



**Response to OMG Manufacturing Domain Task Force  
RFI-3: Manufacturing Execution Systems (MES)**

From

The Boeing Company

Date:

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## Abstract

- Recommends adoption of the MESA definition of MES.
- Discusses a finer-grained breakdown of the Manufacturing Domain than the one of MES and CONTROL
- Suggests a partitioning of MES in terms of business objects and their use cases.
- Lists data and formatting standards relevant to each business object.

## 1. Introduction

### 1.1 Purpose

This document has been written in response to the Manufacturing Execution Systems (MES) Request For Information (RFI) (*Manufacturing Domain Task Force RFI-3 Manufacturing Execution Systems(MES), OMG Document mfg/97-11-01 dated November 6, 1997*) issued by the Object Management Group. It discusses the Boeing perspective on MES from the viewpoint of factory computing systems; describes a set of business objects essential to MES and what factory activities (use cases) they support, and it describes existing standards that impact the data structure of those business objects.

### 1.2 Audience

The audience for this document is the Object Management Group Manufacturing Task Force.

### 1.3 Scope

The scope for this response is limited to Boeing's current experience in modeling business objects and activities that support manufacturing in our airplane factories.

## 2. Definition of Manufacturing Execution System (MES)

Manufacturing Execution Systems (MES) guide, initiate, respond to, and report on plant activities as they occur from order launch to finished goods. Functions provided by MES include:

1. resource allocation and status
2. dispatching production units
3. data collection/acquisition
4. quality management
5. maintenance management
6. performance analysis
7. operations/detail scheduling
8. document control
9. labor management
10. process management and
11. product tracking and genealogy.

MES provides mission-critical information about production activities across the enterprise and supply chain via bi-directional communications.

This definition was reused from the definition available from the Mesa MES web page (<http://www.mesa.org/html/b/b.cgi?link=overview>). Descriptions of each function were also taken from the MESA web site and are reproduced in the table below:



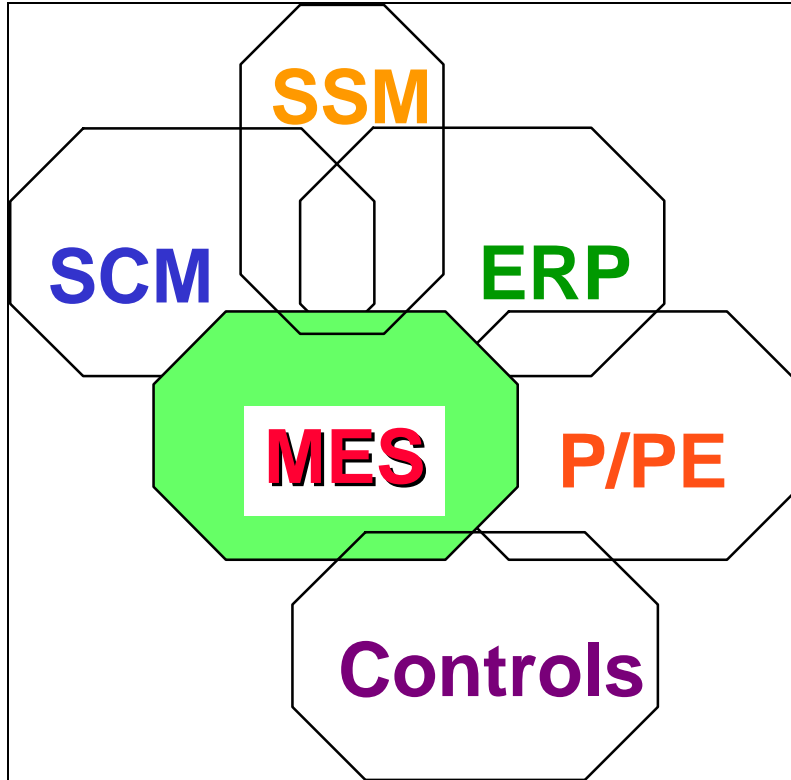
RESOURCE ALLOCATION AND STATUS	Resource allocation and status manages resources including machines, tools, labor skills, materials, other equipment, and other entities such as documents that must be available in order for work to start at the operation. It provides detailed history of resources and insures that equipment is properly set up for processing and provides status real time. The management of these resources includes reservation and dispatching to meet operation scheduling objectives.
DISPATCHING PRODUCTION UNITS	Dispatch of production units manages flow of production units in the form of jobs, orders, batches, lots, and work orders. Dispatch information is presented in the sequence in which the work needs to be done and changes in real time as events occur on the factory floor. It has the ability to alter the prescribed schedule on the factory floor. Rework and salvage processes are available, as well as the ability to control the amount of work in process at any point with buffer management.
DATA COLLECTION / ACQUISITION	Data collection and acquisition provides for an interface link to obtain the inter-operational production and parametric data that populate the forms and records that were attached to the production unit. The data may be collected from the factory floor either manually or automatically from equipment in an up-to-the-minute time frame.
QUALITY MANAGEMENT	Quality management provides real time analysis of measurements collected from manufacturing to assure proper product quality control and to identify problems requiring attention. It may recommend action to correct the problem, including correlating the symptom, actions and results to determine the cause. May include SPC/SQC tracking and management of off-line inspection operations, and analysis from a laboratory information management system (LIMS) could also be included.
MAINTENANCE MANAGEMENT	Maintenance management tracks and directs the activities to maintain the equipment and tools to insure their availability for manufacturing and insure scheduling for periodic or preventive maintenance. Also provides the response (Exceptions) to immediate problems. It maintains a history of past events or problems to aid in diagnosing problems.
PERFORMANCE ANALYSIS	Performance analysis provides up-to-the-minute reporting of actual manufacturing operations results along with the comparison to past history and expected business results. Performance results include such measurements as resource utilization, resource availability, product unit cycle time, conformance to schedule and performance to standards. It may include SPC/SQC. Performance Analysis draws on information gathered from different functions that measure operating parameters. These results may be prepared as a periodic report or presented on-line as current evaluation of performance.
OPERATIONS/DETAIL SCHEDULING	Operations and detail scheduling provides sequencing based on priorities, attributes, characteristics, and/or recipes associated with specific production units at an operation such as shape, color sequencing, or other characteristics that, 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 adjusted to shift patterns.
DOCUMENT CONTROL	Document control provide for the control of records/forms that must be maintained with the production unit, including 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 might also include the control and integrity of environmental, health and safety regulations, and ISO information such as Corrective Action procedures. Storage of historical data is provided.
LABOR MANAGEMENT	Labor management provides status of personnel in an up-to-the-minute time frame. Includes time and attendance reporting, certification tracking, as well as the ability to track indirect activities 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.
PROCESS MANAGEMENT	Process management monitors production and either automatically corrects or provides decision support to operators for correcting and improving in-process activities. These activities may be inter-operational and focus specifically on machines or equipment being monitored and controlled, as well as intra-operational, which is tracking the process from one operation to the next. It may include Exception management to make sure factory personnel are aware of process changes that are outside acceptable tolerances. It provides interfaces between intelligent equipment and MES, possibly through Data Collection/Acquisition.
PRODUCT TRACKING AND GENEALOGY	Product tracking and genealogy provides the visibility to where work is at all times and its disposition. Status information may include who is working on it; components, materials by supplier, lot, serial number, current production conditions, and any Exceptions, rework, or other exceptions related to the product. The on-line tracking function creates a historical record, as well. This record allows traceability of components and usage of each end product.

### 3. Reference Model for MES

#### 3.1 High Level MES Context within Manufacturing



This diagram is the same as was contained in the RFI. Also, the high level scope for each information system area of manufacturing is the identical to the RFI.

#### SALES & SERVICE MANAGEMENT(SSM)

Sales and Service Management (SSM) comprises software for sales force automation, product configurations, order management, service quoting, product returns, and post-sales service.

#### SUPPLY CHAIN MANAGEMENT(SCM)

Supply Chain Management (SCM) includes functions such as forecasting, distribution and logistics, transportation management, electronic commerce, and advanced planning systems.

#### PRODUCT AND PROCESS ENGINEERING(P/PE)

Product and Process Engineering (P&PE) includes computer aided design and manufacturing (CAD/CAM), process modeling, and product data management (PDM). PDM supports information sharing in a distributed environment that can cross company boundaries. The industrial enterprise has a special dependency on its product model information (product data). This product data includes definition of the products that will be manufactured. CAD systems are involved



in designing a product or a facility to build a product. At this time CAD systems utilize drawings and specification documents to maintain the design information.

## CONTROLS

Controls are usually hybrid hardware/software systems such as distributed control systems (DCS), programmable logic controllers (PLC), distributed numerical control (DNC), supervisory control and data acquisition (SCADA) systems, and other controls designed to automate the way in which the product is being manufactured.

## ENTERPRISE RESOURCE PLANNING(ERP)

Enterprise Resources Planning (ERP) consists of those systems that provide financial, order management, production and materials planning, and related functions. The modern ERP systems focus on global planning, business processes and execution across the whole enterprise (intra-enterprise systems), with an accrued recent importance of aspects like supply chain planning and the whole supply chain management aspects and extending to include the whole inter-enterprise supply chain.

### **3.2 More Detailed MES Context within Manufacturing**

#### 3.2.1 Boeing Factory Perspective

To improve integration across functional organizations and geographically-dispersed factory sites and to better support adoption of common standards and practices for all its manufacturing divisions regardless of heritage corporate identity, Boeing has partitioned its factory computing architecture into areas of similar technology and activity interest as nine domains:

1. **Manufacturing Process Improvement** - managing and improving the *Produce* process for each airplane model.
2. **Machine and Adaptive Control** - directing and controlling a machine tool and providing immediate feedback to an ongoing manufacturing process control system to improve its efficiency and effectiveness in real time.
3. **Work Area Control** - providing those processes and capabilities that directly support or control groups of equipment or support an operator in performing manufacturing tasks. Support includes assigning or prioritizing fabrication or assembly work, providing resources to perform tasks, and communication of work status and requests.
4. **Equipment Maintenance** - providing usable equipment and tools.
5. **Numerical Control Programming** - creating and managing NC programs and associated data.
6. **Data Collection** - providing for the extraction or receipt of data from input devices or data generating applications and the transport of that data, in electronic form, to an application for immediate analysis and use or to a data store for future extraction and use.
7. **Measurement** - creating the means for taking measurement of product, process, and equipment and for assessing key quality indicators of either.
8. **Manufacturing Data Management** - managing and distributing the configuration-controlled data to the factory, managing the configuration of data active in the factory during work execution, and uploading of factory-generated data to enterprise systems.





9. **Computing Services** - providing the computing hardware and software services needed to support manufacturing computing applications. This includes hardware such as servers, networks, workstations, and desktop PCs, and software services such as database management, operating systems, messaging and web browsers.

The domains listed as 1-5 above cover the business activities needed to manufacture parts, to assemble parts into an airplane, and to maintain the equipment and tools needed for manufacture and assembly. The domains listed as 6-9 cover supporting activities whose effect is to make the business of manufacturing and assembly more efficient and effective. The intent of viewing domains 6-9 as *utilities* is to treat them as providing standard services to the others. The activities or *services* covered by each factory domain are shown in the table below along with the MES functionality (from the list in the definition above in section 3) covered by that domain. It should be noted that not all MES functionality is covered by the domains listed and that the some of Boeing factory domains provide functionality that is outside the scope of MES.

<b>Primary Business Domain / Utility Domain</b>	<b>Activities / Services</b>	<b>MES Functionality Covered</b>
1. <b>Manufacturing Process Improvement</b>	Manufacturing Process Planning and Management, Statistical Process Control	<ul style="list-style-type: none"> <li>• Quality management</li> <li>• Performance analysis</li> <li>• Labor management</li> </ul>
2. <b>Machine and Adaptive Control</b>	Command Interpretation, Operator Display, Alarming, Status Reporting, Data capture, and feedback	
3. <b>Work Area Control</b>	Transition Management, Order management, Work Area Status Reporting, Work Area Scheduling, Resource Management, History Tracking, Alarm Handling	<ul style="list-style-type: none"> <li>• Resource allocation and status</li> <li>• Dispatch of production units</li> <li>• Performance analysis</li> <li>• Operations and detail scheduling</li> <li>• Labor management</li> <li>• Process management</li> <li>• Product tracking and genealogy</li> </ul>
4. <b>Equipment Maintenance</b>	Calibration, Equipment Condition Management, Maintenance Planning, Maintenance Scheduling, Maintenance Skill Management, Measurement Analysis	<ul style="list-style-type: none"> <li>• Maintenance management</li> <li>• Operations and detail scheduling</li> <li>• Labor management</li> </ul>
5. <b>Numerical Control (NC) Programming</b>	NC Program Development, NC Program Verification, Machine Control Data (MCD) Configuration Management, MCD Post Processing, MCD Storage, Operator Document Management	<ul style="list-style-type: none"> <li>• Document Control</li> </ul>
6. <b>Data Collection</b>	<i>Data Capture, Data Transfer</i>	<ul style="list-style-type: none"> <li>• <i>Data collection and acquisition</i></li> <li>• <i>Performance analysis</i></li> <li>• <i>Process management</i></li> <li>• <i>Product tracking and genealogy</i></li> </ul>
7. <b>Measurement</b>	<i>Planning and Process Development for Parts and Assembly Measurement, Equipment Accuracy, Real time Probing, Machine Capability Management, Overall Equipment Effectiveness</i>	<ul style="list-style-type: none"> <li>• <i>Quality management</i></li> <li>• <i>Process management</i></li> <li>• <i>Product tracking and genealogy</i></li> </ul>

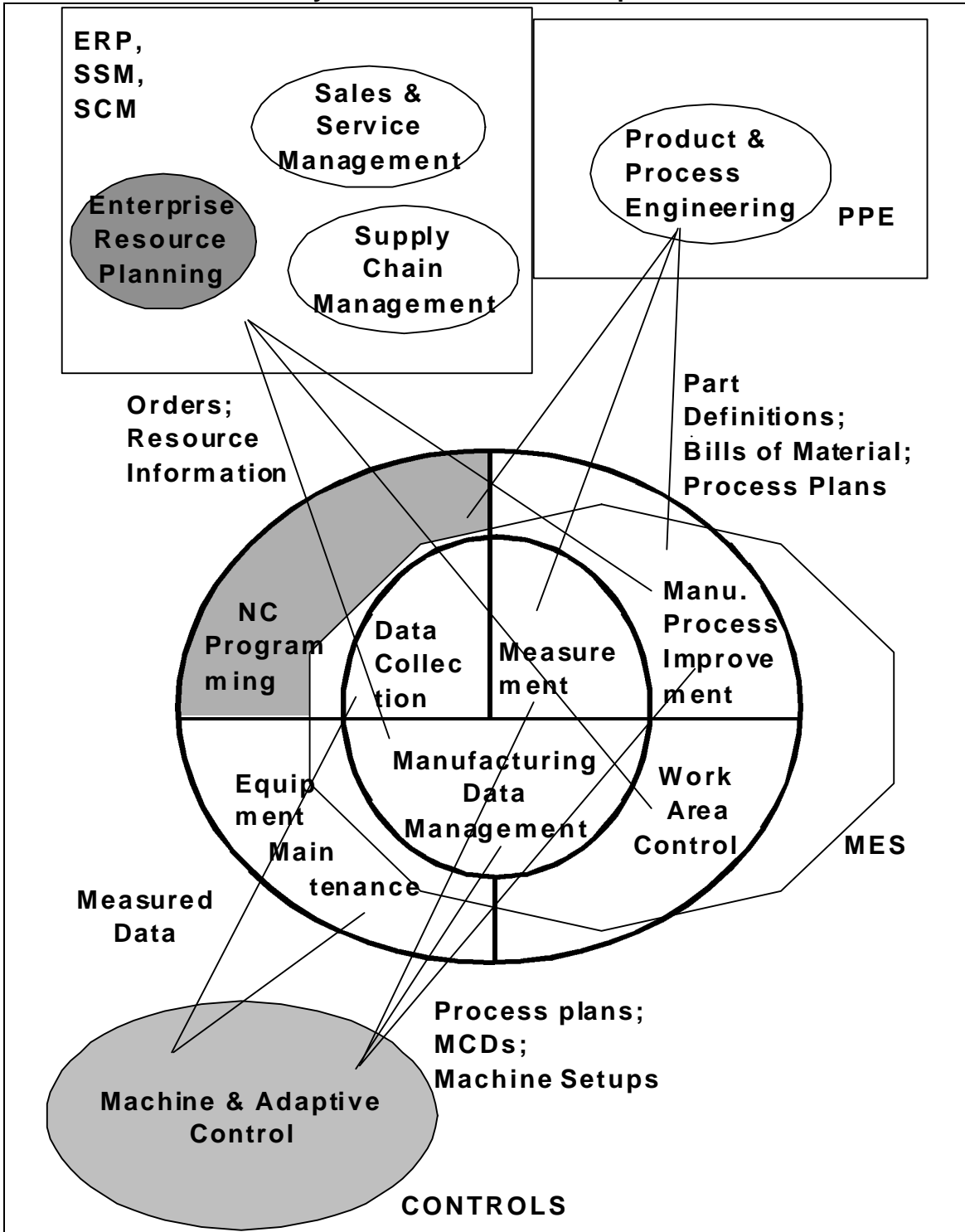


	<i>Measurement, Process Quality Measurement</i>	
8. <b>Manufacturing Data Management</b>	<i>Data Access and Distribution, Data Configuration Management, Data Storage</i>	<ul style="list-style-type: none"> <li>· <i>Document control</i></li> <li>· <i>Product tracking and genealogy</i></li> </ul>
9. <b>Computing Services</b>	<i>User Interface, Operating System, Security, Graphics, Data Interchange, Distributed Computing, System Management, Web Capabilities, Data Management, Transaction, Software Engineering,, Multimedia, Workgroup Collaboration, Network</i>	

In the figure below, the domains are shown in the same context of MES, with the utility/service domains comprising the inner oval of MES. Note that the *Computing Services* domain does not appear as it does not directly contribute functionality of MES but provides the substrate upon which MES systems are built. This view of *Computing Services* is consistent with the CORBA layered architecture. Most aspects of *Numerical Control Programming* provide functionality that is more properly viewed as responsibilities of Product & Process Engineering (PPE). It should also be noted that in the Boeing domain views, functionality of measurement and data collection is a MES responsibility rather than a Machine Control responsibility as is depicted in the current OMG MTF Machine Control draft white paper. That is, Boeing is viewing its *Machine and Adaptive Controls* domain as CONTROLS. Boeing takes this perspective on *Data Collection* and *Measurement* because this functionality serves both Boeing manufacturing needs and requirements imposed by the Federal Aviation Agency for product accountability.

As provided on the diagrams from the 1997 OOPSLA Midyear Workshop on Manufacturing Information Systems (see Appendix A), the figure below also shows general types of objects that would flow across the interfaces among ERP, SSM, SCM, PPE, MES, and CONTROLS. **Orders and resource information** flow between MES and the enterprise systems for ERP, SSM, and SCM. Most of this information flows between these enterprise systems and the domains of *Manufacturing Process Improvement, Manufacturing Data Management, and Work Area Control*. **Part definitions, bills of material, and process plans** flow between PPE and MES, with most of the flow occurring between PPE and *Manufacturing Process Improvement, Numerical Control Programming, and Measurement* domains. **Process plans, Machine Control Data (MCD), and machine setups** flow between MES and CONTROLS, with most of the flow occurring between CONTROLS and *Manufacturing Process Improvement, Measurement, and Manufacturing Data Management*. **Measured data** flows among CONTROLS and the domains of *Data Collection and Equipment Maintenance*. Note that the general types of objects flowing across interfaces among the various factory domains are not shown on the figure. Note also that all flows are assumed to be two way interfaces.

**Factory Domains to OMG macro partitions:**





### **3.3 An Industry Perspective**

There are several ways to partition domains for MES from an industry perspective:

- by major functional area
- by technology
- by major process.

