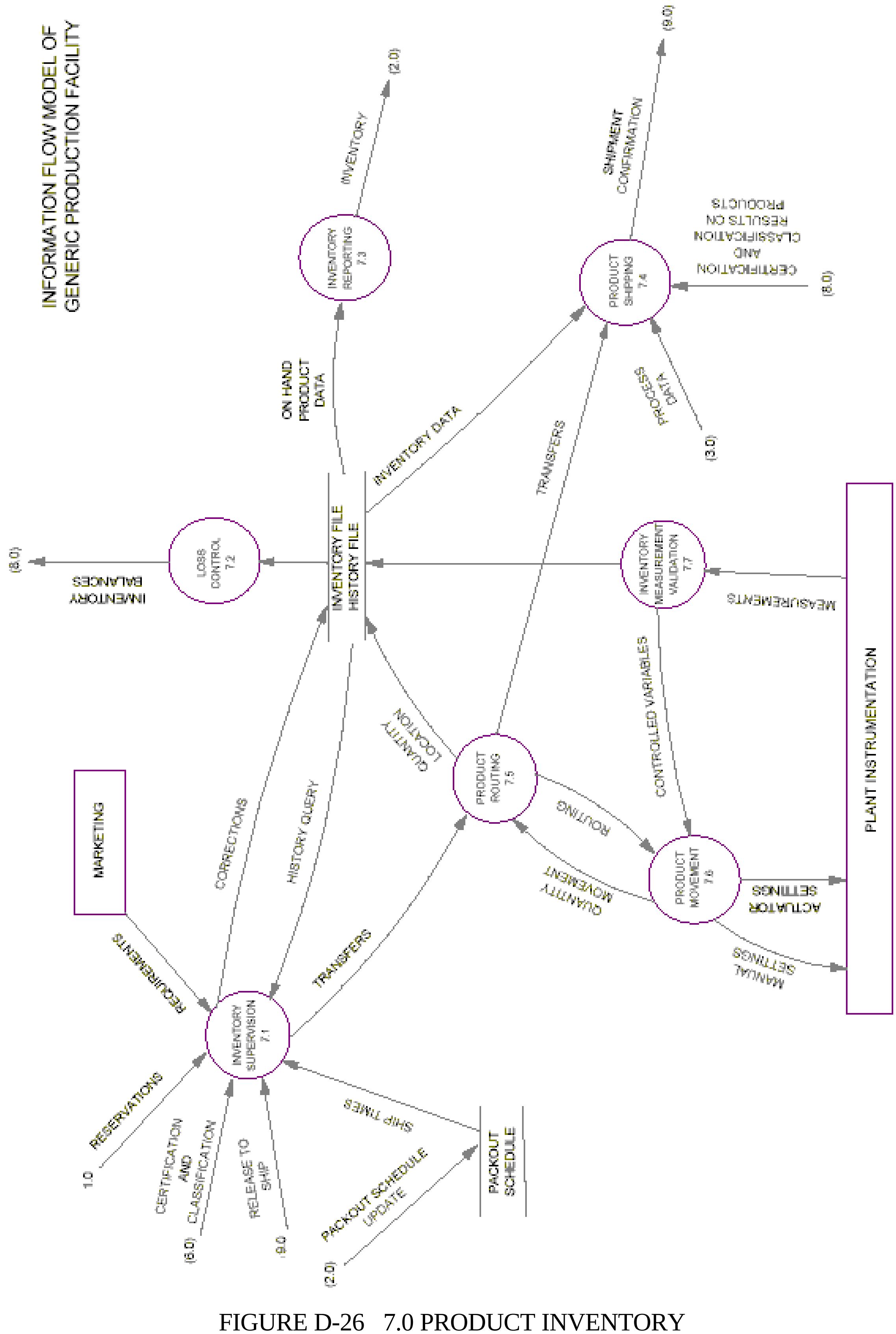

FIGURE D-26 7.0 PRODUCT INVENTORY

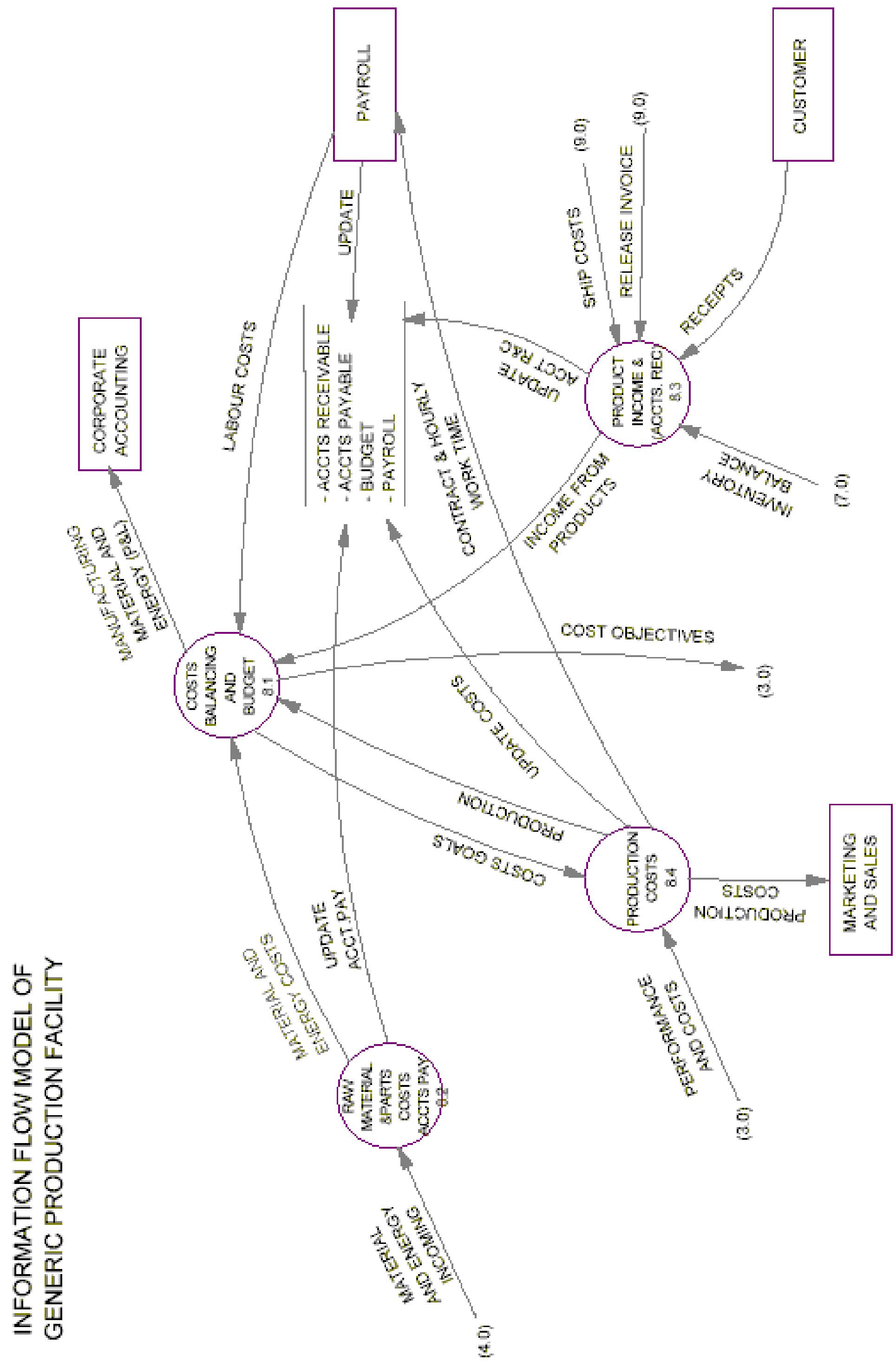

FIGURE D-27 8.0 COST ACCOUNTING

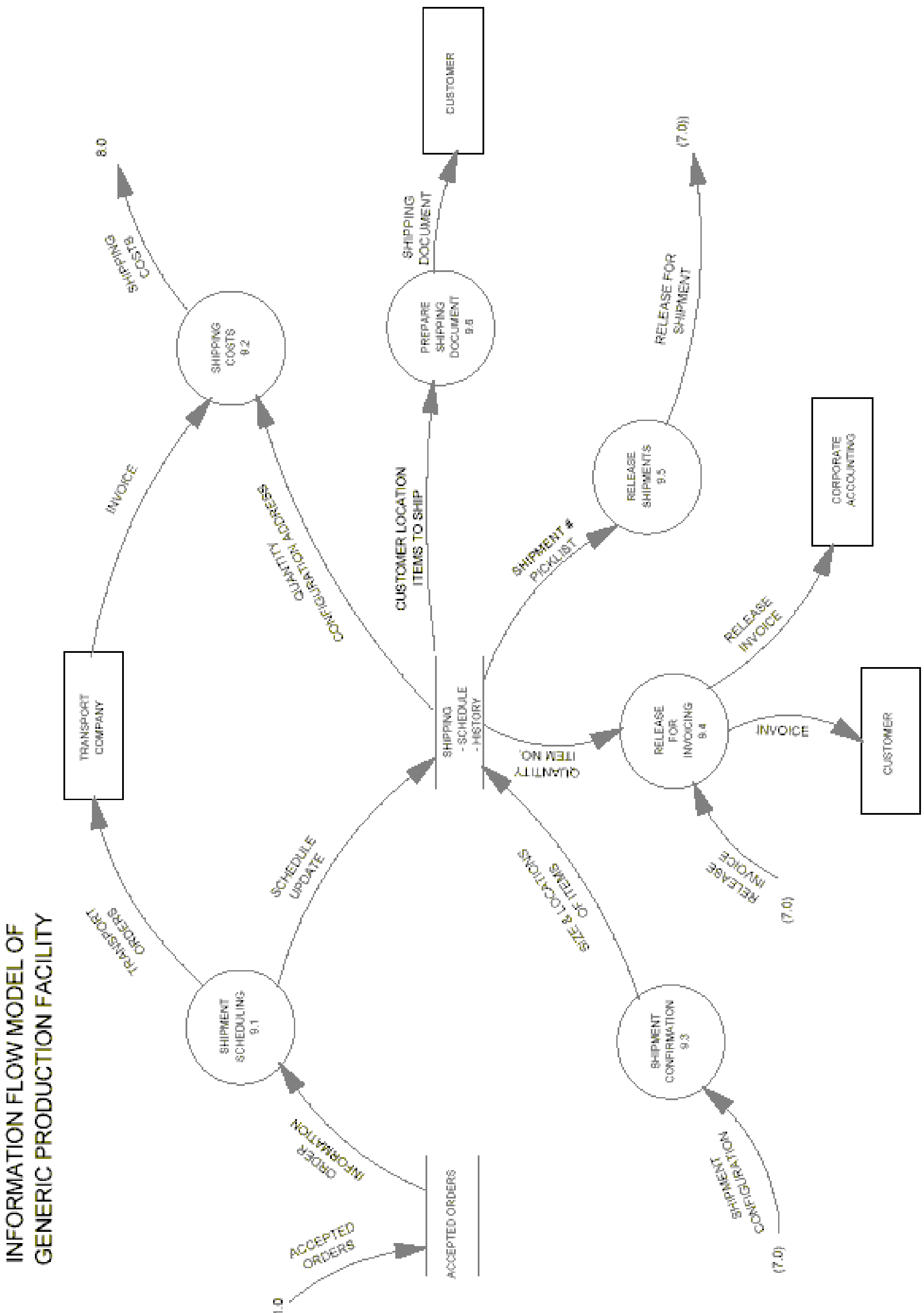

FIGURE D-28 9.0 PRODUCT SHIPPING ADMINISTRATION

TABLE D-XII

CORRELATION OF INFORMATION FLOW TASKS WITH THE TASKS OF THE SCHEDULING AND CONTROL HIERARCHY

Data Flow Diagram Listing		Scheduling and Control Hierarchy Listing	
Figure No. and Location	Title	Table No. and Entry	Title
Figure D-16 Task 1.0	Order Processing	Table D-VI, D-VII Item I(2)	Production Scheduling
Figure D-16 Task 2.0	Production Scheduling	Table D-VI, D-VII, D-VII Item I(1-3,5) Table D-VI, D-VII, D-VIII Item I(1,3)	Production Scheduling Same