Of these three, the last, major process, is most practical. The NIST SIMA model (NISTIR 5939 of December 1996) provides an excellent start with its definition of a

**Produce Products** process as four sub-processes:

1. Develop Production Plan
2. Define Production Jobs
3. Schedule Jobs
4. Control Production.

These could be treated as domains of *Production Planning*, *Production Job Definition*, *Job Scheduling*, and *Production Control*. Other domains would need to be defined that reflected the processes needed to provide MES functionality missing from the NIST SIMA model. Per the definitions listed in Section 2, functionality sparsely covered is:

1. data collection,
2. quality management,
3. maintenance management, and
4. document control, and product tracking and genealogy.

## 4. Overview of MES Partitions

Based on a series of activities that evolved groupings of classes based on industry, Boeing enterprise, and Boeing organization specific models for manufacturing, and then balanced these groupings against Boeing-specific use case models, we suggest the following groupings of classes as partitions for MES (also see diagram at end of this section):

- 1      **Control Program Business Object**  
Control Programs are scripts governing the action of Equipment as it performs its function. Control Programs, such as NC Programs and Recipes, are loaded onto controllers and used to drive NC and process equipment. The *Control Program Business Object* allows users to access the CAD/CAM systems, simulation applications, and control program data management systems, providing for the creation, verification, access and configuration management of control programs and associated models and documents.
- 2      **Document Business Object**  
The *Document Business Object* provides access and version control services for all manner of documents.
- 3      **Exception Business Object**  
An Exception is a deviation from an expected result or an unplanned event. The *Exception Business Object* allows users to define Exception Types and associated Recovery Plans; configure exception reporting and handling options; identify, report and handle exceptions; notify interested parties; and track exception events and responses.
- 4      **Job Business Object**  
A Job is the binding of all necessary Resources in the execution of one or more Operations, specified in a Plan, typically associated with an Order, for the purpose of processing and satisfying (fulfilling) part or all of the Order. The *Job Business Object* provides for the creation, removal, updating and tracking of Jobs, their states, status and run times; and requests for, scheduling and coordination of, resource and document allocations for a Job.
- 5      **Measurement Business Object**  
The *Measurement Business Object* allows users to create, store, analyze and compare actual and nominal measurement and tolerance data of parts, resources, and process.
- 6      **Order Business Object**  
Orders are used to authorize the execution of action per a Plan. The *Order Business Object* is responsible for interfacing to enterprise resource planning systems to allow push or pull of released Orders, and for look-ahead previews of pending upstream orders; Order life cycle management (from the Work Area's point of view, not the enterprise); tracking and profiling Orders; changing and reporting Order status (hold, release, scrap, cancel, complete); and batching and splitting Orders.
- 7      **Plan Business Object**  
Manufacturing environments use a variety of Plans to describe and guide the manufacturing related activities. The *Plan Business Object*

provides Plan life cycle management—creation, tracking and removal of Plans and constituent Planned Operations and Resource Requirements.

8 **Product Business Object**

The *Product Business Object* provides services for the tracking of the constituent pieces of products, their configuration and histories, access to their designs and features, the Plans that describe their manufacture, and any associated Orders.

8.1 **Part Business Object**

The *Part Business Object* provides services for the tracking of products and their constituent pieces of products, their configuration and histories, access to their designs and features, the Plans that describe their manufacture, and any associated Orders.

9 **Request Business Object**

Work Requests are written, verbal, electronic, or other forms of conveyance, for the purpose of requesting information or assistance from a service provider in support of the execution of a manufacturing related Job (e.g., requests for inspection, material movement, planning, tooling, supplies, numerical control programming changes, etc.). The *Request Business Object* provides Work Request life cycle management: request initiation, creation, validation, scheduling, assignment and verifying completion—and for tracking Work Requests and their status.

10 **Resource Business Object**

A Resource is an element required by the business to transform Raw Material and Parts into finished goods and to provide services for sales. Resources include Workers, Equipment, Supplies, Tools and Containers. The *Resource Business Object* provides for the creation and removal of Resources, their description, type, owner, location, and quantity; tracking of Resources and their histories; reservation and allocation of Resources; and profiling of Resources.

10.1 **Equipment Business Object**

A mechanical resource that performs a function is classified as **Equipment**. The *Equipment Business Object* is part of the Resource Business Object, and is used to represent the various Equipment Types (such as machining and processing devices and their controllers), their histories, operating conditions, configuration and status. Found within this business object are abstractions for Equipment, Equipment Function, Equipment Manager, Equipment History, Equipment Interface.

10.2 **Raw Material Business Object**

The *Raw Material Business Object* is part of the Resource Business Object, and is used to track Raw Material consumed in product manufacture.

10.3 **Supplies Business Object**

The *Supplies Business Object* is part of the Resource Business Object, and is used to track supplies consumed in process execution.

10.4 **Tool Business Object**



The *Tool Business Object* concerns itself with the management of Tools—devices that passively support the performing of manufacture operations.

10.5 **Worker Business Object**

The *Worker Business Object* is part of the Resource Business Object, and is used to track Workers, their skills, certifications, assignments, shifts and attendance.

10.5.1 **Worker Role Business Object**

The *Worker Role Business Object* is part of the Worker Business Object, and is used to track the responsibilities and characterization of each interacting role.

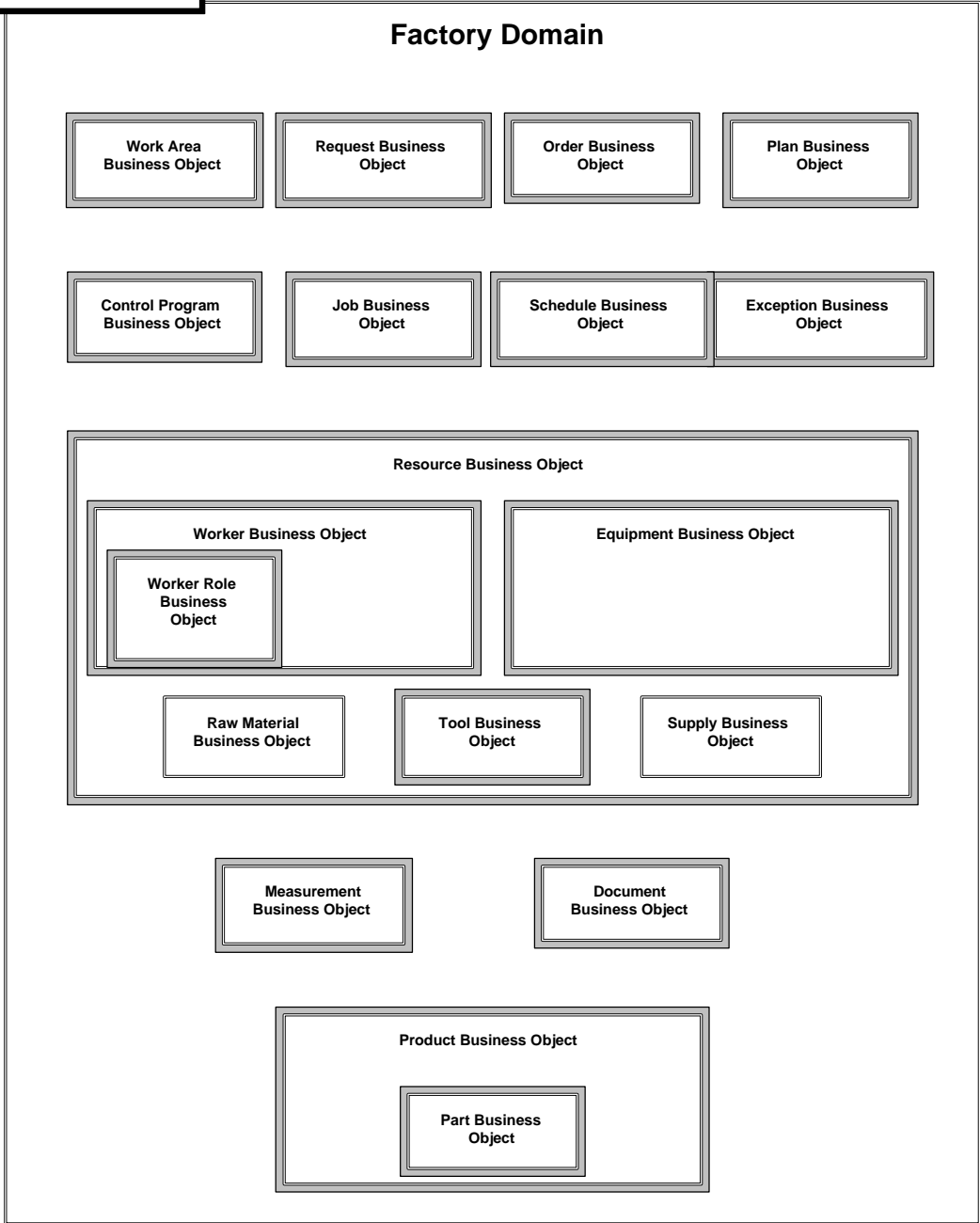
11 **Schedule Business Object**

The *Schedule Business Object* provides event scheduling and schedule simulation services. Schedule Business Object is used to schedule tasks and resources to optimize the use of production time and servicing of resources.

12 **Work Area Business Object**

Factory floor real estate can be organized by Work Area—essentially, a logical or physical grouping of Resources. The *Work Area Business Object* provides for creating and defining the configuration of a Work Area; assigning Resources and Process Capabilities to a Work Area; knowing the Work Area's capacities; queuing, tracking and dispatching Jobs pending execution in that Work Area; determining the Work Area's queuing strategy; and for profiling Work Area status and activity.

CD:Factory Domain Business Objects  
Fri Mar 06 14:30:57 1998  
Class Diagram





## 5. MES Partition Detail

For each business object listed in Section 4, the following subsections provide a class diagram and brief descriptions of the functional role of the classes shown on the diagram. The diagrams were prepared using the UML support of the Paradigm Plus modeling tool suite. Symbolology for these diagrams is briefly explained in Appendix B.

### 5.1 Control Program Business Object

Within this business object, **Control Program Manager** is responsible for actions involving sets of **Control Program** and the life cycle of Control Program. Control Program has two subtypes: **Recipe**, which contains operational steps for a machine and processing parameters such as oven temperatures, and **NC program**, which contains a set of instructions for a numerically controlled machine.

An instance of **NC Program** is produced according to an **NC Model**, which is an aggregation of instances of a **Part Model** (a representation of the Part Design), a **Tool Model** (a representation of the Fixtures and end effector required for manufacture or measurement), and a **Tool Path** (a representation of path end effector takes in material removal or in measurement). The NC Program may be represented as Automatic Program Tool (APT), Dimensional Measuring Interface Standard (DMIS), Standard for the Exchange of Product (STEP) model data, or CAM-dependent source.

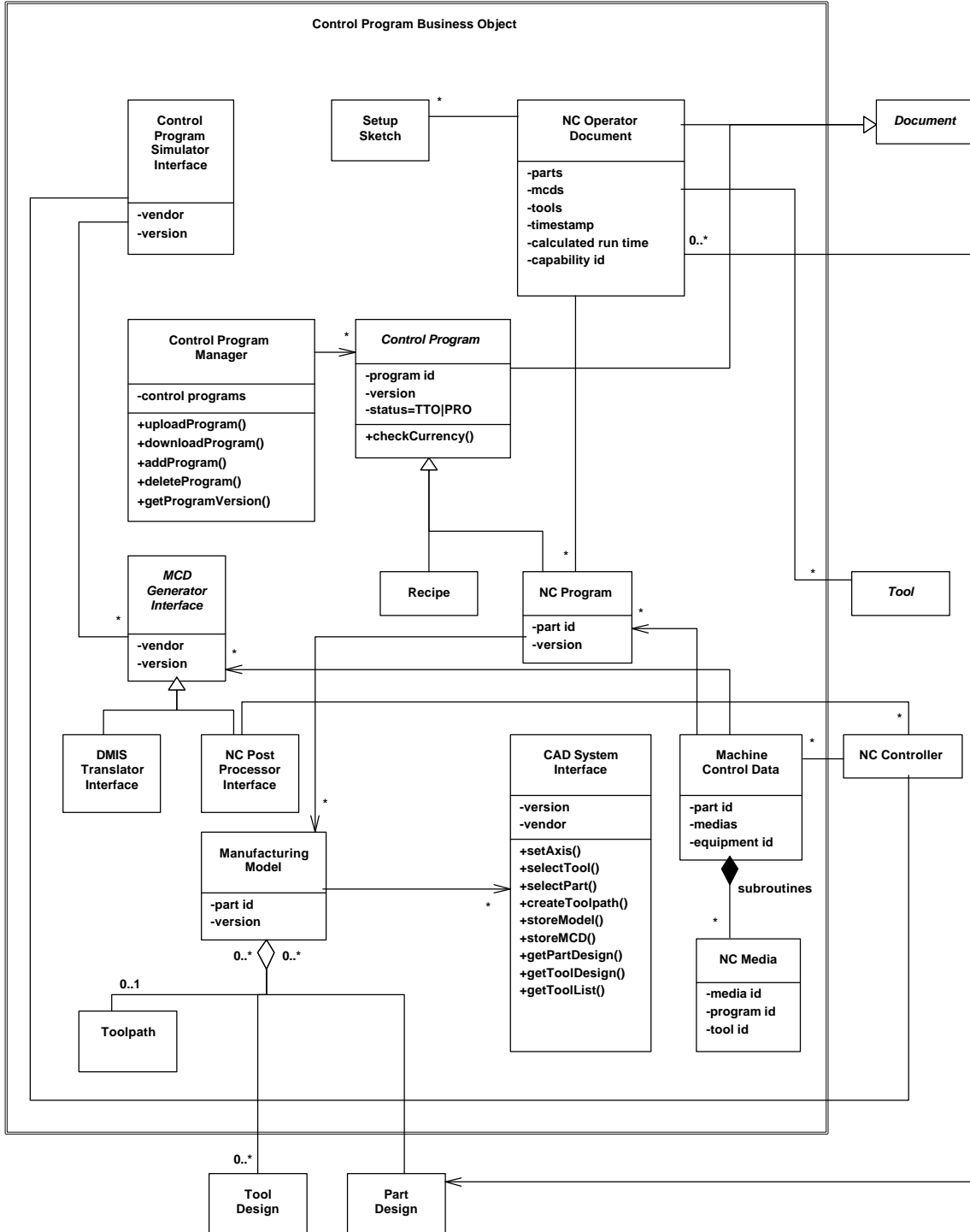
The **NC Operator Document** is a type of Document that with **Setup Sketch** defines the usage of the NC Program with respect to a specific instance of Part Design.

A (Machine Control Data) **MCD Generator Interface** provides access to a software application that uses an NC Program to generate machine executable program code from geometry data. An MCD can also contain automated machine settings as well as inspection data for parts. This program code can be either machine-neutral or machine-specific. An NC Post Processor is a type of MCD Generator which outputs a machine-dependent MCD. **Machine Control Data** is provided access to an instance of Post Processor by an **MCD Generator Interface** that today is usually an **NC Post Processor Interface** or **DMIS Translator Interface**. An NC Post Processor Interface will produce an MCD in a format which is executable by machining NC's, and a DMIS Generator Interface will produce an MCD in a format which is executable by an inspection/measurement machine. A complete MCD can be composed of multiple NC Media (a partition of the total activity created to permit setup change requiring operator intervention or support delivery of a large file to non-networked Equipment).

**CAD System Interface** provides services to Control Program instances to make the individual constituents of an NC model instance available. **Control Program Simulator Interface** provides an interface to a standalone software application, or part of a CAD/CAM System, which (virtually) verifies an NC Program (in the form of an MCD). The simulator executes each machine instruction just as the actual machine would, manipulating the machine, part, and tool geometry to determine if the MCD will in fact manufacture the desired work in progress, part, or assembly or perform the required inspection without damaging itself, the tooling, or the part. It can identify collisions,

invalid toolpaths, and other anomalies. Some simulators can automatically make Control Program corrections.

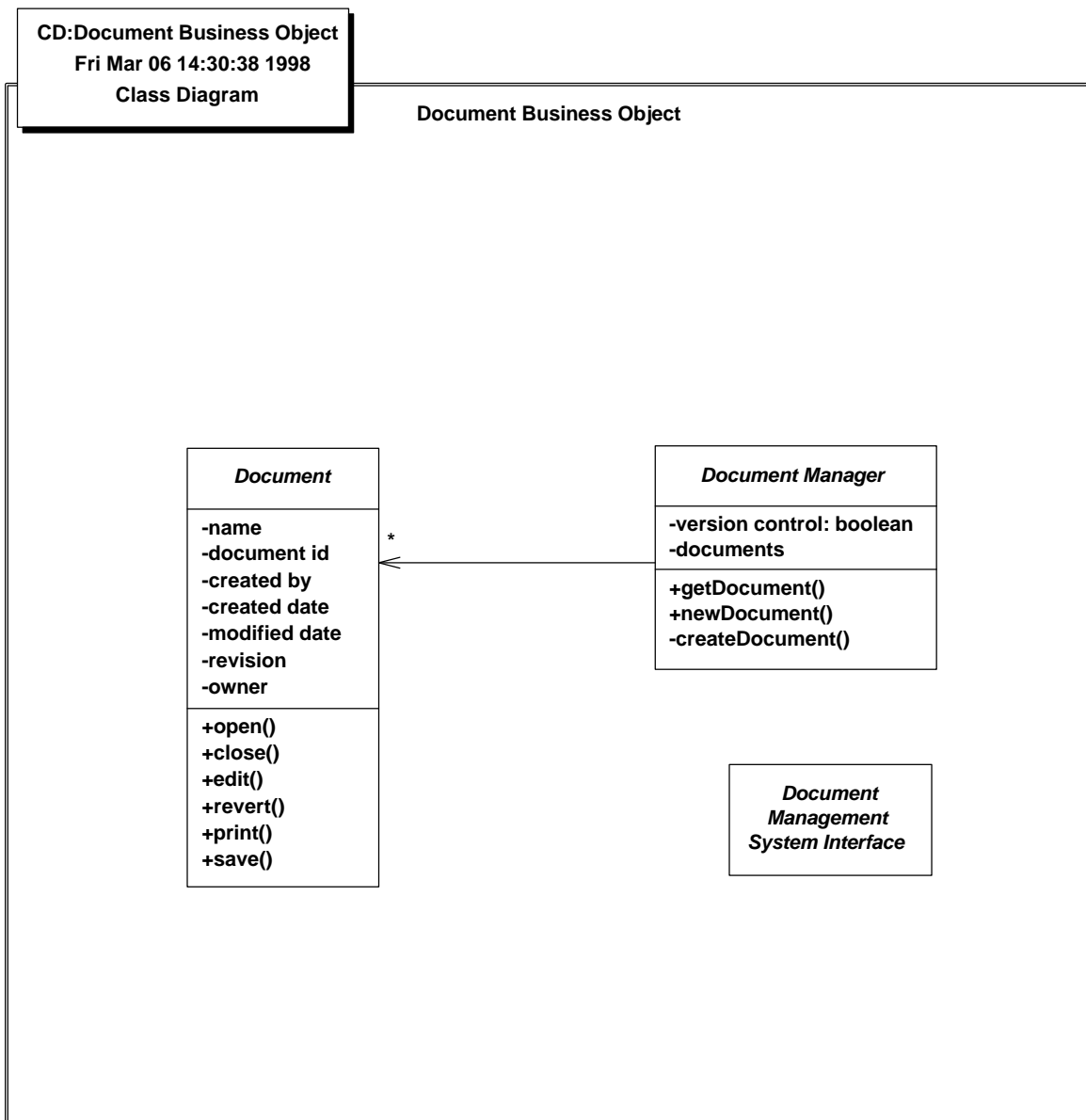
CD:Control Program Business Object  
 Fri Mar 06 14:30:33 1998  
 Class Diagram



## 5.2 Document Business Object

*Document Business Object* should be common across many domains. The functionality shown here is that needed by MES.

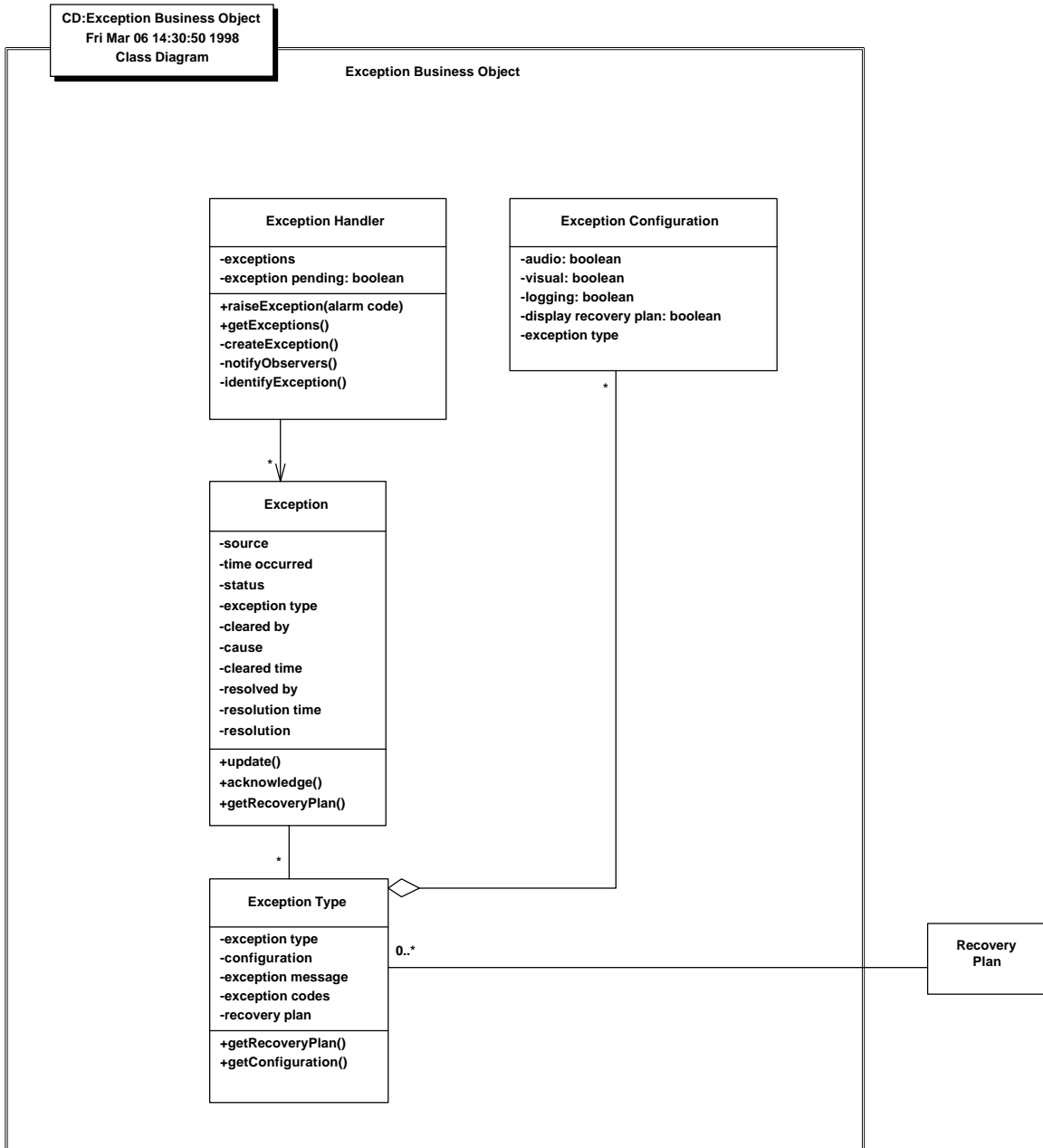
Within the Document Business Object, **Document Manager** is responsible for actions involving sets of **Document** instances and for the life cycle of a single document. Document provides common services including open / close / edit / save as well as revert (to previous content) and print initiation. **Document Management System interface** provides access to functionality that can create, control, and manipulate the type(s) of documents with which it is intimately familiar (e.g., MS Word knows about Word documents, and Direct Numerical Control (DNC) and Manufacturing Data Management systems know about Machine Control Data files).





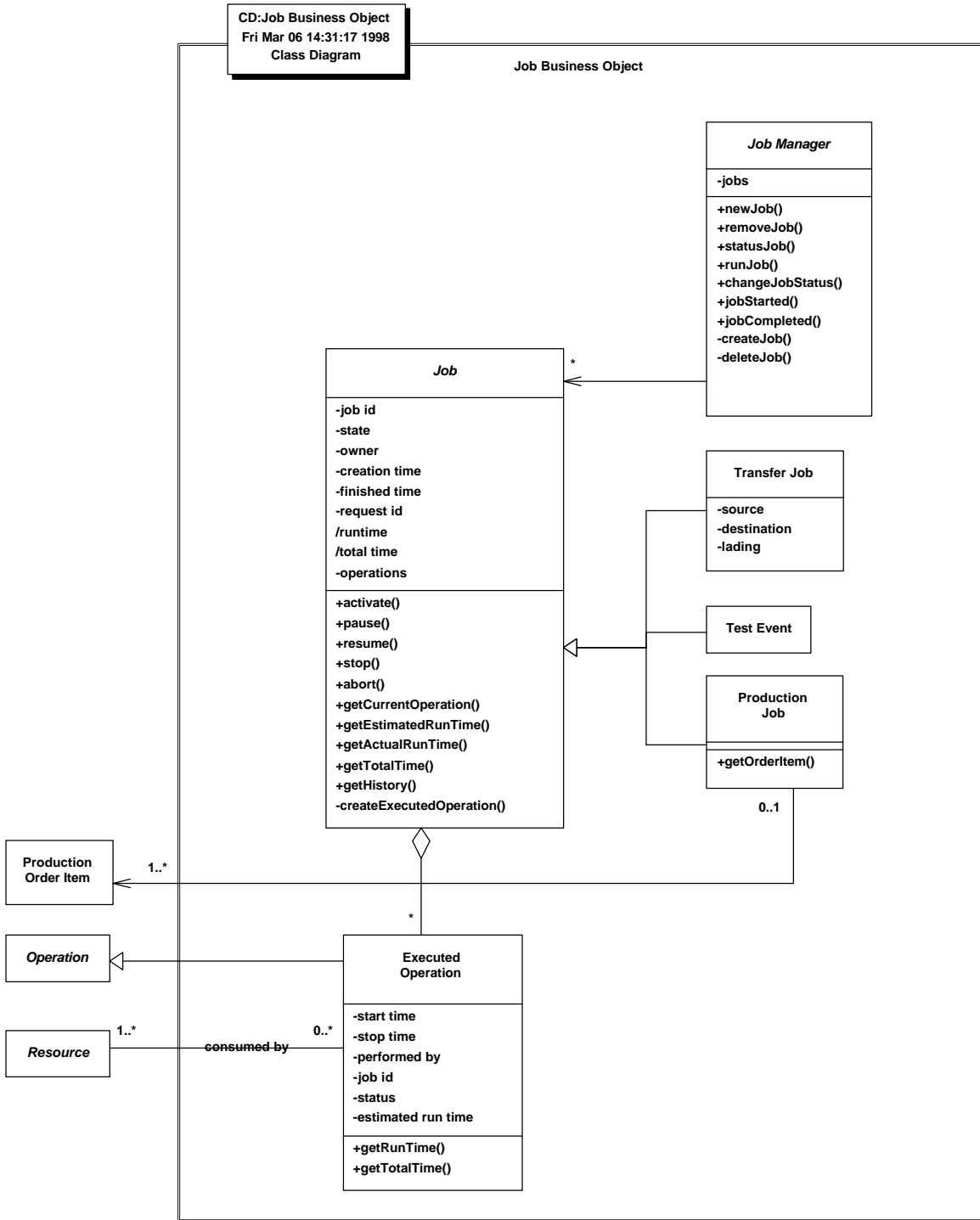
### **5.3 Exception Business Object**

The Exception Business Object provides services for the reporting, tracking and handling of **Exceptions**—abnormal conditions detected in equipment operation or in the manufacturing process. Exceptions keep track of their source, when they occurred, and how and when they were handled and resolved. Related Exceptions can be grouped together, by **Exception Type**, to allow similar handling, according to some **Exception Configuration**—error messages, audio and/or visual alarms, logging procedures and Recovery Plans. Entities which detect an abnormal condition can tell an **Exception Handler** to "raise an exception", thereby creating the Exception. Interested parties register with the Exception Handler for a particular type(s) of Exception. When an Exception of that type is raised, the Exception Handler notifies all interested parties, who can then acknowledge and respond to the alarm.



## 5.4 Job Business Object

Within this business object, **Job Manager** is responsible for action involving sets of **Job** and life cycle management of Job instances. Job types include **Transfer Job** (to effect work piece movement from point to point), **Test Event** (to effect monitoring and analysis activity), and **Production Job**. Job consists of **Executed Operation** that manages the actual performance statistics and totals. Executed Operations utilize Resources per Operation to perform the intended action. The attributes of Executed Operation collect the data necessary for manufacturing process improvement and for compliance with governmental regulations such as the US Federal Aviation Authority imposes.



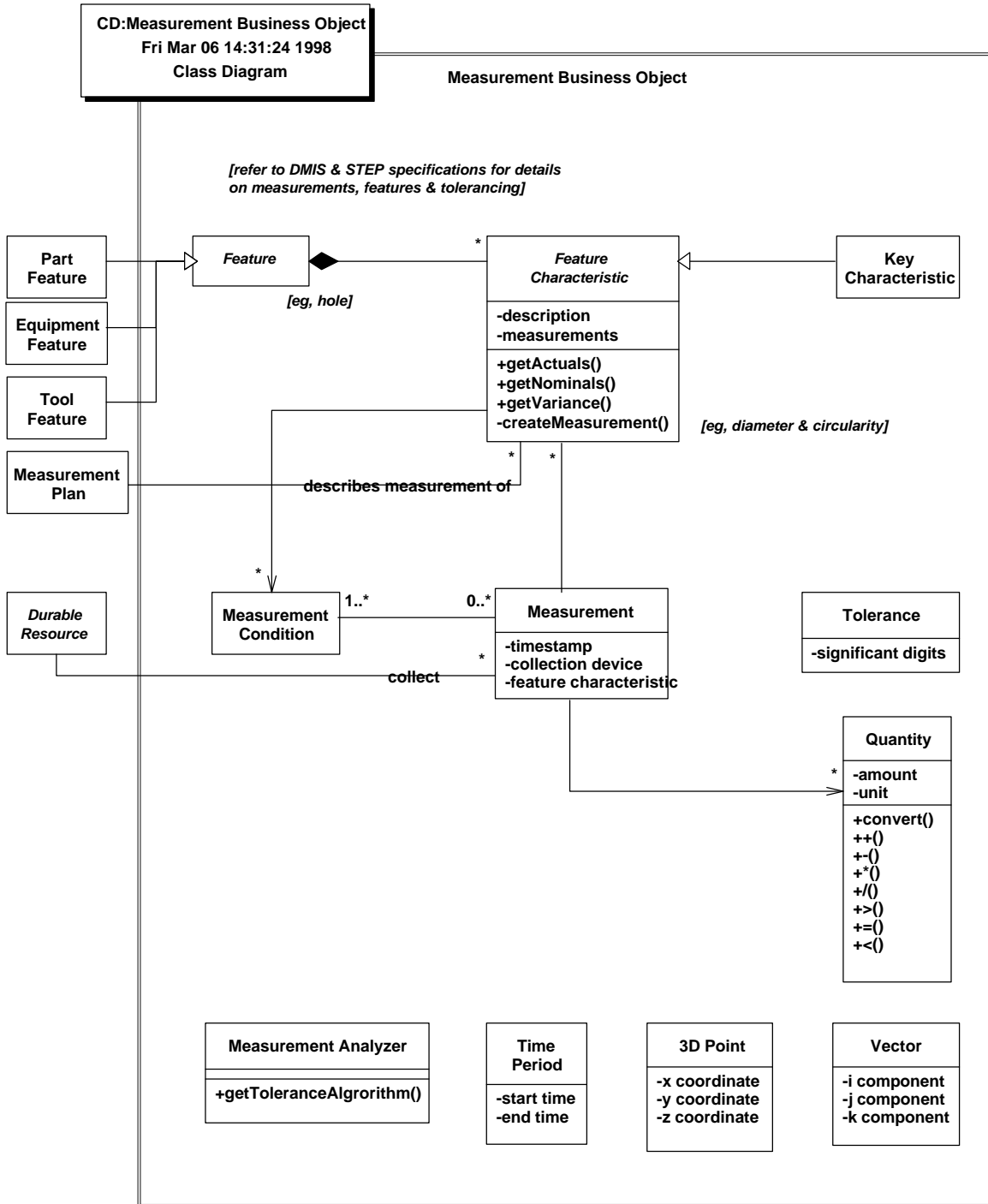


## 5.5 Measurement Business Object

As Document Business Object does, **Measurement Business Object** represents an abstraction used across many domains. A **Measurement** is taken when a certain **Measurement Condition** occurs such as at pre-determined hour, or after a certain amount of use, or after a process step is complete. A *Measurement* instance records a **Quantity** and the units of that quantity. Convenience classes for *Measurement* relevant to MES include **Tolerance**, which contains the significant digits in a quantity measured, **Time Period**, which records start and stop, **3D Point**, which contains the individual values of a three-dimensional location, and **Vector**, which contains the values of a trajectory in three-dimensional space.

**Measurement Analyzer** provides algorithm services (for uniform comparisons of designs or nominal values to actual values, various statistical, various forecast algorithms) for evaluation of sets of measurements.

*Measurement* instances are used to evaluate a **Feature Characteristic**, that is an aspect about a Feature (e.g., radius and depth Characteristics of a Hole Feature, temperature and viscosity Characteristics of equipment engine oil Feature). **Key Characteristics** are types of *Feature Characteristics* that used as decision points in processing or maintenance. **Feature** instances may describe **Part**, **Equipment**, or **Tool Features**.



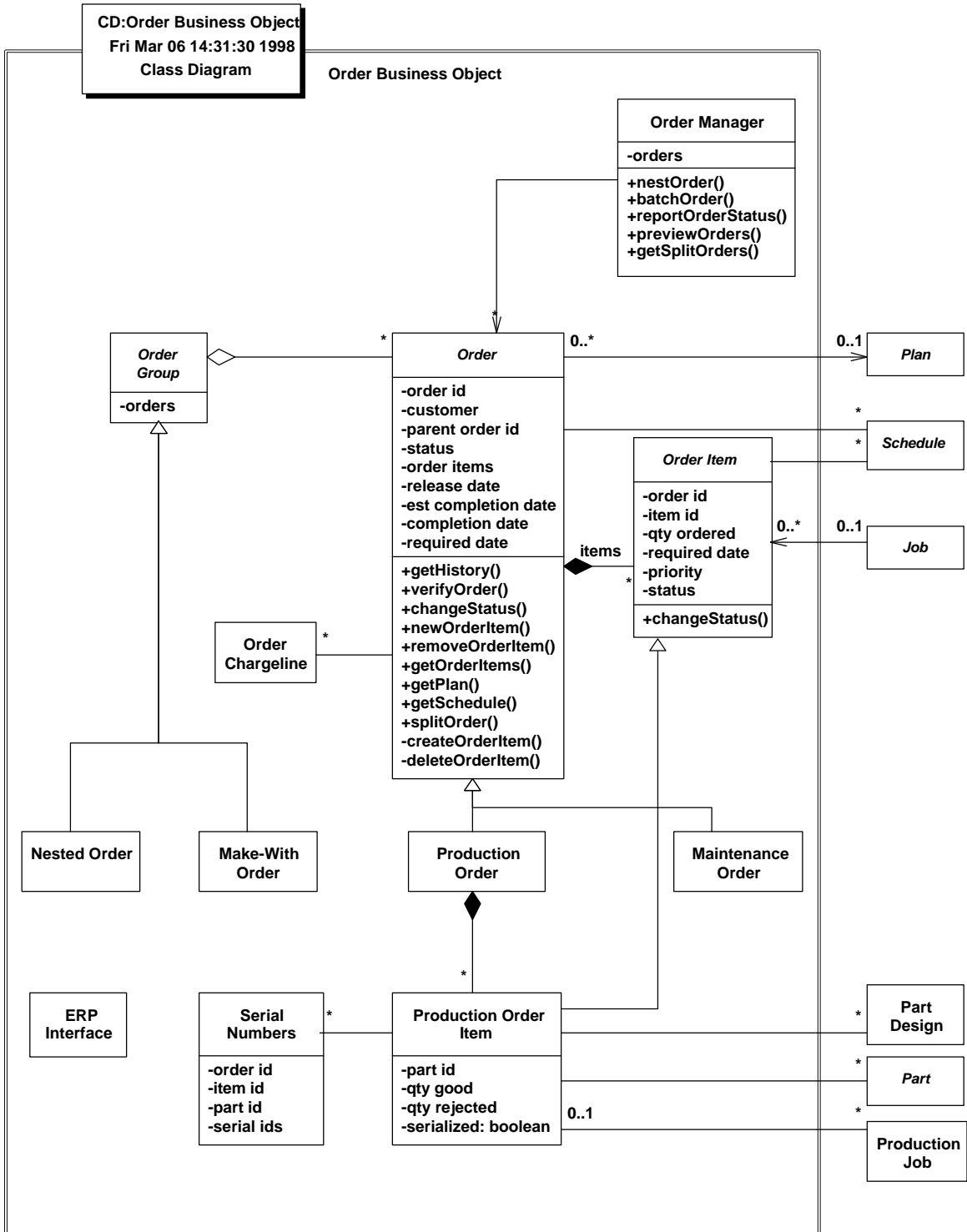




## **5.6 Order Business Object**

Within this business object, **Order Manager** is responsible for action involving sets of **Order** and managing **Order Groups**. Order Groups are formed when a common manufacturing treatment is to be applied to multiple orders. **Nested Orders**, which are grouped for maximizing usage of a raw material, and **Make-With Orders**, which are grouped for maximizing equipment utilization, are subtypes of *Order Groups*. *Make-With-Orders* are to be completed within the same time period. An *Order* instance is associated with an **Order Chargeline** instance for accounting purposes and with an overall **Schedule** instance. An Order is an aggregation of **Order Items**, which in turn, are associated with particular **Job** instances. Order types depicted are **Production Order** and **Maintenance Order**. A *Production Order* instance aggregates **Production Order Item** instances, that are associated with the particular **Part Design**, actual **Part** produced, and **Production Job** used and perhaps, to **Serial Numbers** applied to produced parts.