Figure D-16 Task 3.0	Production Control	Table D-VI, D-VII, D-VIII Item I(2) Table D-IX Item II Table D-X Item II	Area Optimization Control Enforcement Same
Figure D-16 Task 4.0	Raw Material Control	Table D-VI, D-VII Item I(4) Item III (6,7)	Optimum Inventory Levels Procurement Order Entry
Figure D-16 Task 5.0	Procurement	Table D-VI, D-VII Item III (6,7)	Procurement Order Entry
Figure D-16 Task 6.0	Quality Assurance	Table D-VI, D-VII, D-VIII Item III(9) Table D-VI, D-VII, D-VIII Item III(8)	Quality Control File Statistical Quality Analysis and Control Functions
Figure D-16 Task 7.0	Product Inventory Control	Table D-VI, D-VII Item I(4) Item III(8)	Optimum Inventory Levels Goods in Process Inventory
Figure D-16 Task 8.0	Product Cost Accounting	Table D-VI, D-VII Item III(6-8) Table D-VI, D-VII, D-VIII Item III(4,6) Table D-X Item III(3) Table D-X Item III(3)	Production and Raw Material, Energy Source and Spare Parts Use Data Plus Inventory Data Same Same Same
Figure D-16 Task 9.0	Product Shipping Adm.	Table D-VI Item III(1B,2B) Table D-VI, D-VII, D-VIII Item III(8)	Product Inventory and Production Status and Data Same
Figure D-17 Task 1.1	Production Forecasting	Table D-VI, D-VII, D-VIII Item I (1)	Basic Production Scheduling
Figure D-17 Task 1.2	Historian	Table D-VI, D-VII, D-VIII Item I (1)	Basic Production Scheduling
Figure D-17 Task 1.3	Order Entry	Table D-VI, D-VII, D-VIII Item I (1)	Basic Production Scheduling