**ERP Interface** provides an interface to the Enterprise Resource Planning systems.



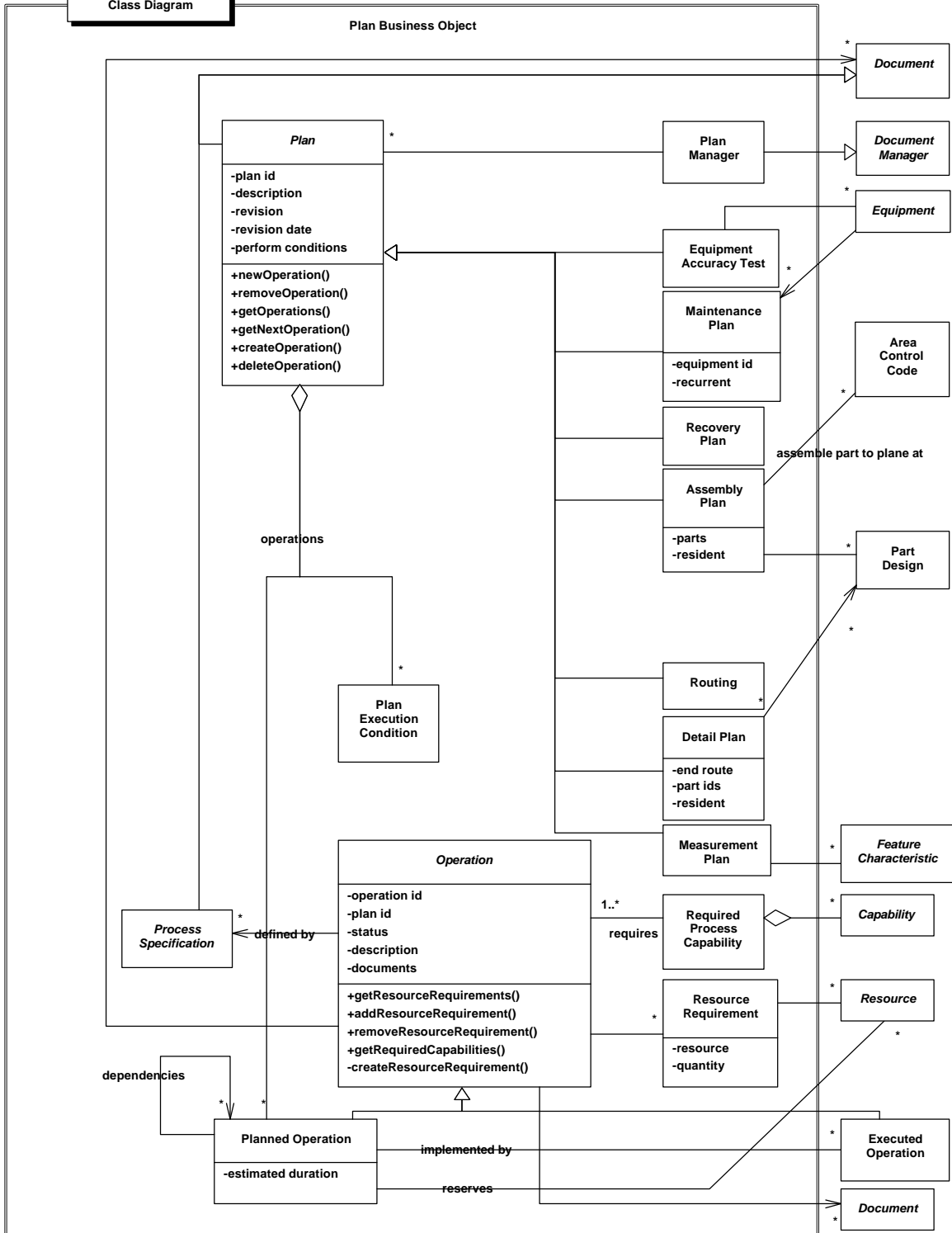


## 5.7 Plan Business Object

Within this business object, **Plan Manager** is responsible for action involving sets of **Plan**. Each Plan instance is an aggregation of **Planned Operations**, that describe what to do, and **Plan Execution Conditions**, that describe when to do the operations, to accomplish some objective. Sequencing of *Planned Operations* are specified through *Dependencies* association. *Planned Operation* and *Executed Operation* are subtype of **Operation**. An *Operation* instance is defined by **Process Specifications** instances and manage the resources specified via **Resource Requirement** and reference Documents to complete a distinct activity. Subtypes of Plan, that are of interest to Boeing, are:

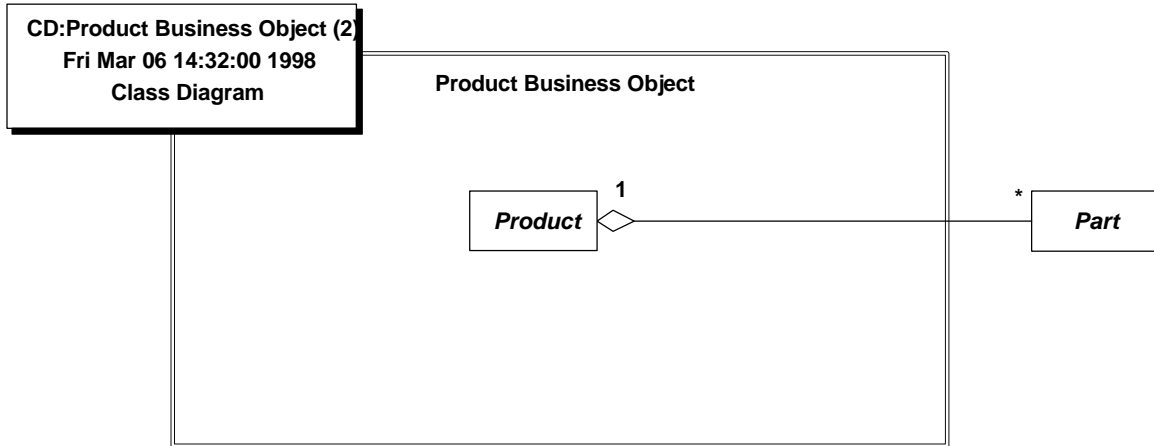
- **Assembly Plan**, whose objective is to assemble detail parts into an assemblage;
- **Detail Plan**, whose objective is to fabricate a detail part from materials;
- **Equipment Accuracy Test**, whose objective is to monitor characteristics of equipment to assure accurate performance;
- **Maintenance Plan**, whose objective is to provide a set of monitoring and repair services to equipment;
- **Recovery Plan**, whose objective is to provide a set of operations in response to an exception to expected conditions;
- **Data Collection Plan**, whose objective is to collect measurement values and provide to analysis routines and/or data storage; and
- **Measurement Plan**, whose objective is to monitor production activity to assure process execution is within accepted norms).

CD:Plan Business Object  
 Fri Mar 06 14:31:47 1998  
 Class Diagram



### 5.8 Product Business Object

**Product** (a good produced for sales) is an aggregation of Part instances. As little information regarding product is required for MES, only this subset of the Boeing model is provided.





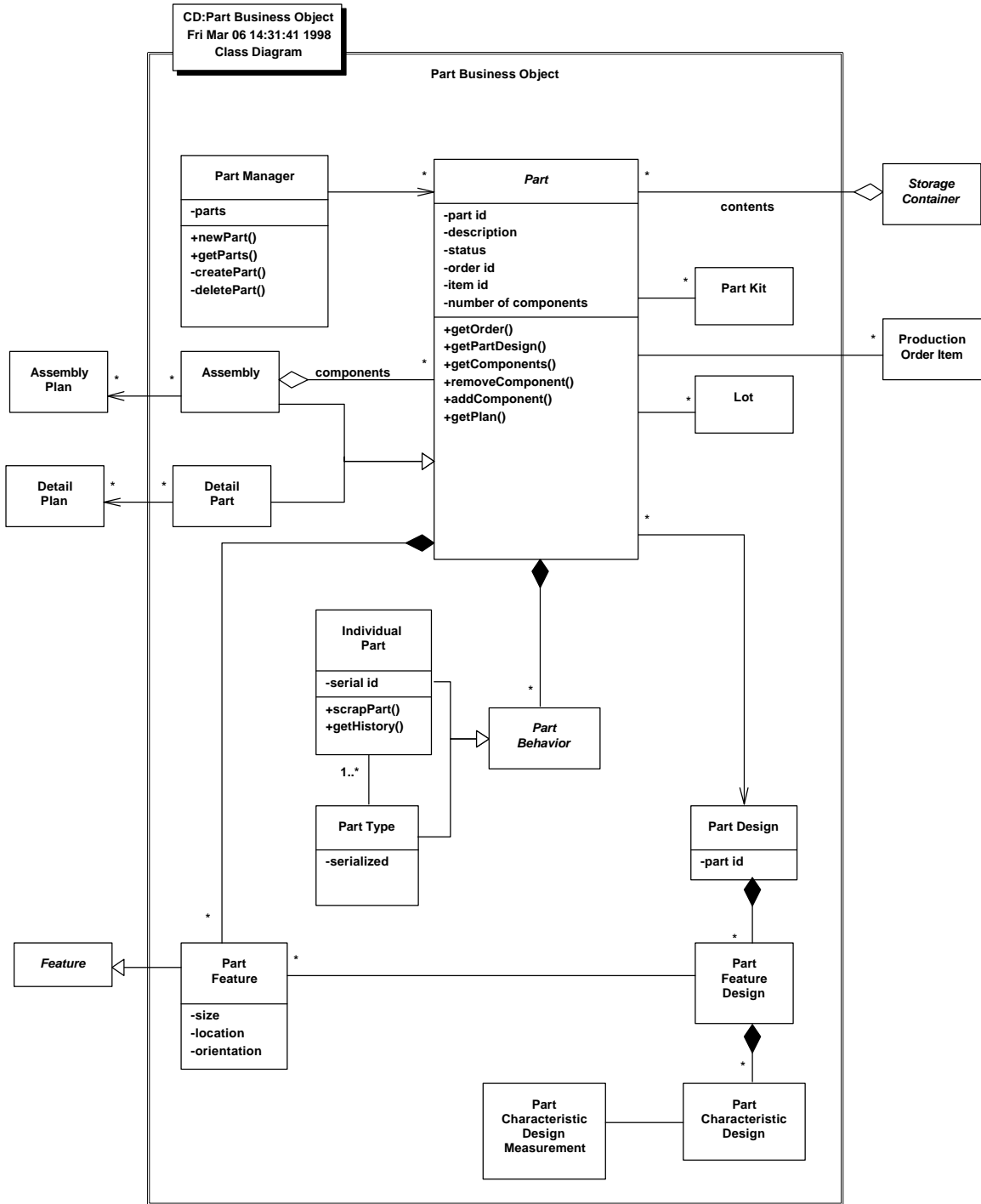
### 5.8.1 Part Business Object

Within this business object, **Part Manager** is responsible for action involving sets of **Part**. *Part* has subtypes of **Assembly**, which is a collection of parts that together function as a unit, and **Detail Part**, that represents a *Part* that has no constituent parts. *Parts* are components of *Assembly*, which means assemblies may be composed of *Detailed Part* instances and of other *Assembly* instances. A *Part* instance may be stored in a **Resource Container** until needed. A *Part* instance may be part of a **Part Kit**, which is a group of disassembled parts for some purpose such as the set which forms an *Assembly*, or may be member of a **Lot**, which is a set of parts made under identical conditions. A *Part* is often called out as a needed **Production Order Item**. *Part* instances are associated with a **Part Design** instance (which can be represented in two dimensional format as a Drawing or in three dimensional format as a Part Model). *Part Design* is an aggregation of **Part Design Features** that are, in turn, themselves aggregations of **Part Characteristic Design** instances. *Part Characteristic Design* instances are described quantitatively by **Part Characteristic Design Measurement** instances. These *Part Characteristic Design Measurement* instances serve as the standard to which the actually manufactured **Part Feature** must conform.

*Part* instances can be specified from the abstraction of a **Part Type**, such as a particular type of part (such as the part type "XYZ"), or identified as an **Individual Part** (such as the particular part "ABC" of part type "XYZ").

A critical piece of the MES captures and records very detailed information about specifically how the Part was built, referred to as the "as-built" part history. These details are necessary to track for, among other reasons, regulatory compliance as well as monitoring of processes. The types of details necessary to record for each Part/Lot would include:

- Identity of the specific Machine / Tool used in the Operation, and the start time and stopping time of the Operation.
- For the specific Machine / Tool used, if it is an automated Machine / Tool track the Controller used and the version of software (operating system executive version, control table version, MCD version, MCD generator / translator / delivery software version, etc.) used in the Operation.
- Identity of the specific Operator / Worker executing the operation.
- The version of the Process Plan, Data Collection Plan, Part Design, and Measurement Plan used for the Order or any associated Split Order.
- The measured values for each characteristic of the Part, as well as the identity of the specific Machine / Tool used for the measurement Operation, any software version running on the measuring Machine / Tool, and the operating parameters of the Machine / Tool at the time the Measurement was taken.
- Any unplanned events which occurred, and any Non-Conformances generated.





## 5.9 Request Business Object

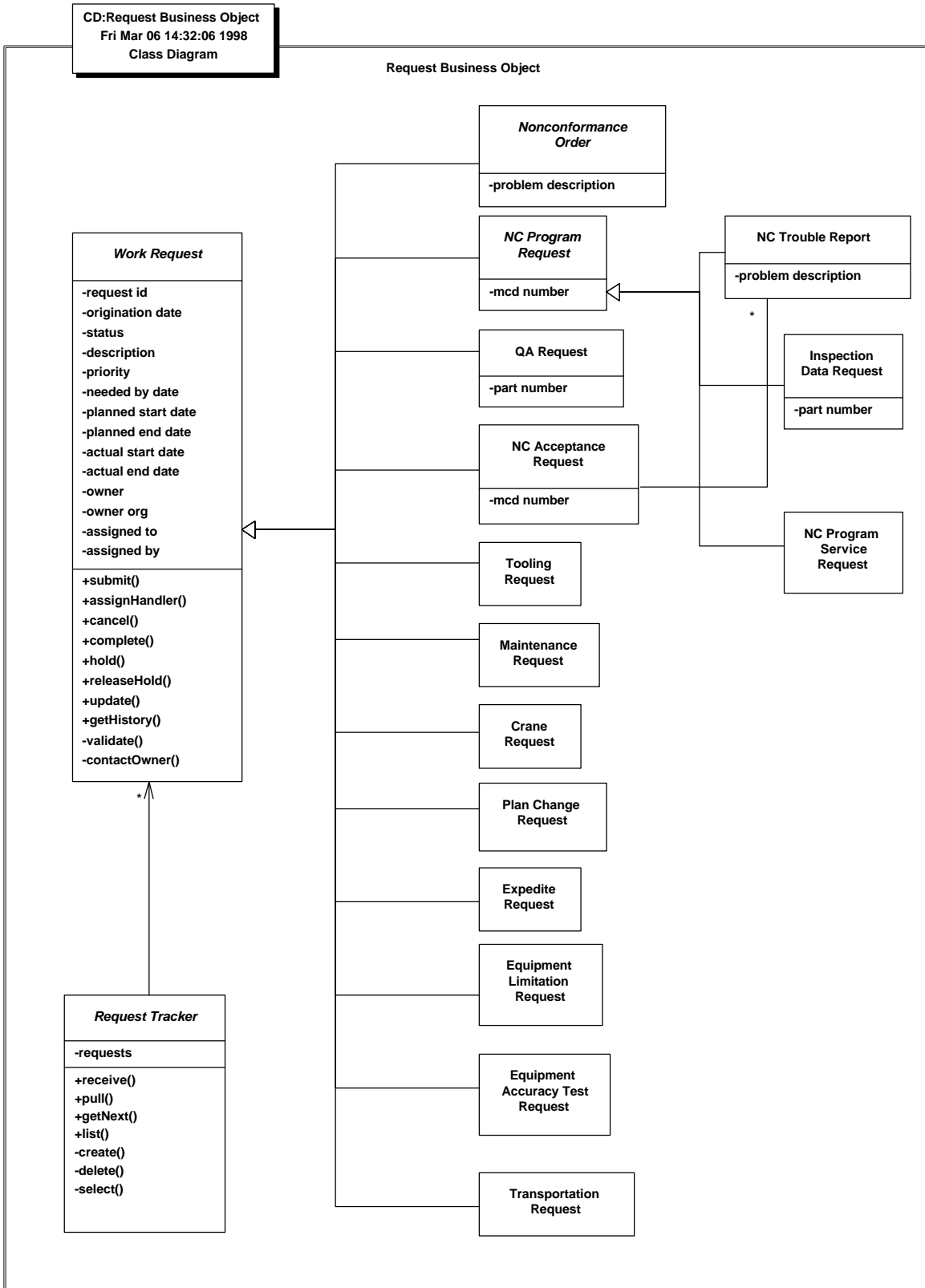
Within this business object, **Request Tracker** is responsible for action involving sets of **Work Requests**. Subtypes of *Work Request* of interest at this time include:

- **Nonconformance Order**, to request action to determine disposition for a part that does not conform to specification;
- **NC Program Request**, to request numerical control programming services;
- **QA Request**, to request an action to assure quality of a product;
- **NC Acceptance Request**, to request that a numerical control program be accepted by manufacturing staff;
- **Tooling Request**, to request action on a tool, such as alignment or issuance;
- **Maintenance Request**, to request services for equipment;
- **Crane Request**, to request a crane services for movement of a work piece;
- **Plan Change Request**, to request a change in an established plan;
- **Expedite Request**, to request that materials and constituent parts be rushed in less than normal lead time;
- **Equipment Limitation Request**, to request a particular equipment unit limitation be altered;
- **Equipment Accuracy Test Request**, to request tests to monitor accuracy be perform; and
- **Transportation Request**, to request transport of a set of items.

NC Program Request is, in turn, subtyped as:

- **NC Trouble Report**, to request services to fix a problem;
- **Inspection Data Request**, to request measurement only services; and
- **NC Program Service Request**, to request part production services.







### 5.10 Resource Business Object

Within this business object, **Resource Manager** is responsible for action involving sets of **Resources**. A *Resource* may be a **Durable Resource**, which is a :

- **Worker**,
- piece of **Equipment**,
- **Durable Tool**; or
- **Storage Container**;

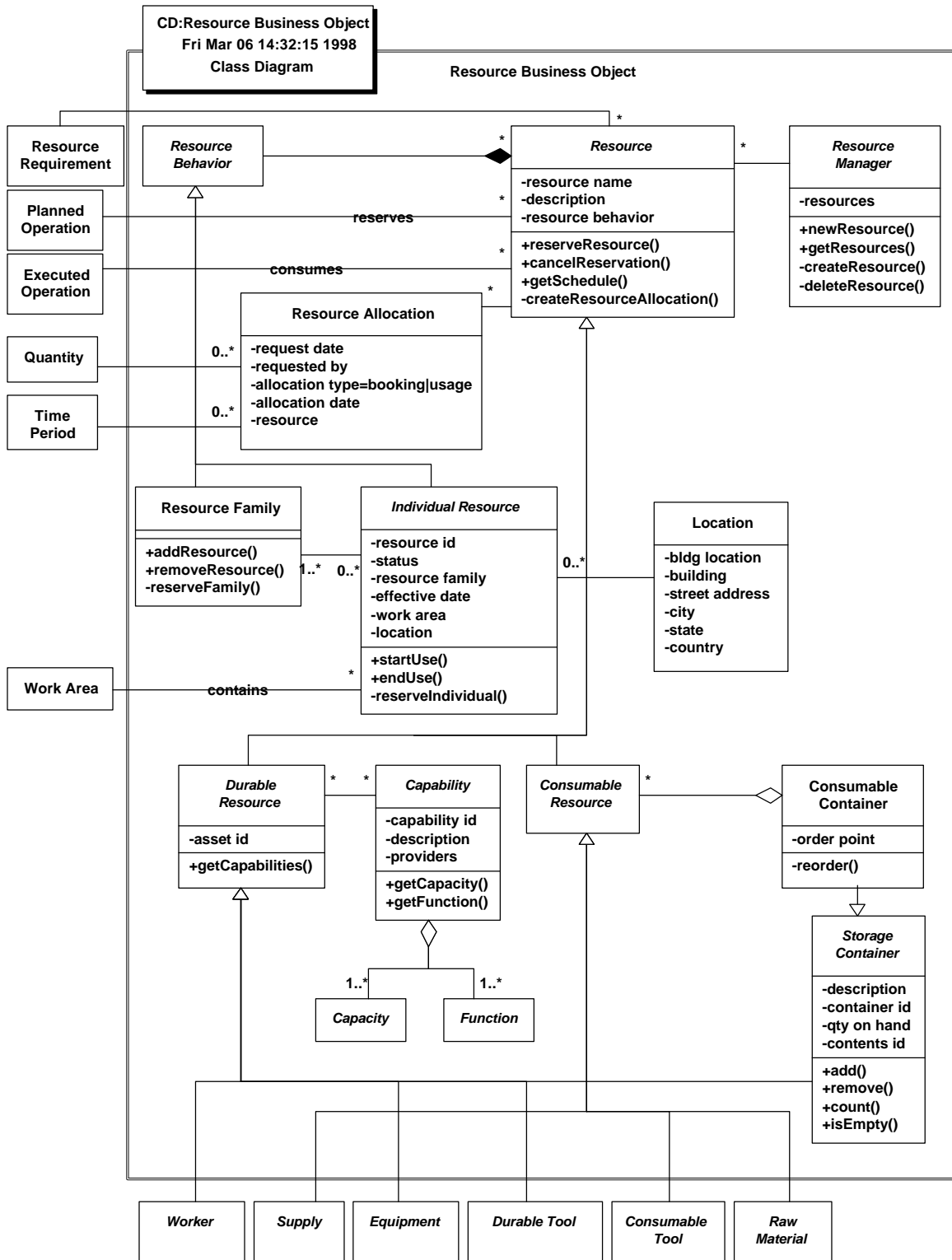
or a *Resource* may be a **Consumable Resource**, which is a:

- **Supply**
- **Consumable Tool**, e.g., a drill bit or a cutter, or
- **Raw Material**.

Each *Durable Resource* has a **Capability**, that identifies one or more **Functions** it provides, and a **Capacity**, that specifies the performance characteristics at which a *Function* is provided, i.e., a measurement of volume or speed over a given time span.

*Consumable Resource* instances are stored in instances of **Consumable Container**, which is a subtype of *Storage Container*.

*Resource* instances can be specified from the abstraction of a **Resource Family**, such as a particular type of equipment (such as one of model "X", type "Y"), or particular type of supplies (such as 10-40 weight oil), or identified as an **Individual Resource** which is found at one time in a particular **Location**. *Individual Resources* are located within **Work Areas**. *Resource* instances are reserved by **Planned Operation** instances. The planned usage of *Resource* instances are tracked by **Resource Allocation** instances.



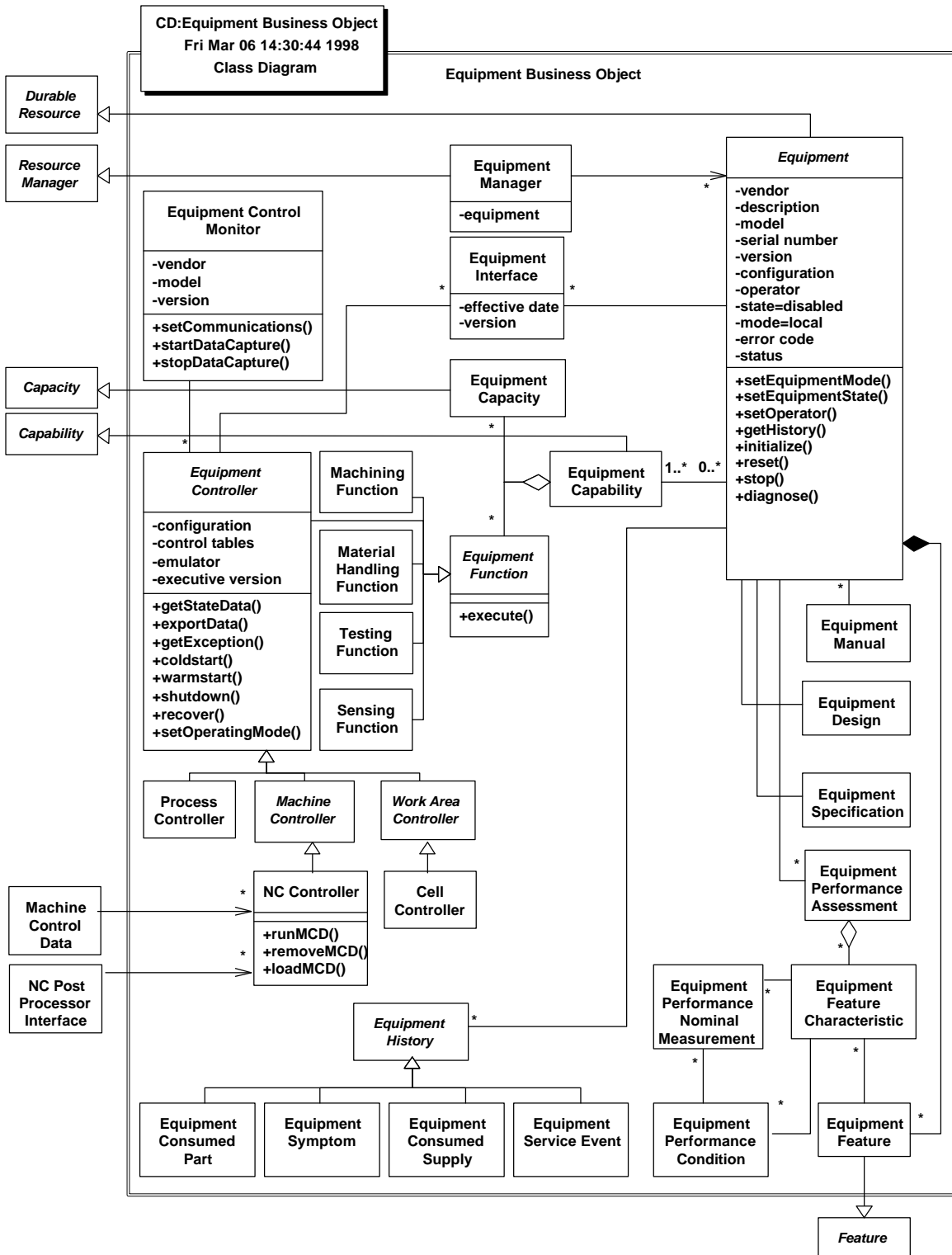


### 5.10.1 Equipment Business Object

Within this business object, **Equipment Manager** is an extension of the services of Resource Manager and is responsible for action involving sets of Equipment.

The **Equipment** abstraction depicts services of any equipment and its **Equipment Capability**. Since multi-function equipment has begun to appear in Boeing's factories, **Equipment Capability** is modeled as an aggregation of multiple **Equipment Functions** and **Equipment Capacities**. Equipment Function depicts services of a particular functionality of interest to the factory, where functionality differentiates among general categories such as control, sensing, machining, testing, and material handling. Equipment Function is modeled as types of equipment functions. For Boeing's discrete manufacturing purposes, types of functionality include **Machining**, as an example of primary discrete manufacturing function; **Sensing**, for measurement of product characteristics or equipment characteristics; **Material Handling**, movement of the work piece; and **Equipment Control**. Types of Equipment Control include **Machine Control**, includes NC Control as an example type; **Process Control**, those services that control the environment applied to a work piece – temperature, chemical application; and **Work Area Control**, those services that support the work area in acquiring and deploying resources to fulfilling a work order. **Cell Control**, as would be relevant for cellular manufacturing, is an example type of Work Area Control.

**Equipment** is described through an aggregate classes of **Equipment History** and **Equipment Performance Assessment**, various supporting Documents, i.e., Equipment Manual, Equipment Design, and Equipment Specification, are associated with the Equipment class. **Equipment History** types provide information required for maintenance decision making; e.g., Service Event, Parts and Supplies Consumed in servicing, Equipment Symptoms that previously required attention. **Equipment Performance Assessment** is a collector class over the specific **Characteristic** objects for which assessments of performance are key (e.g., engine oil temperature). For each Characteristic there is a set of **Nominal Measurements** that form the standard for performance and **Conditions** that that indicate when the standard applies (e.g., after warm up period).





#### 5.10.2 Raw Material Business Object

The **Raw Material Business Object** is part of the Resource Business Object, and is used to track Raw Material consumed in product manufacture. This business object is not developed at this time and no illustrations or further definition is provided.

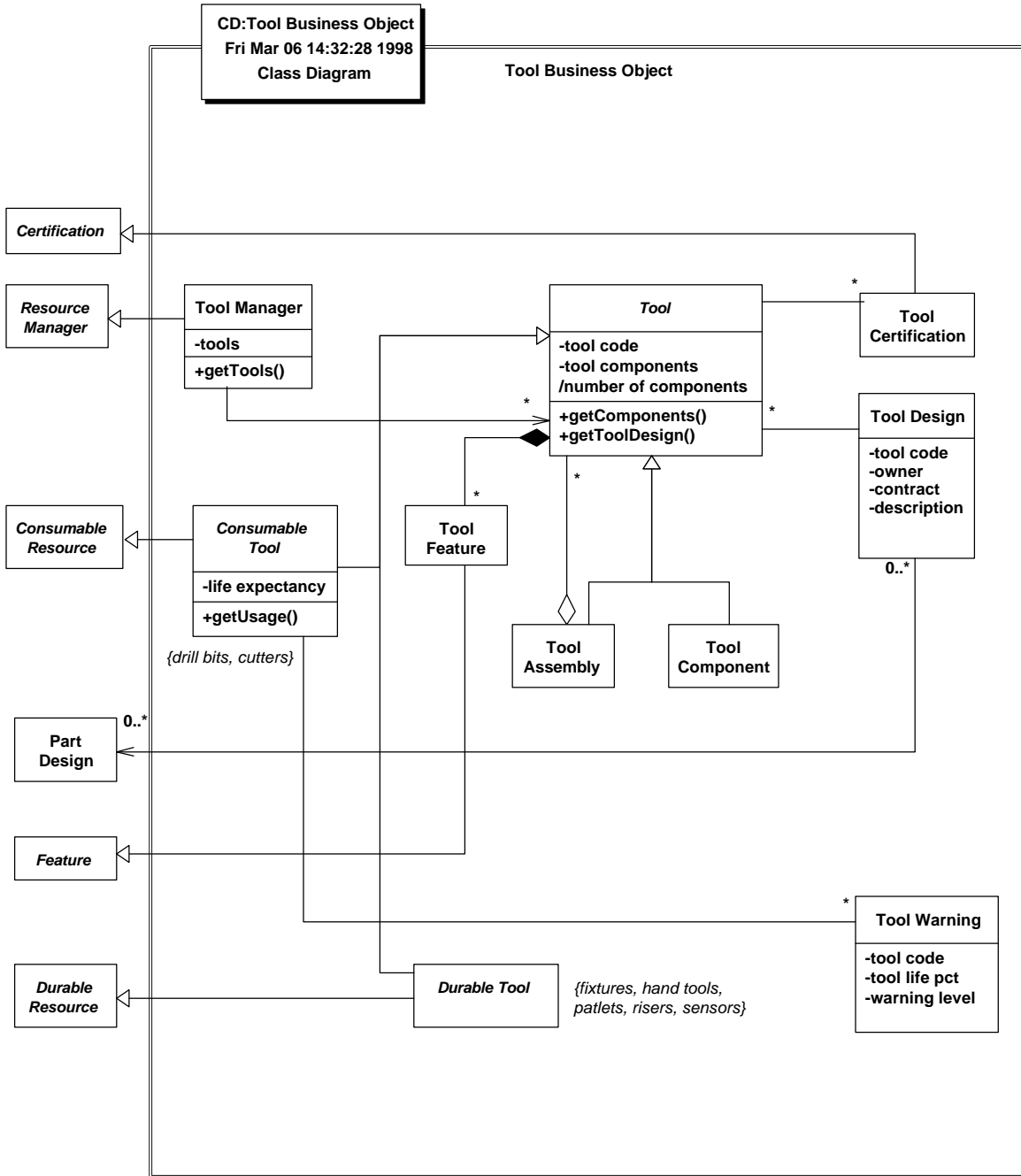
#### 5.10.3 Supply Business Object

The **Supplies Business Object** is part of the Resource Business Object, and is used to track supplies consumed in process execution. This business object is not developed at this time and no illustrations or further definition is provided.

#### 5.10.4 Tool Business Object

As a part of the Resource Business Object, the **Tool Business Object** concerns itself with the management of Tools—devices that passively support the performing of manufacture operations. Tools may be industry standard tool (called standard tool), tools specific to a particular product (called a fixture or contract tool), or tool consumed in operations (called perishable tool). In addition to all the features provided by the Resource Business Object, the Tool Business Object provides for tracking tool assembly/component configurations, tool certifications, tool life expectancy and tool calibrations.

Within this business object, **Tool Manager** is an extension of the services of Resource Manager and is responsible for action involving sets of **Tool**. *Tool* may be supported by a **Tool Design**, may required **Tool Certification** for use, and be assembled of other Tools. *Tool* has subtypes of **Tool Assembly**, which is a collection of tools that together function as a unit, and **Tool Component**, that represents a *Tool* that has no constituent tools. *Tools* are components of *Tool Assembly*, which means assemblies may be composed of *Tool Component* instances and of other *Tool Assembly* instances. Detail Tool is an aggregation of Tool Features. Types of Tool of interest at this time include **Consumable Tool** (e.g., Drill Bit, Cutter) and **Durable Tool** (e.g., Fixture, Hand Tool, Riser, Pallet, Sensor; Assembly Jig as a type to Fixture and Probe as a type to Sensor). Perishable Tool provides a remaining life service which is supported by **Tool Warning**.



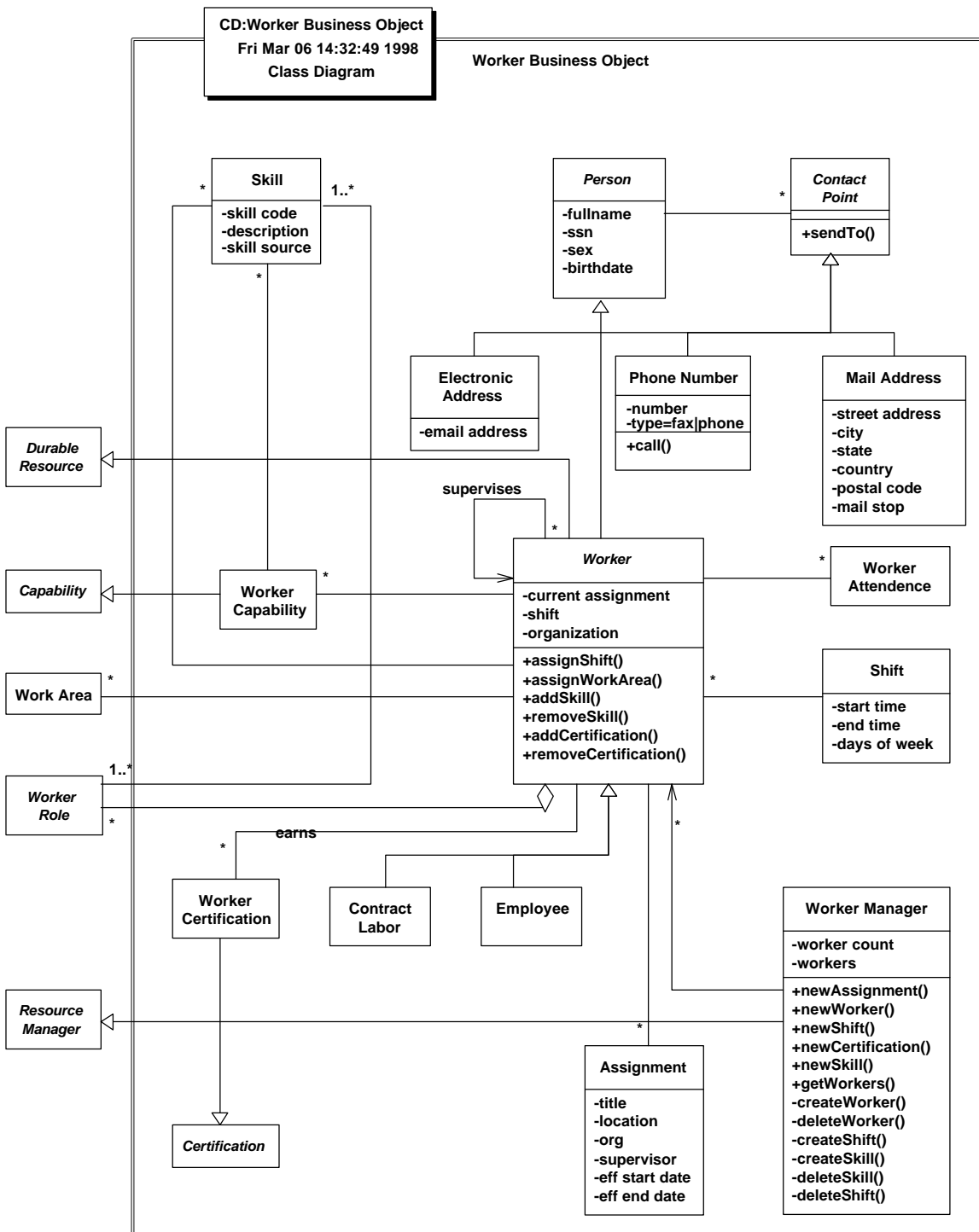


### 5.10.5 Worker Business Object

Worker Business Object should be common across many domains. Within this business object, **Worker Manager** is an extension of the services of Resource Manager and is responsible for action involving sets of **Worker**. Of special interest for Manufacturing, are two classes: **Worker Capability** and **Worker Certification**. *Worker Capability* parallels the concept of *Resource Capability* by identifying what functions the Worker can perform, represented as **Skill** instances, and by identifying some performance measure for executing a *Skill*, which *Worker Capability* implicitly inherits as *Capacity* from its superclass *Capability* (see Resource Business Object). Workers are assigned to perform various *Worker Roles*, which assume that the worker has the necessary skills. In some cases, workers must be explicitly identified as possessing particular skills via **Worker Certification**. These certifications are often requirements of government regulatory agencies.

Other classes (**Person, Contact Point, Electronic Address, Phone Number, Mail Address, Worker Attendance, Shift, Assignment, Worker Manager**) are fairly self explanatory and are provided for context and no further definition is offered at this time.