Figure D-17 Task 1.4	Production Order	Table D-VI, D-VII, D-VIII Item I (1)	Basic Production Scheduling
Figure D-17 Task 1.5	Order Acceptance	Table D-VI, D-VII, D-VIII Item I (1)	Sales Coordination

TABLE D-XII (continued)

Figures 18, 19, 20

Figure D-18 Task 2.1	Process Production Orders	Table D-VI, D-VII, D-VIII Item I (1,2)	Production Scheduling
Figure D-18 Task 2.2	Process Production Orders	Table D-VI, D-VII, D-VIII Item I (1,2)	Inventory Management
Figure D-18 Task 2.3	Process Production Orders	Table D-VI, D-VII, D-VIII Item I (4)	Basic Production Scheduling
Figure D-18 Task 2.4	Process Production Orders	Table D-VI, D-VII Item I (1-3,5) Table D-VI, D-VII, D-VIII Item I (1,3)	Production Scheduling Same
Figure D-19 Task 3.1	Process Support Engineering	Table D-VI, D-VII, D-VIII Item III (8)	Engineering Functions
Figure D-19 Task 3.2	Maintenance	Table D-VI, D-VII, D-VIII Item I (3) Item III (10) Table A7-VIII Item I(1)	Maintenance Scheduling Maintenance Data Immediate Production Schedule
Figure D-19 Task 3.3	Operations Control	Table D-VI, D-VII, D-VIII Item I (2) Table D-IX Item II Table D-X Item II	Area Optimization Control Enforcement Same
Figure D-19 Task 3.4	Operation Planning	Table D-VI, D-VII, D-VIII Item I (1,3)	Production Scheduling
Figure D-20 Task 3.1.1	Project Management	Table D-VI, D-VII, D-VIII Item III (8)	Engineering Functions
Figure D-20 Task 3.1.2	Equipment and Process Design Modification		
Figure D-20 Task 3.1.3	Engineering Specialists		
Figure D-20 Task 3.1.4	Standards and Methods		
Figure D-20 Task 3.1.5	Project Cost Control		
Figure D-20 Task 3.1.6	Project Detailed Engineering		
Figure D-20 Task 3.1.7	Equipment Modification Construction		
Figure D-20 Task 3.1.8	Drafting Documentation		

TABLE D-XII (continued)

Figures 21,22

Figure D-21 Task 3.2.1	Maintenance Planning	Table D-VI, D-VII, D-VIII Item I (3) Item III (10) Table D-VI, D-VII, D-VIII Item I (1)	Maintenance Scheduling Maintenance Data Immediate Production Schedule
Figure D-21 Task 3.2.2	Cost Control	Table D-VI, D-VII Item III (10,11) Table D-VI, D-VII, D-VIII Item III (6,10)	Cost Reporting Same
Figure D-21 Task 3.2.3	Spare Parts	Table D-VI, D-VII Item I (4) Item III (6)	Procurement Same
Figure D-21 Task 3.2.4	Maintenance Crew Scheduling	Table D-VI, D-VII, D-VIII Item III (10)	Personnel Functions
Figure D-21 Task 3.2.5	Documentation	Table D-VI, D-VII Item III (10) Table D-VI, D-VII, D-VIII Item III (6)	Maintenance Data Same
Figure D-22 Task 3.3.1	Operations Supervision	Table D-VI, D-VII Item I, III Table D-VI, D-VII, D-VIII Item I, III	Maintenance Data Same
Figure D-22 Task 3.3.2	Operations Cost Control	Table D-VI, D-VII Item III Table D-VI, D-VII, D-VIII Item III (4, 6-10)	Maintenance Data Same
Figure D-22 Task 3.3.3	Physical Process Control	Table D-IX Item II Table D-X Item II	Maintenance Data Same
Figure D-22 Task 3.3.4	Operational Measurement Validations	Table D-IX Item II Table D-X Item II	Maintenance Data Same