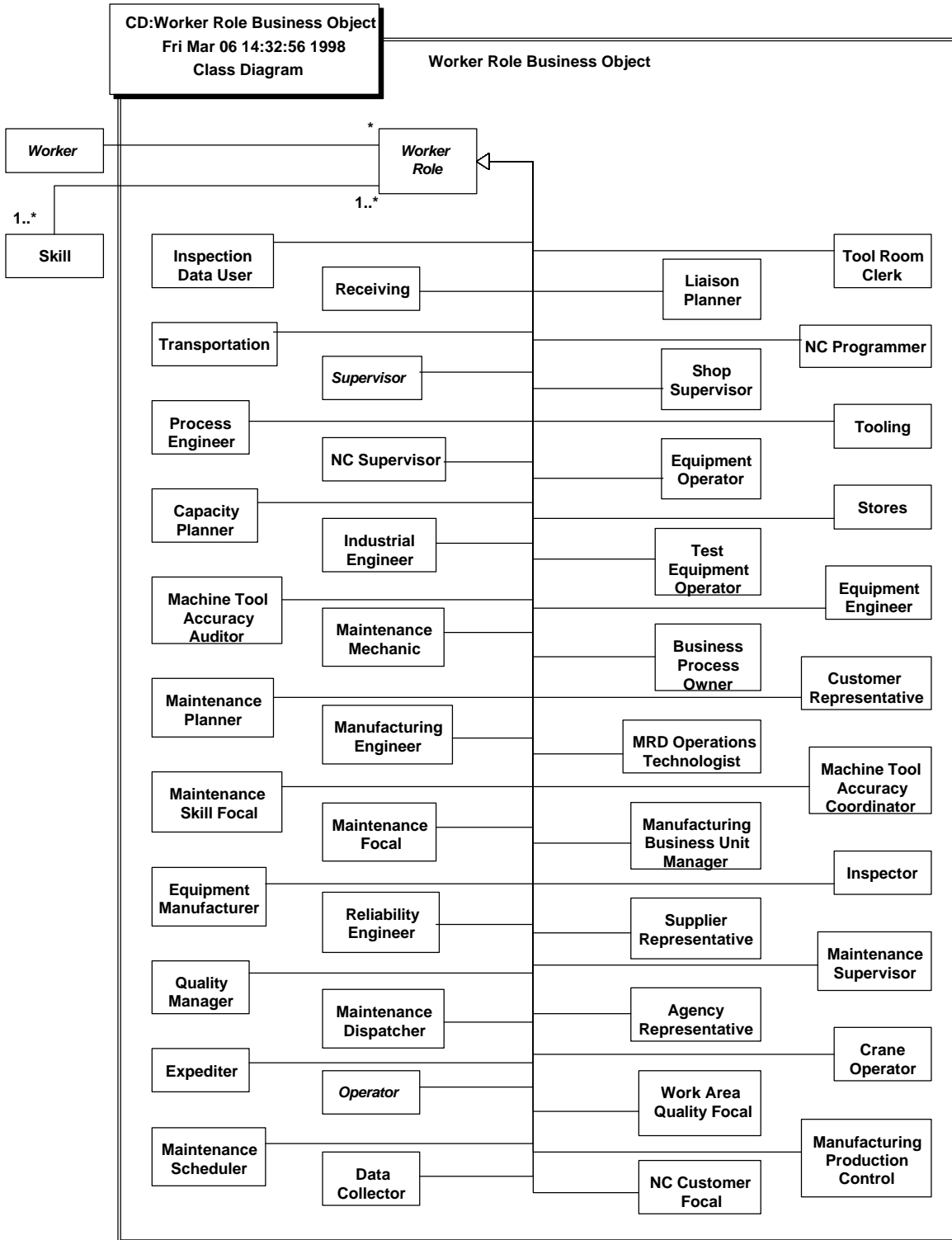






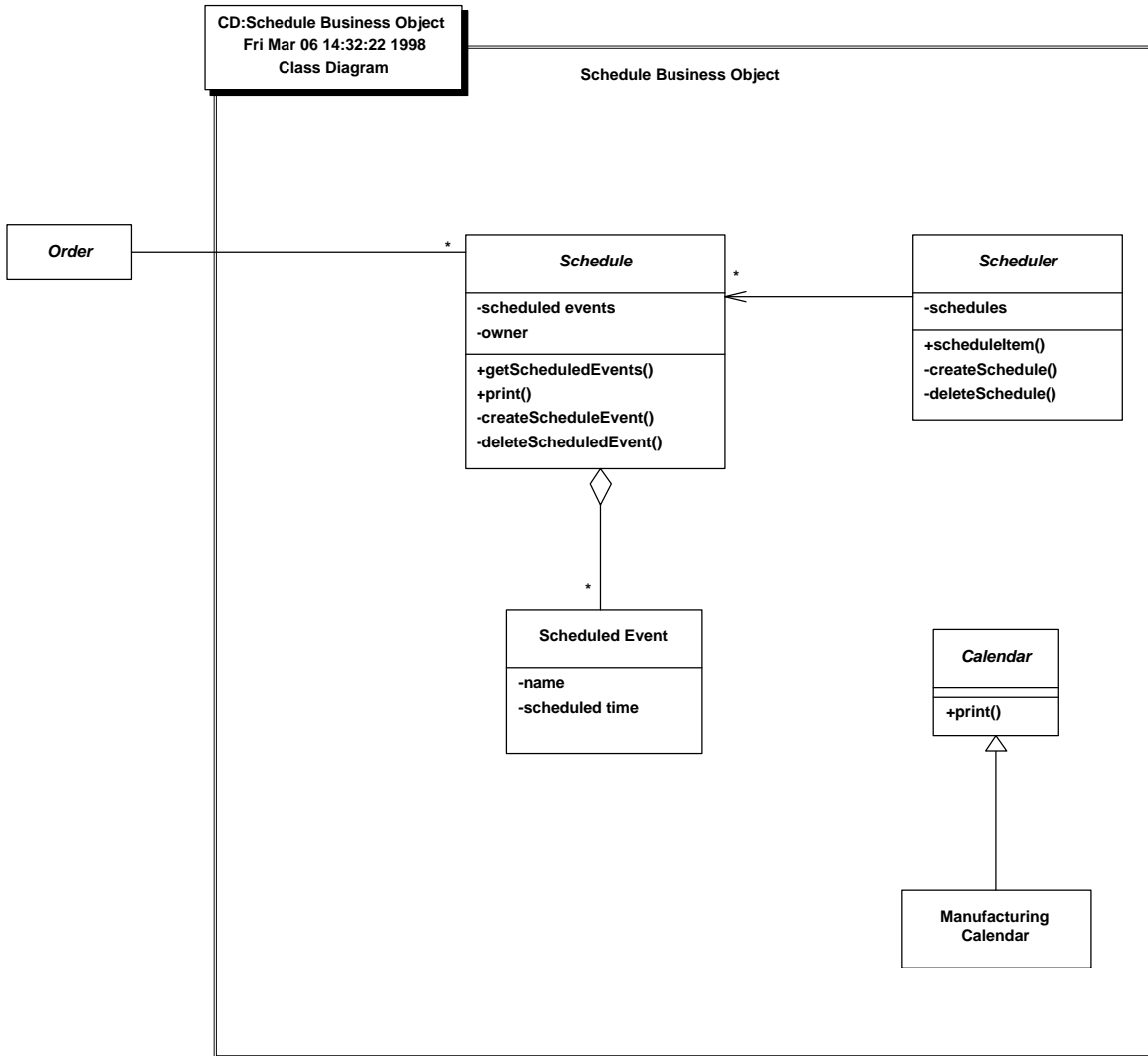
#### 5.10.5.1 Worker Role Business Object

The **Worker Role Business Object** is part of the Worker Business Object, and is used to track the responsibilities and characterization of each interacting role. Typical Boeing roles that manufacturing workers perform appear on the diagram.



### 5.11 Schedule Business Object

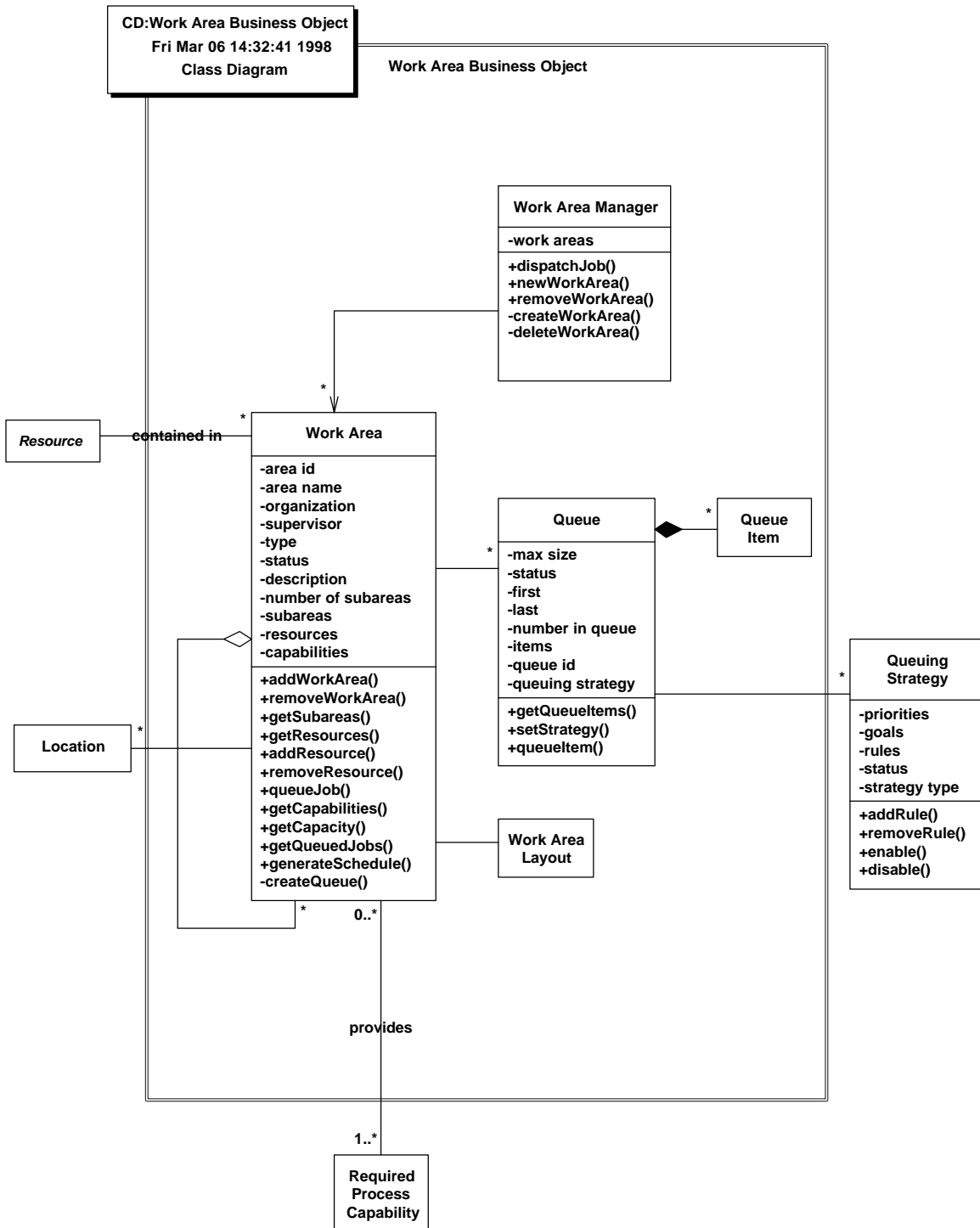
Within this business object, **Scheduler** is responsible for action involving sets of **Schedules** and the Schedule life cycle. Schedule manages an aggregation of **Scheduled Events**. The Schedule and Schedule Events have knowledge of **Calendar** including the type **Manufacturing Calendar**.





### **5.12 Work Area Business Object**

Within this business object, **Work Area Manager** is responsible for action involving sets of **Work Areas** and the Work Area life cycle. Work Areas have a defined **Queue** consisting of an aggregation of **Queue Items**, such as Jobs, that define the items the Work Area is to act upon. Queue Items are acted upon according to a **Queuing Strategy**. Each Work Area has a defined **Work Area Layout** of its Resources.





## 6. Examples and Case Studies within MES

Boeing offers selected portions of a Usage Model as examples of what an MES should support. This section includes an illustration of the extent by domain that is provided in this response and two tables. The first table presents a Use Case Summary by Domain indicating the particular aspect of the business requiring the support. This portion provides the name and purpose of a set of activity a set of actors may perform. The second table presents a Use Case to Business Object Cross Reference indicating what portions of the MES Partions are expected to support the particular Use Case.

UCS:Factory Domains 2  
Fri Mar 06 14:34:24 1998  
Use Case Diagram

Factory Domain

Business Domains

Manufacturing Process Control Domain

**Machine Control Domain**

**Work Area Control Domain**

**Adaptive Control Domain**

*Work Area Configuration  
Work Area Controls  
Order Management  
Resource Management  
Job Execution  
Job Support  
Exception Handling*

**Equipment Maintenance Domain**

*Request Maintenance  
Plan Maintenance  
Schedule Maintenance  
Execute Maintenance  
Define/Assess Equipment*

**Manufacturing Process Improvement Domain**

**Tooling Domain**

**NC Programming Domain**

*NC Request Management  
NC Program Creation  
NC Program Acceptance*

Utility Domains

**Manufacturing Data Management Domain**

**Measurement Domain**

*Product Measurement  
Equipment Measurement  
Define Equip Accuracy  
Define Equip Accuracy Testing  
Execut Equip Accuracy  
Analyze Equip Accuracy  
Process Measurement*

**Data Collection Domain**

*Set Up Data Source  
Capture Data  
Export Data*





## 6.1 Use Case Summary by Domain

### 6.1.1 Work Area Control Domain

USE CASE NAME	PURPOSE
Batch Order	To group two or more orders together for common processes in order to more efficiently utilize materials, equipment and / or time
Change Cell Mode	To change Cell Controller mode of operation-either manual or automatic
Change Cell State	To change operating state of the Cell Control System-to start it up, put it in standby, shut it down, and recover from an exception condition
Change Order Status	To change Production Order status
Change Workstation Mode	To allow Cell-level control over Workstation mode of operation-either local or remote. When in local mode, the Workstation is controlled from its own interface; when in remote, it is controlled from the Cell Controller
Change Workstation State	To allow remote Cell-level control over the operating state of a Workstation-to start it up, put it in standby, pause it, resume operations, reset is, shut it down, and recover from an exception condition
Configure Cell	To allow the customization of Cell operating parameters. The Cell must maintain a record of its configurable options and refers to this configuration during Cell operations
Control Machine State	To control the operational state of a machine
Define Exception Type	To record and store a category of Exception, its description, conditions, equipment error codes, and any associated Recovery Plan
Define Recovery Plan	To create a set of recommended procedures for recovering from a particular Exception or a related group of Exceptions. These recovery procedures should be specific, detailed stepwise instructions, and can be stored in document form, electronically, or on hard copy. Triggered by Exceptions, some automated cells may display and/or execute Recovery Plans automatically
Define Resource	To define a specific Resource, its description, location, type, capabilities, owner and other pertinent information; and to make it known and available to any system tracking and managing the Resources. A Resource is something used to make, or is included in, a business's end product. Resources can include Equipment (e.g., NC Machines, Material Handling Equipment, Coordinate Measurement Machines), Tools (e.g., Fixtures, Cutters, Probes), Workers, etc.
Define Routing	To allow the definition and management (creation, update, removal, storage, retrieval, and version control) of a Routing (sometimes know as Local Process Plan). A Routing is a type of Process Plan which is stored and managed by the local Work Area (Shop, Cell, etc.) and which consists of stepwise instructions for the production of a specific Part-typically a Part which is repeatedly ordered for production. The Routing helps improve process quality and automation of operations. Routing instructions may include the selection of Tools, Fixtures, material handling instructions, load/unload sequences, etc. For automated execution of Routings, instruction formats historically have been (Cell Controller) vendor specific
Define Work Area	To define a specific Work Area, its description, location, capabilities, supervisor and other pertinent information; and to make it known and available to any system tracking and managing Work Areas. A Work Area is a logical or physical configuration and grouping of



	Resources which combine to provide one or more Process Capabilities. Work Areas can be any size and reside in one or more physical locations. Work Areas can contain other Work Areas. Examples include Factory, Shop, Work Center, Cell, and Workstation. Resources can include Equipment (e.g., NC Machines, Material Handling Equipment, Coordinate Measurement Machines, Machine Controllers), Tools (e.g., Fixtures, Cutters, Probes), Workers, etc.
Delete Control Program	To delete an Control Program from the Machine Controller
Expedite Order	To replace missing or incorrect Parts specified in an order
Hold Order	To halt processing on a Order, pending some action, and change its status to "On Hold"
Load Control Program	To load an Control Program file (Machine Control Data) onto a Machine Controller
Load Control Program Utility Program	To load an Control Program Utility Program onto a Machine Controller
Load Workpiece	To fasten a Workpiece (Raw Material/ work in progress) onto a Fixture (in a Machining Cell, typically attached to a Pallet) so that the Workpiece can be processed. While being machined or assembled, Workpieces usually must be rigidly held in a very precise position. To hold the Workpiece, a Fixture is used
Move Resource/Material	To move a Resource or Raw Material within an integrated Work Area, such as a Cell. An example would be moving a Pallet and Fixture to a load station, or move a Workpiece on a Pallet to a Workstation. (Inter-Cell transfers are managed by Transportation and are not addressed here.)
Preview Pending Upstream Orders	To preview orders pending release to the Shop Floor from upstream systems in order to project Capabilities, Work Loads and Schedules
Profile Cell	To access and view static and dynamic Cell characteristics to assist in assessing Cell configuration, current state of Cell, Cell historical and current performance, and Cell problems. These characteristics should include profiles of Cell Resources (Equipment, Workers, Materials, Tools), Parts, Orders, physical layouts, and operational control parameters (such as scheduling strategies)
Receive Order	To accept a Production Order, from an external source, into the Work Area, and store it, pending verification
Receive Part	To receive Parts in Work Area
Recover Cell	To restore Cell to an operating state with a minimum loss of work
Register New Part	To identify, record, and associate (in the Cell Control System ) the necessary Resources (Equipment, Tools, Fixtures, Pallets, etc.), Plans, Control Programs, Routings, and Documents needed to produce a Part
Release Held Order	To allow the resumption of processing on a held Order, and change its status to "Ready"
Release Order	To declare the completion of all processing on an Order, ship the Order out of the Work Area to its next routing, and change its status to "Complete"
Report Exception	To notify Operator that an Exception has occurred. The purpose of the Exception notification is to provide a traceable, loggable event of an error condition, and to provide an opportunity for interested parties to effect corrective actions
Report Order Status	To notify upstream enterprise systems of changes to the status of a Production Order
Request Support Documentation	To obtain, for read-only viewing or printing, Engineering Data, Documents, Drawings, Designs, or Plans
Request Support Service	To define and submit a Request for a specific service (activity or collection of activities) in support of filling an Order, or some other manufacturing activity. These support services are typically provided outside of the Work Area. Services might include: NC Programming,



	QA Inspection, Transportation, Material Handling, Maintenance, Expediting, Tooling, Tool/Supplies Replacement, or Liaison Planning
Respond To Exception	To acknowledge that Exception has been recognized and to perform recovery procedures, to clear error condition(s) and return process to operational state; to diagnose cause of problem if possible. Underlying goals may be to ensure safety, protect Equipment from damage, and maintain process quality
Run Job	To execute all Operations associated with a Job, specified by a Plan, in support of some Order (or Request)
Schedule Maintenance	To plan for Equipment down time due to equipment repair or planned maintenance
Scrap Order	To disposition Workpiece and Raw Materials after occurrence of non-conformance or failed inspection
Set Up Job	To verify that all necessary Resources (Equipment, Tools, Fixtures, Pallets, etc.), Supplies, Materials/Work in Process (workpiece), Control Programs, Plans, Routings, and Documents are available and are prepared for the execution of the Job-one or more Production Operations typically associated with an Order. Specific setup activities vary depending on the type of Job. Some examples of setup activities may include, downloading Control Program to Workstation, loading workpiece, moving Pallet/Stockers, and gathering drawings and operator documents
Shutdown Cell	To deactivate Cell Controller, Workstations and Material Handling System bringing them to a shutdown, or off, condition
Split Order	To allow completion of a partial order. Only part of order can be completed per requirement within allocated time, typically due to material shortage or non-conformance
Startup Cell	To activate Cell Control System, Workstations and Material Handling System bringing them to an operating condition
Teardown Job	To return Work Area to a neutral state in anticipation of the next Job. Basically, the opposite of Job Setup, Teardown can occur at the end of a Job, or just prior to the setup of the next Job, and can include activities such as the dismantling of Assembly Jigs, cleaning of vats or machines, returning unused Materials and Supplies, deleting Control Programs from Workstations, and returning Pallets and Fixtures to Storage locations. These activities vary depending on the Work Area and type of Jobs being performed
Track And Supply Shop Resources	To keep Work Area supplied with sufficient quantities of necessary consumable and perishable Resources
Unload Workpiece	To remove a Workpiece from a Fixture, (typically, after it has been processed)
Verify Order	Determine if the Order has arrived at the correct Work Area, determine that all information is accurate and complete, and that all Resources and capabilities required to execute the Order are accessible (i.e., they are generally available; Resources are not scheduled or allocated here)

### 6.1.2 Equipment Maintenance Domain

USE CASE NAME	PURPOSE
Add Maintenance Plan Element	Create a Plan for maintenance activity. Maintenance Plans include designation of equipment, tasks and task sequence, and resources required
Assess Equipment Condition	Determine operable condition for a specific Equipment Unit. Initiate appropriate response, if any, to that condition
Cancel Maintenance Order	To cancel a scheduled maintenance activity (Maintenance Order). The Equipment and each of the Resources are individually released



	from the Schedule
Cancel Maintenance Plan	Cancel a Plan for maintenance activity
Copy Maintenance Plan Element	Copy an element of one Maintenance Plan to another
Create Maintenance Order	To schedule a specific maintenance activity as defined by a Maintenance Plan. The Equipment and each of the Resources are individually assessed as to availability and scheduling
Create Maintenance Plan	Create a Plan for maintenance activity. Maintenance Plans include designation of Equipment, tasks and task sequence, and Resources required
Delete Maintenance Plan Element	Delete an element of a Maintenance Plan
Deliver Equipment Data	Deliver the collected equipment data (measures of key characteristics such as motor vibration frequency, oil temperature, motor signature) to specified destinations
Dispatch Maintenance	Assigns emergent corrective and lower priority maintenance work to available Maintenance Mechanics. Currently, emergent corrective work is assigned as received, lower priority work is assigned at shift start
Handle Maintenance Exception	Deals with recovery due to encountering circumstances not anticipated in the Maintenance Plan of the Maintenance Order. Includes initiating addendum maintenance activity to be executed as part of the Maintenance Order or for follow on maintenance activity
Harvest Equipment Data	Extract equipment data (measures of key characteristics such as motor vibration frequency, oil temperature, motor signature) from measuring devices, software applications (e.g., machine controllers), other files or databases, and manual entry of data
Issue Maintenance Resource	Issue a Maintenance Resource(s) for a Maintenance Order. Includes kitting
Maintain Equipment	Perform maintenance activity on an Equipment Unit. Includes preventative (such as autonomous) and / or corrective activity to insure production equipment are functionally capable of expected operation. These activities include tests, Measurements, replacements, adjustments and repairs. As a result of these activities, equipment should be in good operating condition (clean, free of hazards, etc.) within specified limitations such as those imposed by age and prior use
Manage Equipment Definition	Maintain the definition of the Equipment Unit
Manage Maintenance Order	Manage execution content and changes to the Maintenance Order. Includes documentation of maintenance activity, changes in status, priority
Reschedule Maintenance Order	To reschedule a scheduled maintenance activity (Maintenance Order). The Equipment and each of the Resources are individually released from the schedule. (Currently, requests to reschedule are initiated from Maintenance Mechanic (currently in person, due to equipment unavailability), Capacity Planner (currently via in person due to production schedule state), from Maintenance Supervisor and Shop Supervisor reviews of activity.
Request Maintenance	To establish and define a request for maintenance activity for a particular Equipment Unit. Request may be for preventative or corrective action
Revise Maintenance Plan	Revise Maintenance Plan
Revise Maintenance Plan Element	Revise an element of one Maintenance Plan to another
Schedule Information Resource Availability	To manage the scheduling activity for Information Resource(s) for a Maintenance Order. Includes establishing, canceling, revising of assignment window of time (start date / time/ shift through end date / time / shift)
Schedule Skill Availability	To manage the scheduling of maintenance activity for a Maintenance Mechanic. Includes establishing, canceling, revising of assignment window of time (start date / time/ shift through end date / time / shift)