TABLE D-XII (continued)

Figures 22,23,24

Figure D-22 Task 3.3.5	Equipment Monitoring	Table D-VI, D-VII Item III (10) Table D-VI, D-VII, D-VIII Item III (1) Table D-IX Item II (1) Table D-X Item II (2) Item IV	Maintenance Data Immediate Production Schedule Emergency Response Reliability Assurance Emergency Response Reliability Assurance
Figure D-22 Task 3.3.5	Production Balancing Optimization	Table D-VI, D-VII Item I Table D-VI, D-VII, D-VIII Item I (2) Table D-IX Item II (2)	Production Optimization
Figure D-23 Task 4.1	Raw Material Requirement Control	Table D-VI, D-VII Item I (4) Item III (6) Table D-VI, D-VII, D-VIII Item III (6) Table D-IX Item III (3) Table D-X Item III (3)	Raw Material Procurement Raw Material Use Data Same Same Same
Figure D-23 Task 4.2	Inventory Balancing		
Figure D-23 Task 4.3	Incoming Raw Material Routing		
Figure D-23 Task 4.4	Material Routing		
Figure D-23 Task 4.5	Inventory Reporting		
Figure D-23 Task 4.6	Material Movement Control		
Figure D-23 Task 4.7	Raw Material Measurement Validation		
Figure D-24 Task 5.1	Order Replacement	Table D-VI, D-VII Item I (4)	Procurement

Figure D-24 Task 5.2	Process Requests		
Figure D-24 Task 5.3	Cost Control		

TABLE D-XII (continued)

Figures 25-26

Figure D-25 Task 6.1	Set Standards and Methods	Table D-VI, D-VII Item III (9) Table D-VI, D-VII, D-VIII Item III (8)	Quality Control Analysis Quality Control Analysis
Figure D-25 Task 6.2	Raw Material Evaluation		
Figure D-25 Task 6.3	Evaluation of Product		
Figure D-25 Task 6.4	Classification		
Figure D-25 Task 6.5	Q/A Measurement Validation		
Figure D-25 Task 6.6	Lab and Automatic Analysis		
Figure D-25 Task 6.7	Analyze Processing Capability		
Figure D-25 Task 7.1	Inventory Supervision	Table D-VI, D-VII Item I (4) Item III (8) Table D-VI, D-VII, D-VIII Item III (6) Table D-IX Item III (3) Table D-X Item III (3)	Product Inventory Same Same Same
Figure D-26 Task 7.2	Loss Control		
Figure D-26 Task 7.3	Inventory Reporting		
Figure D-26 Task 7.4	Product Shipping		
Figure D-26 Task 7.5	Product Routing		
Figure D-26 Task 7.6	Product Movement		
Figure D-26 Task 7.7	Inventory Measurement Validation		

TABLE D-XII (continued)

Figure 27-28

Figure D-27 Task 8.1	Cost Balancing and Budget	Table D-VI Item III (2C) Table D-VI, D-VII Item I (4) Table D-VI, D-VII Item III Table D-VI, D-VII, D-VIII Item III (4, 6-10) Table D-IX Item III Table D-X Item III	Cost Reporting Same Same Same Same Same
Figure D-27 Task 8.2	Raw Materials and Parts (Costs and Accounts Payable)		
Figure D-27 Task 8.3	Product Income (Accounts Receivable)		
Figure D-27 Task 8.4	Production Costs		
Figure D-28 Task 9.1	Shipping Scheduling	Table D-VI Item III (1B, 2B) Table D-VI, D-VII Item I Table D-VI, D-VII Item III (8) Table D-VI, D-VII, D-VIII Item III (6) Table D-IX Item III (6) Table D-X Item III (3)	Product Inventory and Availability Production Scheduling Product Inventory and Availability Same Same Same
Figure D-28 Task 9.2	Shipping Costs		
Figure D-28 Task 9.3	Shipment Configuration		
Figure D-28 Task 9.4	Invoicing		
Figure D-28 Task 9.5	Release Shipments		

Figure D-28 Task 9.6	Prepare Shipping Documents		

Annex E – PRM Correlation to MESA International Model and S95.01 Models

The description of the Scheduling and Control Hierarchy as given above has been taken directly from that described in the Purdue Reference Model for CIM. As noted earlier, there are many such descriptions in the literature, all somewhat different based on the viewpoints of the authors and the organizations they represent.

One particularly popular such description is that developed by MESA International, a consortium of vendor companies in the manufacturing control field. Their publication, "MES Functionality and MRP to MES Data Flow Possibilities,"[1] develops and describes their listing of the functions at Level 3. The MESA International listing of functions is presented below with a reference in each case to the corresponding function in the PRM.

E.1 - Resource allocation and control

These functions are handled in the PRM by Function 3.0, Production Control, and in particular Functions 3.2, Operations Control, and 3.3, Operations Planning. See Sections 6.3.2 and 6.3.3 and Table D-XI of PRM.

E.2 - Dispatching production

These functions would be handled in the PRM by "Establishing the immediate production schedule," as given in Item 5.1.2 here and by the same functions as listed under Item 5.2.1 above.

E.3 - Data collection and acquisition

The PRM in Table D-IV, Item III, Plant Coordination and Operational Data Reporting, of Annex D covers this function. Its applicability in each level of the hierarchy is presented in Tables D-VI to D-X on the PRM.

E.4 - Quality management

The PRM includes the Quality Assurance function in Section 6.6 of this standard and Item 6.0 and subsidiary functions of Table D-XI and Figure D-47 of the PRM.

E.5 - Process management

The PRM defines this function under its concept of Control Enforcement, the carrying out of production scheduling and other upper level directives by the control application functions of Levels 1 and 2 of the hierarchy (Tables D-IX and D-X of the PRM).

Reporting of pertinent data on system and equipment status would be handled by Item III.4, "Service the man/machine interface," of the above tables.

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[1] MESA International, *MES Functionality and MRP to MES Data Flow Possibilities – White Paper Number 2* (1994)

E.6 - Production planning and tracking

In the PRM this function is split between Item I, Production Scheduling, and Item III, System Coordination and Operational Data Reporting, for Levels 3 and lower of the Hierarchical Model. It is presented in Items 2.0 and 3.0 of the Data-Flow Model and particularly Sub-Item 2.1, along with 3.2 and 3.3.

E.7 - Performance analysis

It can be seen here that the PRM handles this functionality, like many others of MESA International, through a mixture of its stated functions. Here we consider Systems Coordination and Control (Item III of Table D-IV and Tables VIII to X of the PRM); Control Enforcement (Item II); and System Reliability and Availability Assurance (Item IV).

E.8 - Operations and detailed scheduling

In terms of the PRM, this function would be considered a combination of most of the tasks from MESA International functions 5.2.1, Resource Allocation and Control, and 5.2.2, Dispatching Production, and would involve those functions from the PRM listed in those locations.

E.9 - Document control

In the PRM document control as described here is a combination of Plant Coordination and Operational Data Recording plus System Reliability and Available Assurance for document data collection and report preparation. It would involve Product Scheduling and Control Enforcement for document use to assure reliable plant operation. The corresponding data flow operations would be involved as well.

E.10 - Labor management

While most personnel functions in the manufacturing plant involve human input and therefore would be considered external entities and thus external to the PRM and to this standard, those specifically mentioned in the MESA International function appear to all be automatable and thus would be encompassed in the hierarchical model function of Plant Coordination and Operational Data Reporting (Item III, Table D-IV and subsidiary listings in Tables D-VIII to D-X).

E.11 - Maintenance management

Maintenance Management is carried out in the PRM through the hierarchical category of System Reliability and Availability Assurance and by the Data Flow listing of Bubble 10.0, Maintenance Management (Bubble 3.2 in the original PRM listing).

E.12 - S95 models

The S95 Equipment Hierarchy Model gives an application implementation flavor to the hierarchy model of the PRM that is itself strictly functional in nature. The present model is particularly applicable to larger plants as is ably illustrated by Figures D-5 to D-10 of Annex D.

The PRM Figure D-4 has been modified to show a different split between the production scheduling & management information systems and the control computation and control enforcement than in the original publication. The split is now shown between level 3 and 4, based on planned changes to the Purdue model as a result of the S95 analysis.

Sub-Function 3.2 (Maintenance) in the PRM is included as a separate major function (10.0, Maintenance) in the S95 model. This is to simplify the representation of the Level 3-4 split in the discussion and associated figures.

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