### 6.1.3 NC Programming Domain

USE CASE NAME	PURPOSE
Buy Off NC Program	To accept or reject, a new NC Program or a change made to an NC Program by the NC Programmer
Delete Control Program	To delete an Control Program from the Machine Controller
Edit Control Program Online	Sometimes the NC Operator has a need to create (or alter) an Control Program (Machine Control Data-machine executable version of an NC Program) on the shop floor. In this case, the Control Program can be edited directly on the Machine Controller, then immediately tried out (without the wait of a typical NC Program creation cycle performed by the NC Programming staff)
Load Control Program	To load an Control Program file (Machine Control Data) onto Machine Controller
Request NC Program Change	To request the correction of an NC Program problem by creating an NC Trouble Report and notifying the appropriate NC Programming contact

### 6.1.4 Measurement Domain

USE CASE NAME	PURPOSE
Align Part	To have coordinate measurement machine (CMM) identify reference point of origin on Part, from which all measurement points will be relative
Analyze Equipment Characteristic Value	Assess the performance of an Equipment Characteristic to defined limits and forecast its ability to remain within defined limits
Analyze Inspection Data	To compare inspection data, captured from the NC Machine, with expected results
Analyze Equipment Accuracy Test	Assess the ability of a given Equipment Unit to produce Part features accurately based upon testing of certain characteristics of the Unit
Approve Equipment Accuracy Test Requirement	Approve a complete specification for a test that is to be performed on a specific type of Machine Tool
Audit Equipment Accuracy Test	Examines the records and procedures for conducting Equipment accuracy activity to verify the accuracy and completeness of the records
Best Fit Part	To have the CMM adjust ("float") the Part alignment to bring the measured points within tolerance, in order to accept Part
Cancel Equipment Accuracy Test Script	Cancel a specification for a test that is no longer to be performed on a specific type of Machine Tool
Capture Inspection Data	To collect coordinate measurement data from the Equipment for subsequent analysis
Collect Equipment Test Resource	Collect Resource(s) for a Equipment Accuracy Test (which hopefully are kitted for use)
Create Equipment Accuracy Test Script	Create a specification for a test that is to be performed on a specific type of Equipment. This specification names all activity to be performed and all resources to be required for the test. This activity includes a Measurement Plan and Data Collection Plan
Determine Equipment Accuracy Bound	Establish the bounds for each characteristic of a unit of Equipment that affect accuracy. Each Equipment Characteristic may have multiple bounds for different conditions (say, at different speed or feed rates). Bounds are generally established from baseline testing
Determine Equipment Test Frequency	Determine the frequency of administering a particular test to a given Equipment Unit to assure accuracy in the Equipment
Determine Equipment Test Requirement	Obtain approval to proceed with an approach to maintaining accuracy for a given set of Equipment



Display Inspection Data	To format and display analyzed inspection data
Export Inspection Data	To export CMM inspection data (to a transfer media, a database, or other system), or to allow the reading of CMM inspection data by external applications for analysis and viewing (e.g., CAD/CAM System might upload the inspection data and display comparison of actual and expected results side-by-side; see Use Cases "Analyze Inspection Data" and "Display Inspection Data")
Initiate Equipment Condition Response	Initiate action to a Equipment Unit which is degrading or has degraded with respect to its ability to produce Part Features accurately
Inspect (Accept) Part	To verify (physically) Part is produced according to Process Specification and conforms to Part Design
Manage Equipment Accuracy Test Schedule	Manage all scheduling for Equipment Accuracy Testing. Includes scheduling the Equipment Unit, rescheduling, and canceling scheduled testing
Monitor Operation	To start/stop communications between Machine Controller and Equipment Monitor, which stores captured data
Qualify Probe	To have the CMM identify all Probe operational characteristics relative to CMM machine arm
Report Machine Accuracy Condition	To assemble information regarding the ability of a Equipment to perform accurately and distribute (or otherwise make available)
Request Equipment Part Limitation	To establish and define a request to limit the usage of a particular Equipment Unit to accommodate accuracy conditions of that Unit (as in the case of deterioration). This request would name the type of manufacturing activity which is appropriate for the Equipment Unit
Request Equipment Accuracy Test	To request a specific testing activity as defined by a Equipment Accuracy Test Script occur within a specific time
Request Equipment Test Media	Complete a NC Media Request to produce Media that supports testing of a type of Equipment for accuracy assessment
Request Process Plan Change	To establish and define a request for a change to a Process Plan for a Part to accommodate accuracy conditions of a type of Equipment that produces the Part. This request would be placed to alter speed or feed rates, alter cutter tool, or to suggest a more appropriate type of Equipment(as in the case of deterioration in the type of equipment or if the type of Equipment is a mismatch for the Part)
Revise Equipment Accuracy Test Script	Revise a specification for a test that is to be performed on a specific type of Equipment. This specification names all activity to be performed and all resources to be required for the test
Run Equipment Accuracy Test	Execute the prescribed Equipment Accuracy Script

### 6.1.5 Data Collection Domain

USE CASE NAME	PURPOSE
Data Capture	To extract the data from a machine or measuring device
Data Transfer	To transfer data from the source to the destination
Set-up Data Source	To select and configure the appropriate device, machine tool and/or software application for the measurement task assigned.

### 6.2 Use Case to Business Object Cross Reference

USE CASE NAME	BUSINESS OBJECT NAME
Add Maintenance Plan Element	Plan Business Object Document Business Object
Align Part	Equipment Business Object



USE CASE NAME	BUSINESS OBJECT NAME
Analyze Equipment Characteristic Value	Measurement Business Object Job Business Object
Analyze Inspection Data	Measurement Business Object Equipment Business Object Part Business Object
Assess Equipment Condition	Request Business Object Equipment Business Object Resource Business Object Measurement Business Object
Batch Order	Order Business Object
Best Fit Part	Equipment Business Object
Buy Off NC Program	Request Business Object
Cancel Equipment Accuracy Test Script	Plan Business Object Document Business Object
Cancel Maintenance Order	Request Business Object Plan Business Object Order Business Object
Cancel Maintenance Plan	Request Business Object
Capture Inspection Data	Equipment Business Object Part Business Object Measurement Business Object
Change Cell Mode	Equipment Business Object
Change Cell State	Equipment Business Object
Change Order Status	Order Business Object
Change Workstation Mode	Equipment Business Object
Change Workstation State	Equipment Business Object
Check Tool Alignment	Request Business Object Measurement Business Object Tool Business Object
Collect Equipment Test Resource	Plan Business Object Control Program Business Object Tool Business Object Resource Business Object Document Business Object Equipment Business Object
Configure Cell	Equipment Business Object
Control Machine State	Equipment Business Object
Copy Maintenance Plan Element	Plan Business Object Document Business Object
Create Equipment Accuracy Test Script	Plan Business Object Resource Business Object Document Business Object
Create Maintenance Order	Plan Business Object Request Business Object Order Business Object Document Business Object
Create Maintenance Plan	Request Business Object Plan Business Object Document Business Object



USE CASE NAME	BUSINESS OBJECT NAME
Define Exception Type	Exception Business Object
Define Recovery Plan	Plan Business Object
Define Resource	Resource Business Object Equipment Business Object Tool Business Object
Define Routing	Plan Business Object Document Business Object
Define Work Area	Work Area Business Object
Delete Maintenance Plan Element	Plan Business Object Document Business Object
Delete Control Program	Control Program Business Object Equipment Business Object
Determine Equipment Accuracy Bound	Equipment Business Object Resource Business Object Job Business Object Plan Business Object Measurement Business Object Document Business Object
Determine Equipment Test Frequency	Equipment Business Object Resource Business Object Plan Business Object Document Business Object
Determine Equipment Test Requirement	Plan Business Object Document Business Object Work Area Business Object Equipment Business Object Resource Business Object Job Business Object
Dispatch Maintenance	Request Business Object Plan Business Object Order Business Object Document Business Object
Display Inspection Data	Measurement Business Object
Display Monitored Data	Measurement Business Object
Edit Control Program Online	Equipment Business Object Document Business Object Control Program Business Object
Expedite Order	Request Business Object
Export Inspection Data	Equipment Business Object
Handle Maintenance Exception	Order Business Object
Hold Order	Order Business Object
Inspect (Accept) Part	Request Business Object Document Business Object Part Business Object Plan Business Object
Issue Maintenance Resource	Plan Business Object Document Business Object Resource Business Object Order Business Object Tool Business Object





USE CASE NAME	BUSINESS OBJECT NAME
Load Control Program	Control Program Business Object Equipment Business Object
Load Control Program Utility Program	Equipment Business Object
Load Workpiece	Job Business Object
Maintain Equipment	Equipment Business Object Order Business Object Plan Business Object Tool Business Object Resource Business Object Document Business Object
Manage Equipment Definition	Equipment Business Object Document Business Object Resource Business Object
Manage Maintenance Order	Order Business Object
Monitor Operation	Equipment Business Object Measurement Business Object
Move Resource / Material	Job Business Object
Preview Pending Upstream Orders	Order Business Object
Profile Cell	Equipment Business Object Work Area Business Object Resource Business Object Job Business Object
Qualify Probe	Equipment Business Object
Receive Order	Order Business Object Schedule Business Object
Receive Part	Part Business Object
Recover Cell	Equipment Business Object Job Business Object Resource Business Object Order Business Object Work Area Business Object
Register Control Program	Control Program Business Object Document Business Object
Register New Part	Part Business Object
Release Held Order	Order Business Object
Release Order	Order Business Object Request Business Object
Report Exception	Equipment Business Object Exception Business Object
Report Order Status	Order Business Object
Request Additional Maintenance Resource	Order Business Object Equipment Business Object Resource Business Object Request Business Object
Request Equipment Accuracy Test	Job Business Object Request Business Object
Request Equipment Part Limitation	Request Business Object
Request Equipment Test Media	Request Business Object



USE CASE NAME	BUSINESS OBJECT NAME
Request Maintenance	Request Business Object Equipment Business Object Resource Business Object
Request NC Program Change	Request Business Object
Request Process Plan Change	Request Business Object
Request Support Documentation	Request Business Object Document Business Object
Request Support Service	Request Business Object
Reschedule Maintenance Order	Request Business Object Order Business Object
Respond To Exception	Exception Business Object Plan Business Object Document Business Object
Revise Equipment Accuracy Test Script	Resource Business Object Plan Business Object Document Business Object
Revise Maintenance Plan	Plan Business Object Document Business Object
Revise Maintenance Plan Element	Request Business Object Plan Business Object Document Business Object
Run Job	Equipment Business Object Job Business Object Resource Business Object Plan Business Object
Run Equipment Accuracy Test	Job Business Object Plan Business Object Control Program Business Object Equipment Business Object Tool Business Object Resource Business Object Measurement Business Object Document Business Object
Schedule Maintenance	Request Business Object
Schedule Skill Availability	Order Business Object Worker Business Object
Scrap Order	Order Business Object Work Area Business Object Job Business Object Resource Business Object
Set-up Data Source	Plan Business Object Equipment Business Object Resource Business Object
Shutdown Cell	Equipment Business Object Resource Business Object Work Area Business Object Job Business Object Order Business Object
Split Order	Order Business Object
Startup Cell	Resource Business Object Work Area Business Object Job Business Object Equipment Business Object Order Business Object



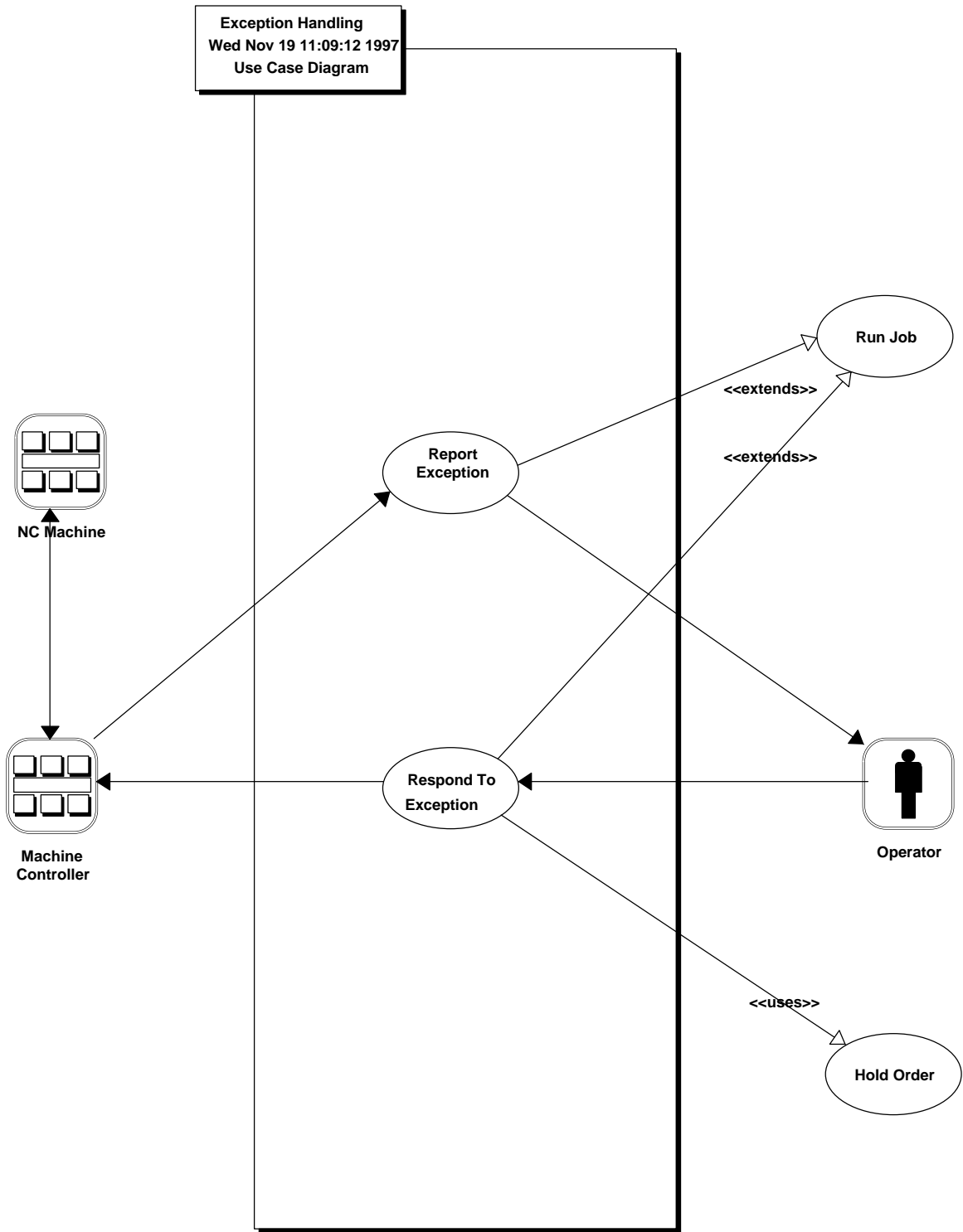
USE CASE NAME	BUSINESS OBJECT NAME
Track And Supply Shop Resources	Resource Business Object Tool Business Object
Unload Workpiece	Job Business Object
Verify Order	Order Business Object

### 6.3 Usage Model Detail Illustration

This section presents detailed illustration of a portion of the Usage Model. Usages are documented in collections of Use Cases indicating the interaction of actors conducting activity within the Domain. Each Use Case is textually defined as a sequence of steps, then transformed into a Sequence Diagram indicating the interaction among the Objects which carries out the Use Case. (See Appendix B for Notation explanation.)

#### 6.3.1 Representative Use Case Diagram

The following illustration summarizes the set of use case supporting the handling of exceptions. When an exception occurs as an **NC Machine** operates, the **Machine Controller** interacts with **Report Exception** with information regarding the event. *Report Exception* notifies the role **Operator**. *Operator* and the *Machine Controller* interacts with **Respond To Exception** to disposition the Exception. When running a Job, these two use cases can conditionally execute when an Exception occurs. These use cases “extend” the way **Run Job** use case behaves. *Respond to Exception* causes the Order to be held, that is *Respond to Exception* “uses” the **Hold Order** use case.





### 6.3.2 Sample Complete Use Case Definition

The following details the single use case **Respond to Exception**:

#### **Use Case: *Respond To Exception***

##### **Purpose:**

To acknowledge that an Exception has been recognized and to perform recovery procedures, in response to an Exception; to clear error condition(s) and return process to operational state; to diagnose cause of problem if possible. Underlying goals may be to ensure safety, protect equipment from damage, and maintain process quality.

##### **Participants:**

Operator (Maintenance Mechanic, etc.)  
Subject Matter Expert (optional)  
NC Machine via Machine Controller or Machine Control Monitor

##### **Preconditions:**

An Exception has occurred and has been reported (see Use Case *Report Exception*).

##### **Results:**

Recovery Plan for Exception has been retrieved and executed (e.g., Machine may be stopped, Maintenance Mechanic may be contacted for assistance, Production Order may be put on hold, etc.). Error condition cleared and process returned to operational state.

##### **Description:**

1. Operator recognizes error condition.
2. Operator, if able, diagnoses problem; else Operator requests help from Subject Matter Expert.
3. Operator formulates Recovery Plan, or retrieves one if it is already available.
4. Operator executes steps to return process to operational state.
5. Operator clears Exception.
6. Operator logs Exception and corrective actions taken.

##### **Notes:**

1. Under certain extreme situations, if failure detected, Machine Controller will shut down Machine.
2. If communications between the Machine Controller and a Machine Control Monitor fail for any reason, and Machine Control Monitor has reported an exception, the Operator should attempt to re-establish communications.
3. If attempts to correct problem are still unsuccessful or failure continues to occur frequently, a log entry should be made, Maintenance should be contacted to diagnose and correct problem, and Production Order status may be put on hold (see Use Case *Hold Order*).
4. Multiple Exceptions, in some situations, may be treated collectively as symptoms of one problem, or may be handled sequentially as individual problems.

5. Depending on severity of the problem and effectiveness of the recovery activities, the process will:
- continue from the point at which the Exception occurred
  - continue from a point prior to occurrence of the Exception
  - need to be reset (restarted from the beginning)

**Exceptions:**

None

**Extends/Uses:**

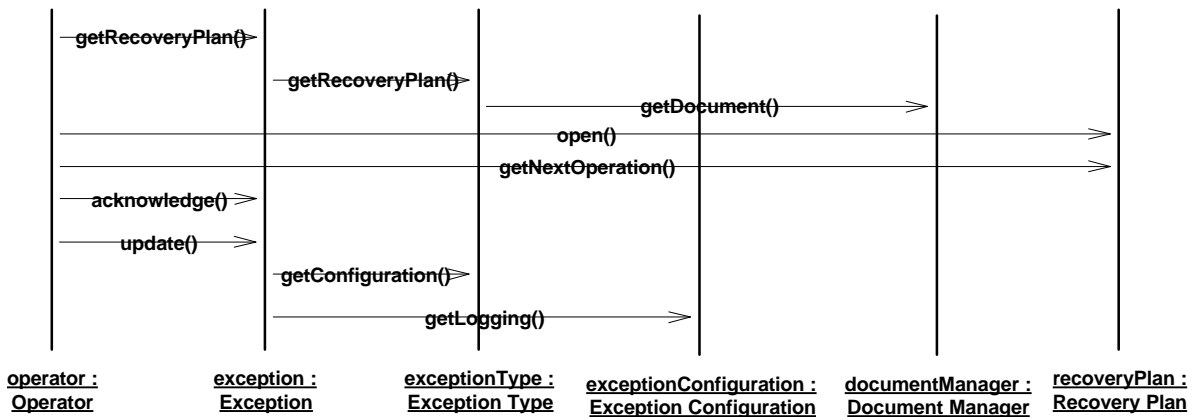
Uses *Hold Order*

Extends *Run Job*

6.3.3 Sample Sequence Diagram

The following illustrates the interaction of the Objects to satisfy the intent of the use case **Respond to Exception**.

SD:Respond To Exception  
Wed Feb 11 14:45:17 1998  
Sequence Diagram





## 7. Applicable Standards

At this time, Boeing recommends standards for the following:

- Measurement Business Object
- Order Business Object
- Product Business Object
- Raw Material Business Object

### 7.1 Measurement Business Object

**Title:** **Dimensional Measuring Interface Standard** Version 3.0

**Document Number:** ANSI/CAM-I 101-1995

**Summary:** A standard for the bi-directional communication of inspection data between computer systems and inspection equipment. It is a vocabulary of terms which establishes a neutral format for inspection programs and inspection results data. DMIS is also designed to be both man-readable and man-writable.

**Title:** **Methods for Performance Evaluation of Computer Numerically Controlled Machining Centers**

**Document Number:** ANSI/ASME B5.54-1992

**Summary:** This standard establishes requirements and methods for specifying and testing the performance of CNC machining centers. In addition, it facilitates performance comparisons between machines by unifying terminology, general machine classification, and the treatment of environmental effects. It defines testing methods capable of yielding adequate performance results for the majority of machining centers.

**Title:** **Methods for Performance Evaluation of Turning Centers**

**Document Number:** B5.57

**Summary:** *to be provided*

**Title:** **Methods for Performance Evaluation of Coordinate Measuring System Software**

**Document Number:** B.89.4.10 (draft)

**Summary:** Standard methods for evaluating mathematical algorithms.

**Title:** **Methods for Performance Evaluation of Coordinate Measuring Machines**

**Document Number:** ASME B89.4.1-1997

**Summary:** This standard establishes requirements and methods for specifying and testing the performance of CMMs with three linear axes perpendicular to each other and up to one rotary axis positioned arbitrarily with respect to these linear axes. The standard facilitates the performance comparisons among machines by unifying terminology, general machine classification and the treatment of environmental effects. It also defines the simplest testing methods capable of yielding adequate results for the majority of CMMs.

**Title:** **PDES/STEP (Product Data Exchange Specification/ Standard for Exchange of Product Model Data)**

**Document Number:** Application Protocol 219 Dimensional Inspect and Inspection Planning for CMMs  
ISO 10303

**Summary:** The STEP standard specifies a representation of product information in a neutral form along with the necessary mechanisms and definitions to enable product data to be exchanged. AP 219 provides a set of standard data definitions for development of inspection and measurement plans.

### 7.2 Plan Business Object

**Title:** **PDES/STEP (Product Data Exchange Specification/ Standard for Exchange of Product Model Data)**



**Document Number:** Application Protocol 213 Numerical Control Process Plans for Machined Parts  
ISO 10303  
**Summary:** The STEP standard specifies a representation of product information in a neutral form along with the necessary mechanisms and definitions to enable product data to be exchanged. AP 213, is divided into five categories: geometric shapes, manufacturing resources, design data, manufacturing activities and configuration management.

### **7.3 Product Business Object**

**Title:** PDES/STEP (Product Data Exchange Specification/ Standard for Exchange of Product Model Data)

Application Protocol 203 Configuration Management

**Document Number:** ISO 10303

**Summary:** The STEP standard specifies a representation of product information in a neutral form along with the necessary mechanisms and definitions to enable product data to be exchanged. AP 203, Conformance Class 3 is used to exchange part topology data with vendors, Conformance Class 6 is used to exchange part “solids” data with vendors.

**Title:** PDES/STEP (Product Data Exchange Specification/ Standard for Exchange of Product Model Data)

Application Protocol 224 Machine Parts Definition for Process Planning

**Document Number:** ISO 10303

**Summary:** The STEP standard specifies a representation of product information in a neutral form along with the necessary mechanisms and definitions to enable product data to be exchanged. AP 224 provides a library of machining features used to define and manufacture key parts.

### **7.4 Raw Material Business Object**

**Title:** PDES/STEP (Product Data Exchange Specification/ Standard for Exchange of Product Model Data)

Application Protocol 203 Configuration Management

**Document Number:** ISO 10303

**Summary:** The STEP standard specifies a representation of product information in a neutral form along with the necessary mechanisms and definitions to enable product data to be exchanged. AP 203, Conformance Class 1 is used to convey Bill of Material data to our suppliers. It includes configuration management data, product structure and specifications.





## 8. References

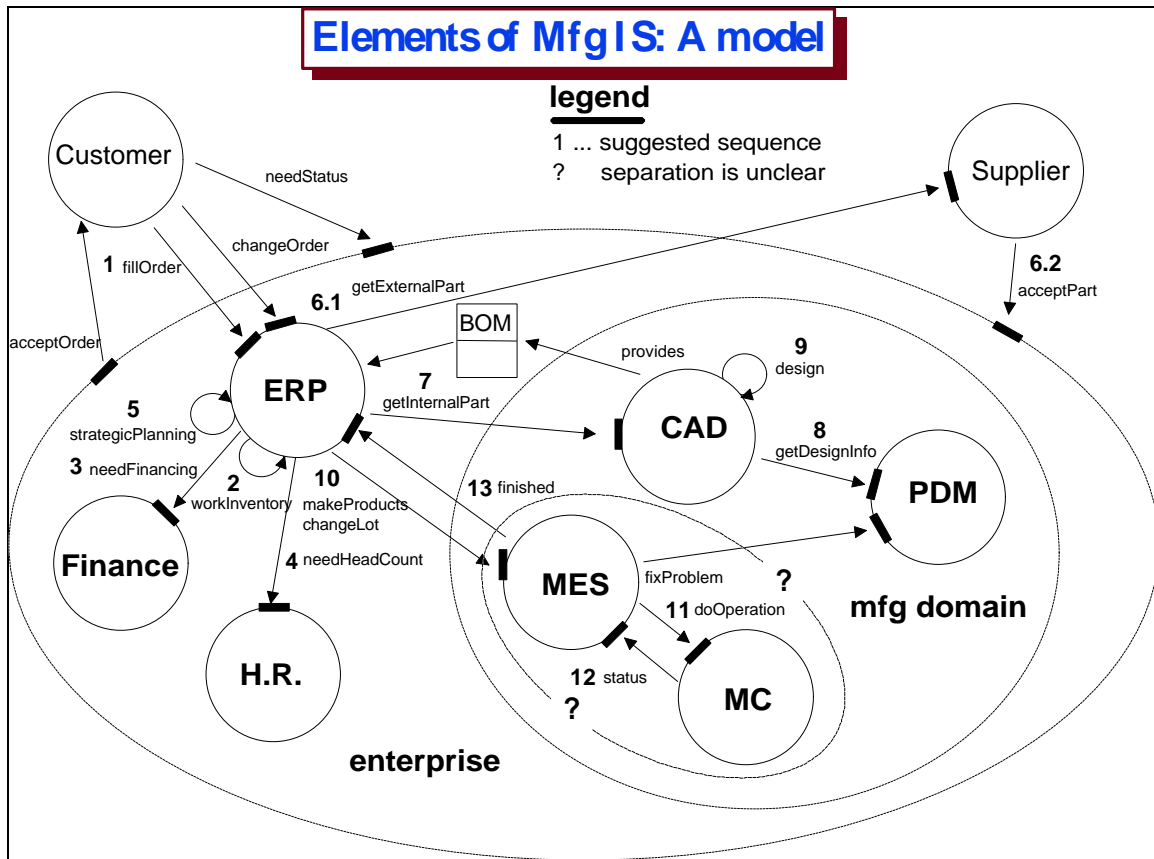
The material used as reference in building this response was:

1. Object Management Group, Manufacturing Domain Task Force, *RFI-3 Manufacturing Execution Systems (MES)*, OMG Document mfg/97-11-01, November 6, 1997.
2. National Institute of Standards and Technology (NIST), *SIMA Reference Architecture, Part 1: Activity Models*, NISTIR 5939, December 1996.
3. Gartner Group, various articles on MES available to subscribers from [www.gartner.com](http://www.gartner.com).
4. MESA International, various articles and white papers on MES from [www.mesa.org](http://www.mesa.org)
5. SEMATECH, Computer Integrated Manufacturing (CIM) Framework Specification 1.5, 930616971-ENG, [www.sematech.org](http://www.sematech.org).
6. The Boeing Company, internal material on Boeing Intranet.
7. OOPSLA 1997 Midyear Workshop on Manufacturing (to become available on WWW).

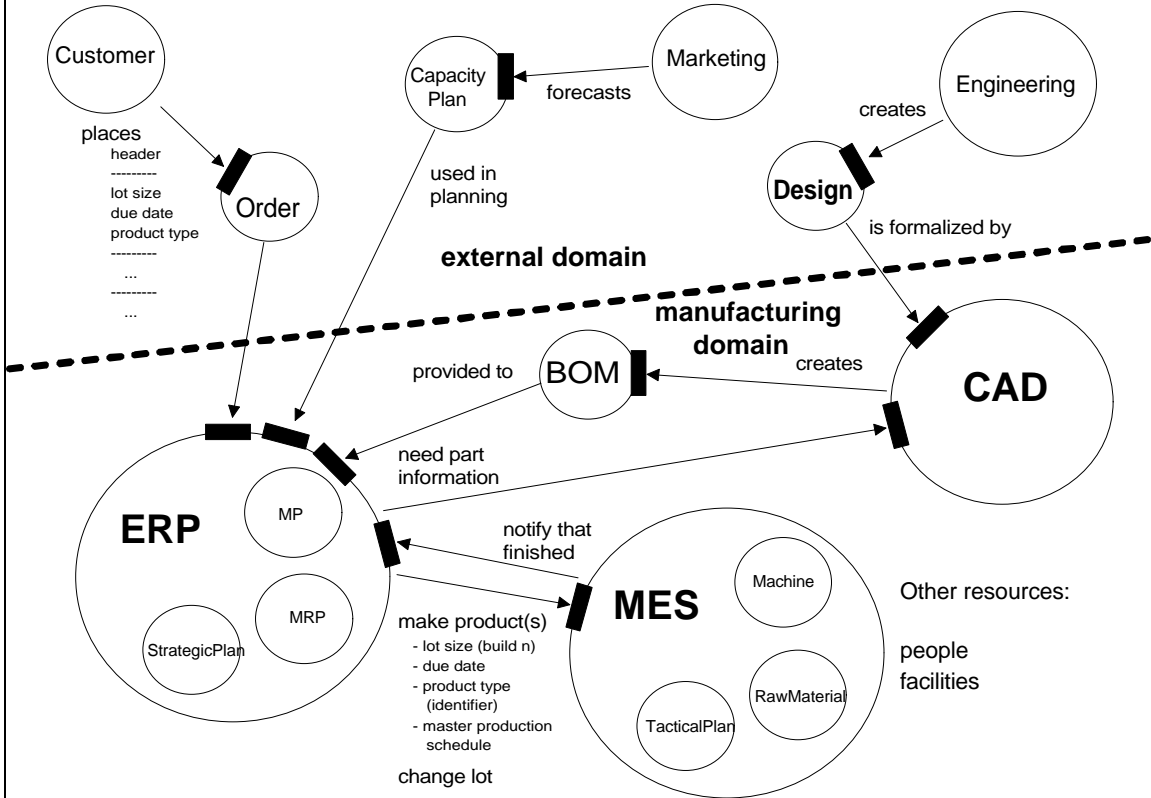
## Appendix A: OOPSLA Midyear Manufacturing Workshop Diagrams

Diagrams from the 1997 MidYear OOPSLA Workshop on Manufacturing Information Systems

Not only do the two diagrams here show interaction with other systems supporting manufacture, they also show what types of data flow among them and suggest a process flow in the sense of a sequence of steps.



# Elements of Mfg IS: A model (starting to “drill down”)



## Appendix B: Specifications Notations Overview

The notations used are from the Paradigm Plus implementation of UML.

### 1.1 Model Contents

The Model can be separated into two parts: a *Domain Object Model* and a *Usage Model*.

The **Domain Object Model**, which depicts the static, structural aspects of the domain, consists of:

- *Class Diagrams* which show business domain objects and their structural relationships, such as inheritance (generalization/specialization), composition/aggregation, and general associations; and are titled “CD:<diagram name>”.

The **Usage Model**, which depicts the behavioral aspects of the domain, consists of:

- *Use Case Diagrams* which describe external, “black box” views of behavior, from an end user’s perspective. They summarize participants, and functional partitions; and are titled “UCD:<diagram name>”.
- *Use Case Descriptions* are textual descriptions of Use Cases referenced in the Use Case Diagrams.
- *Sequence Diagrams* show Objects (packages, or encapsulations, of both data and function) and the sequenced interactions between them, in support of the Use Cases. These are Use Case-centric views; and are titled “SD:<diagram name>”.

### 1.2 Diagram Representations

The types of diagrams used in this Object-Oriented Model, supported by the Unified Modeling Language (UML) 1.0 Notation, are:

- Class Diagrams

Within each group of diagrams, summary or overview diagrams are shown first, followed by detail diagrams, ordered alphabetically.

Section 6.3 also includes a sample of the Usage Model diagrams used in development of the Object Model. The sample consists of one each:

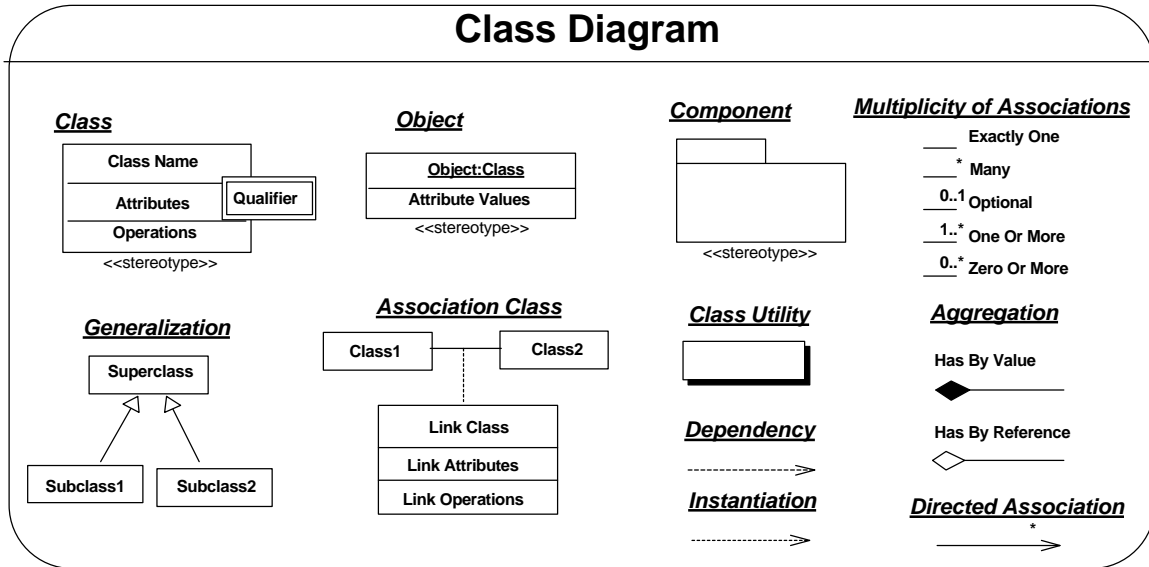
- Use Case Diagram UCD: Process Control
- Complete Text of the Use Case Inspect Part
- Sequence Diagram for the Use Case SC: Inspect Part

#### 1.2.1 Class Diagram Representations

**Class Diagrams:** essentially “classify” Objects into Classes (templates used to create instances of Objects), and show the relationships of *inheritance* (e.g., Maintenance Request is a type of Request) and *composition* or *aggregation* (e.g., Queue is composed of Queue Items). Groups of related Classes are shown together on a single Class Diagram, labeled as a “Business Object” (e.g., Tool Business Object shows, Tool, Tool Manager, Tool Certification, etc.) This model includes a Business Object summary

diagram to provide a high level overview of all Business Objects. Note that the component illustrated in this document is of type “category” as depicted with a double line rectangle.

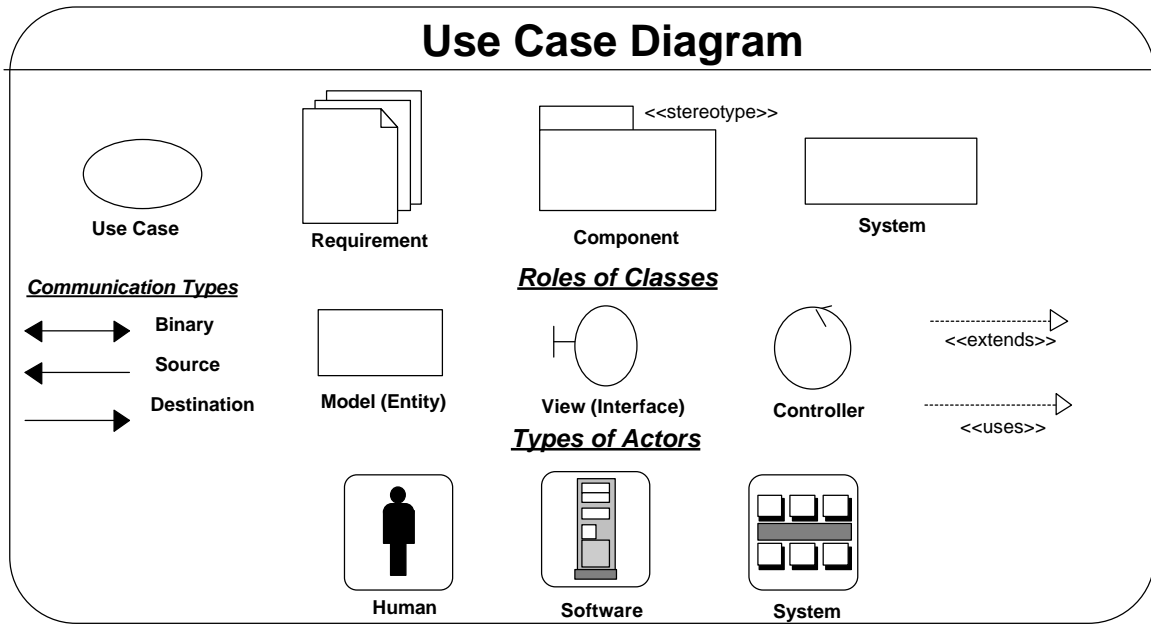
The following depicts the UML notation used for Class Diagrams:



### 1.2.2 Use Case Diagram Representations

**Use Case Diagrams:** are used to capture business or system requirements by describing how the business entity or system will be used, from the customer’s or user’s point of view. Each Use Case depicts some discrete collection of events and all its participants (people, machines or software applications, called “Actors”).

The following depicts the UML notation used for Use Case Diagrams:



### 1.2.3 Sequence Diagram Representations

**Sequence Diagrams:** are used to depict the Objects which are germane to, and responsible for carrying out, each Use Case. There is a one-to-one correspondence between an individual Use Case and a Sequence Diagram. Each Sequence Diagram shows the Objects (vertical bars), and their collaborations (directed, horizontal lines)--messages to, or requests for services from, other Objects. These collaborations are shown in the sequence or order the events occur (read from top-to-bottom on the diagram).

The following depicts the UML notation used for Sequence Diagrams:

