Reliability, Availability, and Maintainability Program Development Process for Existing Power Plants

AN AMERICAN NATIONAL STANDARD

The American Society of Mechanical Engineers

ASME RAM-2–2016

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The American Society of Mechanical Engineers
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FOREWORD

The purpose of this Standard is to provide a program development process to complement the higher-level reliability, availability, and maintainability (RAM) program described in ASME RAM-1. This Standard describes one way to implement a RAM program in an existing power plant.

The concept of RAM is based on the fundamental principle that power plant availability is a necessary goal. Plant personnel are responsible for ensuring availability by protecting the functional performance of critical equipment. This is done by finding the ideal balance between reliable engineering design, proper equipment operations, and effective and efficient maintenance at the best time. The RAM program is designed to address each of these points in a practical way that achieves measurable, real-life availability goals.

By addressing reliability and maintainability, ASME RAM-2 provides a process for developing a complete and effective availability program. It follows a risk-informed, performance-based approach. Risk calculations, expert opinion, and failure experience identify risks inherent with the design, which are then used to develop an effective scheduled maintenance and monitoring program.

Traditional terms addressing RAM-related work include preventive maintenance, scheduled maintenance, operations monitoring, and rounds. This Standard assists those responsible for programs that manage equipment assets by providing directly actionable guidance. This guidance should help power plants develop efficient, effective reliability and maintainability programs. It can also support the development of efficient, reliable maintenance for new designs.

This Standard assumes plant practices follow manuals, industry standards, and related asset management guidance. The RAM program is intended to control practices that influence results, following established industry practices. This RAM Standard does not cover human performance.

ASME RAM-2–2016 was approved by the RAM Standards Committee, under the jurisdiction of the Board on Standardization and Testing, on September 13, 2016, and approved by the American National Standards Institute (ANSI) as an American National Standard on December 2, 2016.

ASME RAM COMMITTEE
Reliability, Availability, and Maintainability of Power Plants

(The following is the roster of the Committee at the time of approval of this Standard.)

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General. ASME Standards are developed and maintained with the intent to represent the consensus of concerned interests. As such, users of this Standard may interact with the Committee by requesting interpretations, proposing revisions or a case, and attending Committee meetings. Correspondence should be addressed to:

Secretary, RAM Standards Committee
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Two Park Avenue
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http://go.asme.org/Inquiry

Proposing Revisions. Revisions are made periodically to the Standard to incorporate changes that appear necessary or desirable, as demonstrated by the experience gained from the application of the Standard. Approved revisions will be published periodically.

The Committee welcomes proposals for revisions to this Standard. Such proposals should be as specific as possible, citing the paragraph number(s), the proposed wording, and a detailed description of the reasons for the proposal, including any pertinent documentation.

Proposing a Case. Cases may be issued to provide alternative rules when justified, to permit early implementation of an approved revision when the need is urgent, or to provide rules not covered by existing provisions. Cases are effective immediately upon ASME approval and shall be posted on the ASME Committee Web page.

Requests for Cases shall provide a Statement of Need and Background Information. The request should identify the Standard and the paragraph, figure, or table number(s), and be written as a Question and Reply in the same format as existing Cases. Requests for Cases should also indicate the applicable edition(s) of the Standard to which the proposed Case applies.

Interpretations. Upon request, the RAM Standards Committee will render an interpretation of any requirement of the Standard. Interpretations can only be rendered in response to a written request sent to the Secretary of the RAM Standards Committee.

Requests for interpretation should preferably be submitted through the online Interpretation Submittal Form. The form is accessible at http://go.asme.org/InterpretationRequest. Upon submittal of the form, the Inquirer will receive an automatic e-mail confirming receipt.

If the Inquirer is unable to use the online form, he/she may mail the request to the Secretary of the RAM Standards Committee at the above address. The request for an interpretation should be clear and unambiguous. It is further recommended that the Inquirer submit his/her request in the following format:

Subject:	Cite the applicable paragraph number(s) and the topic of the inquiry in one or two words.
Edition:	Cite the applicable edition of the Standard for which the interpretation is being requested.
Question:	Phrase the question as a request for an interpretation of a specific requirement suitable for general understanding and use, not as a request for an approval of a proprietary design or situation. Please provide a condensed and precise question, composed in such a way that a “yes” or “no” reply is acceptable.
Proposed Reply(ies):	Provide a proposed reply(ies) in the form of “Yes” or “No,” with explanation as needed. If entering replies to more than one question, please number the questions and replies.
Background Information:	Provide the Committee with any background information that will assist the Committee in understanding the inquiry. The Inquirer may also include any plans or drawings that are necessary to explain the question; however, they should not contain proprietary names or information.

Requests that are not in the format described above may be rewritten in the appropriate format by the Committee prior to being answered, which may inadvertently change the intent of the original request.

ASME procedures provide for reconsideration of any interpretation when or if additional information that might affect an interpretation is available. Further, persons aggrieved by an interpretation may appeal to the cognizant ASME Committee or Subcommittee. ASME does not "approve," "certify," "rate," or "endorse" any item, construction, proprietary device, or activity.

Attending Committee Meetings. The RAM Standards Committee regularly holds meetings and/or telephone conferences that are open to the public. Persons wishing to attend any meeting and/or telephone conference should contact the Secretary of the RAM Standards Committee.

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RELIABILITY, AVAILABILITY, AND MAINTAINABILITY PROGRAM DEVELOPMENT PROCESS FOR EXISTING POWER PLANTS

1 INTRODUCTION

A reliability, availability, and maintainability (RAM) program is a structured way to identify and deliver the RAM requirements of a power plant in the most cost-effective manner. This Standard provides guidance for the program implementation portion of the RAM process described in ASME RAM-1. It is intended to implement a comprehensive availability assurance program. This Standard is intended for existing facilities.

2 SCOPE

This Standard amplifies and clarifies the requirements of ASME RAM-1 for implementing a RAM program for a power-generation facility. This Standard assists in developing program goals, identifying a master equipment list (MEL) to load into the enterprise asset management system (EAMS), and populating scheduling systems with finished content as complete work orders that are ready to perform work. A RAM program includes hierarchical breakdown of the facility, tagging of equipment (i.e., components), risk categorization of systems and equipment tags, development of common standards for components, and customization for similar context locations in the plant. This Standard finalizes work organization as task lists in work orders, routes, and rounds. It provides a process to implement ASME RAM-1 based on terminology and methodology used in power plants.

This Standard addresses the following:

(a) equipment assessment for risk
(b) asset tagging
(c) template selection and application
(d) equipment asset management software
(e) development and organization of work (e.g., development of operating procedures, rounds, and work orders)
(f) RAM program plans
(g) training required to implement the program

3 PURPOSE

The purpose of this Standard is to provide information to enable plant personnel to develop an effective RAM process in accordance with ASME RAM-1. An effective RAM program ensures that critical plant equipment performs cost-effectively as intended by design. This Standard provides an all-encompassing RAM support process that develops simple, clearly worded RAM analysis in accordance with ASME RAM-1.

4 DEFINITIONS

The following is a list of terms relating to the implementation and use of RAM programs:

age exploration: systematic examination of the lifetime a component or part can support in an application in-service.

coding scheme: an often mnemonic scheme that assigns equipment codes or tags; the scheme usually embeds the plant, unit, system, component type, numbered sequence of the component and higher-tier equipment of which the component is a part (system), subsystem, and perhaps additional information. Each plant requires a common coding scheme.

complex equipment:

(a) equipment that displays many unique combinations of parts, failure modes, and failure causes, none of which is predominant in failure of its functions.

(b) equipment that displays random failure patterns in-service. See also *simple equipment.*

contextual risk map: a map of all master equipment list (MEL) component tag information, customized with component risk information.

critical: likely to cause functional failure directly; failing a high-level performance goal in single fault.

custom template: an application of a standard template based upon one context, e.g., a standard template maintenance plan customized for one location. See *standard template.*

direct failure criteria: criteria limiting criticality risk classification to the failures that, with only a single occurrence, have the ability to affect operating goals. This criteria focuses scheduled maintenance resources and efforts where they will do the most good.

diversity: the use of different methods to achieve functional but not exact physical redundancy within a RAM program.

dominant failure mode (DFM): a likely failure mode of a component or part; it is considered in the design of the component or part and addressed in the maintenance plan.

evident: term used to describe events or failures that experienced operating crews should be expected to notice.

evident failure: a failure that is evident to experienced operating crews and staff (nonspecific to cause). Experienced staff should notice and report the failure, based on general experience with off-normal conditions and failure criteria. Knowing what symptoms operators will be able to see to identify a failure affects mitigation planning for addressing that potential failure. Conversely, when failures are not evident, different mitigation strategies to manage those failures must be used.

failure mechanism: the mode and cause of an equipment failure.

generalized time parameter: a parameter that measures the passage of time and aging of a component, and which may be used as the basis for scheduled maintenance. Number of operations, mileage, rotations, tons moved, and gallons flowed are examples of generalized time parameters.

incipient failure: preexisting, emerging, and developing, though not evident, condition whereby equipment is nearly ready to fail; a hidden failure that is presumed to have existed prior to its becoming evident.

life limit: a limit that ensures the rework or replace task for an aging component or part is performed prior to the component or part reaching its end of life. See *safe life limit.*

maintainability: the ability to access equipment, perform maintenance work, and return the equipment to operation. Access to parts, spare parts, and support tools; availability of trained, skilled personnel; ability to preplan work; and flexibilty of work rules all affect equipment maintainability. Maintainability supports the performance of "on-condition" (condition-directed) maintenance on short notice.

master equipment list (MEL): an equipment registry listing all installed plant equipment.

partitioning: the process of conceptually separating a component into its constituent parts for further evaluation and to differentiate risk; the development of a hierarchy that identifies system, component, and part subassemblies contributing functions. Also called system or component breakdown into constituents.

primary component: the component of direct interest in a failure analysis; the failed component for which mitigation measures are developed. See *secondary component.*

primary failure: a failure of a primary component; a failure within the analysis boundary.

RAM:

(a) reliability, availability, and maintainability.

(b) an ASME RAM program comprising a scheduled maintenance program with rounds and its complementary condition-based maintenance program response.

rounds: tasks performed at short intervals by operators to monitor areas and alarm conditions; these tasks may include routine alarm resets, equipment observations, and equipment realignments. Each round takes the operator on a path through a section of the plant to monitor local conditions.

routes: repetitive work performed on many different applications of the same component by a skilled technician or mechanic in the same way. Repetitive calibrations, for example, may be placed into one route.

safe life limit: a limit that ensures an aging safety-critical component or part provides uninterrupted service before reaching its end of life, or is replaced before reaching its minimum age limit. A safe life limit virtually guarantees items with direct safety risk never age out before a rework or replace task.

scheduled maintenance: planned maintenance tasks, including condition assessments, scheduled based upon a generalized time parameter. Equipment asset management scheduling systems (EAMS) primarily generate scheduled maintenance work orders; operator rounds software installed on personal digital assistants (PDAs) controls rounds. Operator distributed control system (DCS) screen sampling points on visual control screen displays are equivalent to EAMS work orders for operators.

secondary component: a component outside the boundary of the primary component; a separate component from the primary component of consideration.

secondary failure: failure of a secondary component; a failure outside the primary component's boundary, caused by a primary component failure. A secondary failure is external to the primary component, caused by the primary component, and therefore uncontrollable within the secondary component's boundary. Examples include secondary failures caused by fires, load falls from hoists or cranes, and missiles created from disintegrating rotating parts. No amount of scheduled maintenance on a primary component can eliminate the effects of external secondary component failures. Secondary failure can be avoided only by controlling failure at the original primary component itself, where the failure is a primary failure. See *primary failure.*

simple equipment:

(a) equipment that displays few failing parts, failure modes, and failure causes, or equipment for which only a few predominant failures occur.

(b) equipment that displays few dominant failure patterns in-service. Simple equipment is the opposite extreme from complex equipment (see *complex equipment*).

skid: a group of equipment that is purchased or assembled for delivery and /or final installation in the plant.

standard template: a model that summarizes and presents fundamental information for use and reuse; a standard building block for reliability analysis that presents critical information in a common style suitable for replication and use. It can then be applied to an actual component application. Standard templates present the equipment in abstract form separate from the plant, contextually.

tag: one plant-installed equipment item, coded by type for traceability and listed on the master equipment list (MEL). Also called equipment tag or equipment identifier (EQ-ID).

task: in RAM analysis, a unique, discrete, actionable, and measureable work activity intended to address a dominant failure.

train: a grouping of equipment redundant to an identical set of equipment that performs the same function as backup (i.e., redundantly).

type: a physical component type, such as pump, motor, or valve.

work order: a work control document required for maintenance.

work scope: multiple discrete tasks organized to perform together under common conditions. Work-order task content derives from RAM analysis. Planners aggregate tasks into a work scope to perform under a work order. Complex work-order plans like turbine overhauls include tens or even hundreds of tasks under one work scope. Also called work plan.

5 RAM PROGRAM

5.1 General

A RAM program shall be customized to the specific needs of a power plant. The program shall

(a) support other applicable qualified programs, such as the following:

(1) applicable standards (e.g., ASME Boiler and Pressure Vessel Code, ASME Performance Test Codes)

(2) inspection and scheduled maintenance requirements of government agencies (e.g., Environmental Protection Agency, Department of Transportation, Occupational Safety and Health Administration, Nuclear Regulatory Commission)

(3) regulatory program licenses

(4) equipment reliability programs

(5) jurisdictionally accepted safety programs (safety issues range from high risk, such as public health and occupational safety, to lower risk, such as chronic environmental health hazards)

(b) allow incremental implementation. A section-by-section implementation of the RAM program allows plant personnel to accommodate immediate needs, risk, and cost concerns.

Partial RAM program development supports safety, budget, and other practical factors, and supports operating plants, making continuous improvement possible.

(c) measure results. RAM's goal is to prevent functional failure. Equipment failure rate and system availability are measures of maintenance performance effectiveness. Other measures may be helpful as well. RAM programs shall measure performance effectiveness. The RAM program shall support engineering decisions based on the available failure data.

(d) routinely gather feedback from the following:

(1) age exploration, to improve technical content understanding

(2) new failure mode/mechanism recognition

(3) operating experience from similar equipment elsewhere

(4) root cause analysis, ranked bar charts, fishbone diagrams, and technical failure analysis

(e) incorporate feedback for improvement and learning. RAM programs shall be adaptable to sustain practicality and applicability (preventing obsolescence). They shall be able to use routine work performance feedback to update tasks and work intervals. Methods for incorporating feedback include the following:

(1) noting the absence of incipient failures found on completing work

(2) adjusting to shorter/longer intervals

(3) incorporating rounds feedback

(f) update solutions with actual data obtained in the field. The RAM program should continually evolve, too.

(g) incorporate current technology, such as

(1) microprocessor and sensors

(2) distributed control system (DCS) controls

(3) effectiveness monitoring screens

(4) diagnostics and monitoring equipment as separate measurement and test equipment

The RAM program should be capable of incorporating improvements in technology and processes, and should evolve as equipment aging introduces new deterioration mechanisms.

(h) address maintainability.

5.2 Maintainability

Maintainability determines turnaround, i.e., how quickly maintenance jobs can be completed. Many issues effect maintenance turnaround, including design and support hardware and other systems.

Maintainability is affected by access to equipment for monitoring, maintenance, and return to service. Maintainability should be a design, construction, and commissioning consideration. Other plant-operations considerations, such as the type and level of work expected, and the personnel and training required to do it, affect maintainability, too. A plant's processes and procedures play a hidden role in operators' ability to quickly restore equipment to service.

The RAM program shall address plant maintainability for the following areas:

(a) access — ease of access to work locations and the ability to work safely without special rigging and tools; assurance that workers have access to equipment that may need service, i.e., equipment is designed so that workers can open, remove, or enter it, and perform other activities

(b) laydown — availability of space to disassemble and store major components such as turbines, compressors, valves, and pumps, and provisions for disassembly and servicing of large equipment

(c) tools — need for special tools and tooling, and assurance that special tools are available ahead of work, or available through contracts

(d) training — availability and execution of specialized training to support scheduled activity and condition-directed work, and assurance that workers are adequately trained to do the work

(e) tagouts — predeveloped tagouts for anticipated work

(f) spare parts — establishment of a spares strategy that ensures availability of spare parts for specialized and other equipment, and that documents sources of emergency spares

(g) contracts and contingency parts — predevelopment of standard contracts for work

(h) maintenance plans — predeveloped plans for anticipated, scheduled, and condition-based maintenance; determination of the work the plant personnel can reasonably be expected to do

(i) diagnostics — diagnostics capabilities are known for failure modes

(j) rebuild — overhaul instructions and support are known and available by contract

The RAM program should have a comprehensive list of all plant equipment that identifies the expected service life of each plant component. This list of equipment assists in and simplifies maintainability planning. By developing a RAM program, plant owners can explore maintainability issues before construction begins. As plant physical construction proceeds, the ability to inexpensively address maintainability declines. The RAM program shall include equipment wear-out and aging information. This information shall be used to develop effective maintenance plans that prevent critical equipment aging failures and that avoid unanticipated but foreseeable high costs from deferring recognized, predictable work.

5.3 RAM Process Overview

The following is a summary of the RAM process, which is included in ASME RAM-1:

Step 1. Predevelopment

(a) Establish clear owner requirements as well as goals for reliability, availability, and maintainability of all critical systems.

(b) Establish the scope of the RAM program.

Step 2. Program Development

(a) Develop the MEL, utilizing a universal tagging classification.

(b) Define and assign equipment criticality based on risk.

(c) Develop the critical equipment list based on the following factors:

(1) component type and subtypes

(2) risk and service environment and use contexts

(3) replication of tags for components with similar contexts

(4) use of an efficient template application process

(d) Compare component templates; the prioritized MEL and systems descriptions enable this step. Replicate equipment in identical contexts.

Step 3. Implementation

(a) Develop the scope of work to do the tasks listed in work orders.

(b) Organize the tasks in Step 2 into structured work order plans (rounds and routes) by the conditions (i.e., the state of the equipment), tagout, and skill required to perform the work.

(c) Load the work scope that results from (a) and (b) into work control systems, principally EAMS and personal digital assistant (PDA) rounds, to finish work development.

Step 4. Revision

(a) Develop performance and exception reports.

(b) Review critical trends.

(c) Review, assess, and adjust the RAM plan accordingly.

(d) Based on experience (i.e., lessons learned), update work scopes and their tasks with changes, such as new equipment.

(e) Query personnel, and use the diagnostics to answer any questions.

(f) Efficiently structure work for the craftspeople by tagout, tools, skills, and other classifications.

(g) Present background material for use, and apply analysis and its results.

6 PREDEVELOPMENT

The owner shall set the scope, goals, and requirements for implementing a RAM program. Each of these shall be documented, and the documentation shall identify what is available and how it was used. Where materials to implement the RAM program are not complete, the RAM program owners and staff shall develop them when necessary to support work.

7 DEVELOPMENT

The following design materials, resources, and data shall be used, if available, to implement a RAM program:

(a) facility plans, strategies, and operating goals

(b) the MEL, also known as the asset registry
(c) vendor technical design documentation, including operation and maintenance (O&M) manuals
(d) system descriptions
(e) process and instrumentation drawings, and other engineering drawings
(f) guiding documents, e.g., corporate policies, standards, and goals
(g) documentation tools and libraries to develop work
(h) program development software and tools
(i) staffing and resources to develop the program and review results
(j) criticality criteria

The RAM program owner shall document the key program elements [(a) through (j)] and their contributions to the RAM program. Where program elements to implement the RAM program are not complete, the RAM program owners and staff shall develop them to support necessary work.

7.1 Scoping of Equipment

Systems that provide critical plant functions determine the scope of the RAM program, and thus the work specified by the RAM program is critical. RAM programs address, at a minimum, all critical systems, equipment, and parts. Equipment scope review starts with the plant's MEL (or registry) — a comprehensive list of installed equipment. The RAM program shall review all MEL equipment for scope inclusion. The order of review should be by system, component (including type), and group, or any logical combination of these that leads to a complete RAM program. In the end, all equipment reviewed is either in or out of the RAM scope, classified by criticality. "In scope" equipment is equipment that shall be considered for scheduled maintenance or predictive maintenance tasks based on risk; "out of scope" equipment is excluded from specific direct, scheduled maintenance, or predictive maintenance tasks in a RAM support system.

7.2 Systems Risk Categorization

Risk categorization helps rank (classify) critical equipment by context. This ranking brings focus to the equipment by level of risk. Classifying risk differentiates the levels of work on the same order, improving decision-making when budget limits force work-order tasks to compete. The RAM program shall identify each safety, production, and cost impact category based on consequence, and shall base categorization of "critical" on criticality of the function provided, using direct failure (DF) criteria.

The RAM program shall develop a criteria scheme and apply hierarchy levels, using DF criteria. The following table provides example relative values for the purposes of risk caterorization. The RAM program may use any risk subcategories or criteria scheme (qualitative values) as long as it ranks risk in the relative priority shown in the table. Of the risk categories shown in the table, safety, production, and cost are required (in that order).

Risk Category	Relative Value
Safety	1,000
Public	500
Environmental	500
Air	500
Water	500
Land	500
Site	900
Personnel	900
Production	
Primary system full	100
Efficiency systems partial	40
Cost	10
None (out of scope)	0

NOTE: The relative values shown in the table are arbitrary numerical values assigned to each of the risk types to illustrate the priority of each risk relative to the other risks. The values are provided as an example only.

7.3 Classifying Criticality

Classifying critical systems, components, parts, and their failures focuses scheduled maintenance failure management activities. Performing this step leads to exact, focused scheduled maintenance programs that achieve common support because the value of their proposed tasks is clear.

To determine what equipment is critical for analysis, the RAM program shall apply the functionality of each component using the following with DF criteria logic:

(a) Critical plant functions directly support plant operations.
(b) Critical systems provide critical plant functions.
(c) Loss of critical plant functions introduces risk.
(d) Probability and consequences (at a minimum) determine combined risk of function loss.
(1) risk = probability × consequences
(2) Any other use of the term "risk" shall be defined to ensure consistent use.
(e) Analysis determines risk of system function loss.
(1) Lower-probability events present a lower risk of function loss.
(2) Indirect low-probability events present a lower risk of function loss.
(3) Experts determine the probability of an event and the related risk of function loss based on experience, guidance, and facts. For indirect, nonsafety events, experts may rely on their opinion alone to determine probability and risk.

(4) Equipment tasks may concurrently mitigate multiple risks.

This analysis develops a hierarchy of functional requirements that complements physical equipment.

7.4 Partitioning (System Breakdown)

Breaking down a plant into functions (functional partitioning) and the components that support those functions (equipment partitioning) helps structure work, clearly revealing critical functions and components. Every component in the plant provides functions, some more important than others. The process of partitioning helps determine which are critical and which are noncritical. Critical components shall be addressed by the RAM program.

7.4.1 Functional Partitioning. Functional partitioning on multiple levels shall be logically performed. One method is as follows:

(a) Develop a functional block diagram (functional hierarchy) to identify the functions of the plant's systems and subsystems.

(1) A subsystem function supports a system function.

(2) A component function supports one or more subsystem function(s).

(b) Classify and rank functions by risk (critical and noncritical).

7.4.2 Equipment Partitioning. Equipment partitioning on multiple levels shall be performed according to a logical structure, such as the following:

(a) Develop an equipment block diagram (equipment hierarchy) to identify the equipment in the plant's systems and subsystems.

(1) Piping and instrumentation drawings (P&IDs) should be used in developing equipment.

(2) A system is comprised of subsystems.

(3) A subsystem is comprised of components.

(4) A train or skid may be considered a subsystem.

(b) Utilizing the functional block diagram, identify components that support critical functions.

(c) Perform a single-point-failure analysis on systems and subsystems containing critical components.

(1) Critical components whose direct failure interrupts a critical function of a system shall be considered "critical."

(2) Noncritical components provide functions indirectly through redundancy or diversity.

(d) Address risk control of components that will present critical function loss should direct failure occur.

7.4.3 Critical Components. Identifying critical components allows the most effective use of RAM templates. Identifying components' critical basis reduces work, which lowers costs and reduces risk.

The following factors should be considered when determining component criticality:

(a) Critical components directly affect critical functions in single direct failure.

(1) Criticality depends on the component's effect on critical system functions.

(2) To be critical, component failure must cause critical function loss.

(3) A single failure that causes a critical function loss shall be considered a direct failure.

NOTES:

(1) Using the DF risk criteria restricts use of the term "critical." If "critical" use is not restricted to specified critical equipment with critical failure modes, analysis becomes inexact, i.e., it is more difficult to apply consistently. More equipment will be classified as critical than should be. This dilutes critical-failure-risk equipment with low-risk equipment, burdening the RAM program with inconsequential scheduled maintenance performed on less important equipment.

(2) The RAM program designates equipment component hardware as critical if its failure would result in the direct loss of a high-level function. For standby redundant safety instrumentation or alarms, analysts shall assess criticality of the protected failure, treating the event as if it has already occurred and placing the instrument or alarm on demand. Similarly, in criticality analysis for instrumentation and redundant trains, analysts shall treat the protected-condition equipment function as if the alarmed or protected condition is present.

(b) Design documentation identifies critical systems, equipment, components, and parts. Design documentation includes, but is not limited to, the following:

(1) system outputs and descriptions

(2) the coded MEL

(3) as-built drawings, P&IDs, functional block diagrams, and instrumentation and controls drawings

(4) control vendors' technical material (VTM), including O&M manuals

(c) Equipment partitioning (e.g., system, division, skid, train, component, and parts) assists in identifying critical components because it shows the relationship between critical system functions and the equipment.

(d) Analysis of design documentation reveals critical component single-failure points.

(e) Codes, standards, and industry design literature help define critical components and their parts.

7.5 Standard RAM Templates

The RAM program shall be based on the replication of identical work. Component-type templates offer an efficient, effective way to achieve consistent replication for multiple similar components. Standard RAM component templates enable development of consistent programs for common equipment that is replicated many times in a plant. Templates can be used for equipment, tasks, and work orders. The RAM program shall standardize data format to simplify operating-program work and reduce costs. Every component has a context. Components that share the same context shall use the standard templates. Components with rare or unique contexts shall use custom templates as described in 7.6.

7.5.1 Definition and Use. RAM programs shall use standard templates. Templates replicate common critical plant equipment and standardize its information content review, application, retrieval, and use. Standard templates model plant components as common building blocks of pertinent information. Equipment suppliers provide initial content to develop standard templates, which are then used to provide the source information to develop custom templates for equipment installed in the plant.

RAM template content shall address the following:

(a) equipment/component type, name, nominal application (generic context), and supplier (this information is available from the MEL)

(b) function(s) (as indicated on the functional block diagram; see 7.4.1)

(c) equipment hierarchical ranking (as indicated on the equipment block diagram; see 7.4.2)

(d) dominant failure modes (DFMs)

(e) failure diagnostic symptoms and response

(f) anticipated scheduled maintenance

(g) manufacturer's service recommendations

(h) references and applicable standards and codes

RAM templates shall provide failure mitigation tasks organized based on component design using a type/subtype structure (e.g., motor/form wound rotor; pump/vertical low head).

7.5.2 Component RAM Template Models. Component templates model discrete elements of replicated plant equipment, reflecting actual use in the plant. Using a component model that emulates the actual as-built plant decreases the complexity of plant designs. The following are guidelines for the development of template models:

(a) Model components, e.g., low-head vertical pump, DCS drop, microprocessor board.

(b) Provide common component nomenclature (name description and tag code) that suggests functions, e.g., coolant pump, Train-A condensate pump, boiler feedwater pump.

(c) Provide common design information (beyond the tag and name) to identify all component functionality.

(d) Standardize component maintenance programs.

(e) Customize the context of multiple components, where needed.

(f) Provide common standard components.

(g) Differentiate component type/subtype (class/subclass) (e.g., valve/safety; pump/vertical).

(h) Provide access to VTM and O&M manuals available from component suppliers.

(i) Provide links to any parts, diagnostics, tests, repairs, use, and service context identified in the VTM.

(j) Identify missing information from the supplier (e.g., failure mechanism data).

7.5.3 Failure Hierarchy

(a) The component failure hierarchy is as follows:

(1) Functional failures originate at the physical-part level of a component.

(2) Part constituents are physical entities with physical properties.

(3) Parts exhibit DFMs.

(4) Failure modes can be identified as changes in a constituent property.

(5) Constituent properties may change dependently over time due to aging. That is, aging of component parts and their properties is a time-dependent process.

(b) Part restoration requires identification and localization of failure, to allow for planning and performing the actual work. Breaking down component functions by constituent parts differentiates sources of risk and traces them to physical equipment parts that can be serviced.

(1) Part functions relate to proximate (local) failures.

(2) Parts relate proximate failures to component and system functions via failure mode and effects analysis (FMEA).

(3) Selection of effective failure mitigation strategies depends on the nature of the part failure, i.e., whether it is hidden or evident.

(c) Parts hierarchy depends on the parts and the functions supplied. The following concepts should be considered:

(1) relationship of parts to component failures (determined via FMEA)

(2) failures based on service in the context of the plant

(3) maintainability

(4) similarity to other parts and context when no failure history experience is available

7.5.4 Failure Modes. Systematically identifying all DFMs at the parts level supports focus on physical causes. Using templates facilitates an effective, complete program with lower risk of ambiguous, overlooked failing items. Leaving even one DFM unidentified raises the risk of critical failure because it means there is no plan for dealing with that DFM.

RAM plans shall identify all DFMs of each critical component part. Failure mitigation tasks shall address the physical failure, identified at the part. The following provides an approach for establishing DFMs:

(a) All failures begin at a component part.

(b) Parts exhibit DFMs.

(1) DFMs are failures actually observed over a component part's life.

(2) Simple, common terms should be used to describe DFMs.

(c) A component's part provides a proximate failure location.

(d) A failure mode is how a failure occurs.

(1) The RAM program shall address each cause of a critical failure mode.

(2) Critical failure modes directly fail critical parts and components.

(3) Depending on design, parts and components may exhibit multiple, one, or no direct failure modes over the expected life of the plant.

(4) Failure modes further develop failure. The RAM program should also use simple, common terms to describe failure modes.

(e) A failure cause is why the failure occurs. The RAM program shall identify the failure cause so an effective task may be identified to correct the failure and restore functionality.

(f) Actionable discrete activities termed "tasks" manage (detect, prevent, and/or mitigate) failures by addressing failure causes.

EXAMPLES:

(1) Stress Corrosion Cracking

– Failure mode is cracking.

– Failure cause is stress corrosion due to susceptible material.

– Corrective task: Replace susceptible material with resistant material (mitigate), provide a protective coating (prevent), or increase inspection frequency (detect).

(2) Pipe Failure

– Failure mode is pipe rupture.

– Failure cause is water hammer due to insufficient start-up draining capability.

– Corrective task: Redesign or install increased draining capability (mitigate), modify operational procedures to stay within drain capability (prevent), or install drip-leg float alarms (detect).

7.5.5 Tasks. Identifying tasks that mitigate their associated DFMs reduces the risk of ineffective task development and component loss. Developing tasks in application context ensures a more consistent, usable program. Preestablished intervals that address expected failures provide critical information so users know what to expect before a component enters service in the plant.

A RAM program shall base tasks on critical DFMs and shall address all critical safety failures and establish safe life limits for aging components. The following provides a logical approach to the development of tasks:

(a) Task activities for DFMs and their causes shall be based on the following:

(1) Subject matter experts select tasks to address failure causes.

(2) Tasks mitigate, prevent, and/or detect DFMs.

(3) Tasks shall be objective, repeatable, and measurable.

(4) Tasks shall explicitly identify the failure modes and causes that they address (traceability).

(b) Tasks shall be objective factors that explicitly define exact limits (tolerances) and intervals (frequency).

(c) Tasks shall identify all necessary requirements, such as

(1) outage of equipment or system

(2) craftspeople, skill set, expertise

(3) parts or consumables

(4) special tooling for equipment

(d) Tasks shall consider the context, including design service and environment stress.

(e) Types of tasks include

(1) time-based rework, replacements, and overhauls (must be within safe life limits)

(2) conditional testing (predictive maintenance-type testing)

(3) condition monitoring

(4) functional testing

(5) doing nothing (no scheduled maintenance)

7.5.6 Preblocking Work. Organizing tasks into preliminary work blocks (work groups) conserves resources by effectively enabling related work to be completed under one tagout boundary. The intent is for one work scope to complete as much work as possible in a single procedure. Preblocking populates work orders with tasks to optimize resources. Standard template work orders shall preblock task requirements. The following provides a logical approach to the preblocking of tasks for work orders:

(a) Tasks identify content and requirements.

(b) Work orders consist of multiple related tasks. Work orders shall comply with the following:

(1) Tasks preblocked within a work order shall be related by content and/or requirements.

(2) Each work order shall comprise only one tagout boundary.

(3) Work orders shall consider the equipment and its context, attributes, and system application.

(4) Work orders should reference the reasons for preblocking specific tasks when those reasons are not clear from the work.

(5) Work orders shall consolidate redundant or duplicate tasks to minimize required resources.

(6) Work orders shall facilitate maintenance and retrieval of inspection data.

7.5.7 Vendor's Recommendations. The RAM program should consider vendor's recommendations as the starting point for the development of maintenance tasks. These are found in official technical literature, especially vendor O&M, design, and installation manuals. The RAM engineer is responsible for modifying and adjusting the vendor recommendations to customize the maintenance and resources to the site-specific context that most effectively mitigates risk.

7.6 Custom RAM Templates

Custom templates account for the site-specific variation of an actual component's installation. Custom templates limit the tasks performed (from standard templates) to just those necessary, and adjust intervals and reorganize tasks to reflect specific plant context, application, and attributes.

7.6.1 Contexts. A context is a function of the attributes of a component that make the component unique, such as location in the plant, service, risk, criticality, environment, and age. Contexts should be grouped by relevant application. Use of context permits a standard template to be customized.

7.6.2 Sources. Standard templates are used as the basis, or source, for most custom templates; this minimizes rework and maintains consistency across all templates. Development of a custom template without the use of a standard template should be considered only where the equipment is unique. In such cases, it is the responsibility of the RAM engineer to consult the VTM and subject matter experts regarding the specific context and the risk associated with using a non-standard-based template.

7.6.3 Common Context Application. Multiple equipment items in a plant often share a common context. Using a common context standardizes work task content across all common instances of a group and is another way to simplify and standardize work. Grouping minimizes customization and variation that would increase program complexity, lower effectiveness, and raise costs. Context may include

(a) duty cycle based on installation usage
(b) installation-dependent environmental stress
(c) functions, provided directly, indirectly, or redundantly
(d) diversity of equipment functions
(e) design margin
(f) other risk functions

RAM programs shall identify the common contexts by component type, and then group similar tags that share the same program based on similar context. A common equipment tag may identify a context group. The group may be identified by a common application, common tag, or similar unique name.

7.6.4 Custom Template Attributes. A custom template should be based on a similar component-type standard template and its attributes. RAM personnel customize standard templates into custom templates by modifying the existing or providing additional application attributes, based on context. Custom templates share common attributes with standard templates. Considerations for custom template application include the following:

(a) Specific failure causes should be individually identified and grouped for common tasks.
(b) Work scopes organize tasks into activity groups that depend upon specific plant design, organization, and tagout boundaries. Work scopes should be
(1) organized independently for tasks and tagouts
(2) based on plant context for tagouts, which depend on the plant
(c) Consider operator rounds tasks as generalized work scopes.

See Mandatory Appendix I, Figure I-2 for information on creating a custom template.

8 IMPLEMENTATION

Implementation schedules and conducts monitoring, testing, inspection, and maintenance of critical equipment to achieve the RAM program goals.

8.1 Work Activity

Operations manages control, configuration, and monitoring of the plant; maintenance personnel manage equipment functionality. Operations typically performs established fixed-routine, short-term tasks for surveillance and monitoring in the form of rounds. Maintenance personnel typically perform longer-term planned activities requiring change-of-state of equipment using tagout controls under a work order system. Based upon the plant-specific differences (e.g., personnel, equipment complexity, management), the context and definitions may vary. All RAM program work shall be loaded into rounds or the work order system.

8.1.1 Operators' Rounds

(a) Physical Rounds. Operators' rounds are an effective means of handling simple, short-duration tasks as part of routine (e.g., daily) activity rather than as part of a work order. Operators physically walk through the plant doing useful checks on mostly random failures that result in local condition changes, alerts, and alarms. These physical checks mitigate risk on equipment that is not remotely monitored. Operators' rounds provide a simple way to do highly repetitive operator tasks. Assigning craftspeople or operators to do the same tasks under a work order would be inefficient and would increase the costs of short-term operational checks.

Consider the following attributes when developing rounds:

(1) Rounds apply to simple, short-interval tasks.
(2) Rounds are performed on equipment in-service without tagout.
(3) Rounds should not exceed what operators can do during a typical shift.
(4) Rounds primarily consist of area checks, alarm checks, and condition checks across multiple areas, and may include, but are not limited to the following:

(-a) visiting spaces to check for audible noises or unusual smells

(-b) checking restricted access areas to confirm doors are closed

(-c) checking remote areas for unusual conditions (e.g., leaks, smells, flooding, arcing) so that such conditions don't affect operations

Routes capture routine rounds or craft activities, addressing similar tasks on many pieces of equipment in a repetitive way.

(b) *Operator Monitoring Screens.* For the control room operators, screens present a means of performing visual rounds. The operators regularly monitor the screens, which, in the event of an unusual condition, prompt the operators to act. Monitoring screens thus are a form of automated rounds.

8.1.2 Work Orders

(a) Work orders shall manage maintenance functions, control and complete plant work, and address RAM program goals. Work orders should include

(1) scheduled work

(2) planned routine work or repetitive common tasks

(3) emergent conditional work

(4) preventive maintenance

(5) condition-directed maintenance

(b) Work order tasks may be categorized as

(1) rework/replace/overhaul

(2) condition assessment (i.e., conditional check followed by on-condition work, when needed)

(3) failure-finding tests (e.g., pass–fail test, operational test, start-up surveillance test)

(4) combinations of (1) through (3) for high-risk event control assurance, e.g., safety

Servicing and overhaul typically include multiple tasks.

8.1.3 Blocking. Blocking is an administrative tool used to ensure that the maximum work possible is performed efficiently under one tagout. Work orders, which comprise one or more tasks, shall block work. Reblocking customizes standard template work for the plant's tagout and work classification rules. Blocking shall

(a) integrate tasks into logical groups to perform work

(b) use tagouts, worker skills, and other group attributes

(c) support multiple work plan steps

(d) support routes

(e) block tasks for shutdown

(f) consider tagout, worker classification, and other crafts and factors like specialty skills

(g) evaluate and then reblock work order tasks based on the content of (f) above when customizing a standard template

8.1.4 Work Planning. All RAM program work activities shall be planned. Work planning should follow the following guidelines:

(a) Work plans include all information needed to execute and perform work effectively, such as

(1) engineering review to identify tasks to perform

(2) plans for independently integrating tasks into blocked work

(3) tagouts

(4) tools

(5) support services and related personnel, such as nondestructive test technicians, welders, heat treat technicians, and contractors

(6) spare parts

(7) consumables

(8) procedures

(9) excerpts from VTM

(b) Work plans identify the worker(s)—e.g., plant-assigned skilled worker, contractor, corporate support staff—who performs the work, and the worker's skill.

(c) Work plans should resource-load work with estimated time, duration, materials (including parts serviced or required, and tools), and services.

(d) Work plans provide links to related reference information.

(e) Work plans include historical failure experience for reference.

(f) Work is done under the control of a work order. Tasks are discrete elements of work.

8.2 Measurement

A RAM program implementation shall measure and monitor the following:

(a) metrics to gauge

(1) plant performance against the established objectives and goals (e.g., failure statistics of critical equipment and actual versus budgeted costs)

(2) program development (e.g., MEL, engineering analysis, templates)

(3) program implementation (e.g., work orders and rounds complete)

(4) program completion and revision (e.g., audit)

(b) failures for task appropriateness and interval changes on a continual basis. Repeat failures are analyzed for root cause.

(c) components and their associated systems for reliability, longevity, and indirect failure risk where integrated with digital control systems.

These measures will assist RAM program management in the quantification of risk.

8.3 Training

The RAM program shall develop appropriate technical and process training for

(a) engineering and program development

(b) planning and implementation

(c) scheduling and completion
(d) auditing

9 REVISION

9.1 General

The RAM program, including the MEL, templates, rounds, and work orders, shall be reviewed and revised on a periodic basis. The review and revisions shall be documented.

9.2 Revision Evaluation

The revision process requires feedback from all technical aspects of the program, and assessment of programmatic goals, purpose, and scope. Plant operators can then act on the feedback, making needed changes in a timely manner and thus preventing program obsolescence.

9.2.1 Work Activities. Routine work regularly reveals new information about how equipment performs and how easily it can be serviced. Monitoring of equipment reveals how well parts perform in contrast with plans. Based on information learned during regular work activities, plant maintenance and operators can adjust and revise the RAM program, ensuring that it evolves where needed.

9.2.2 Failures. RAM programs shall routinely review critical failures and maintenance work orders to identify new equipment failure trends, such as new failure modes and their causes, as well as programmatic issues. Understanding failure trends by component type allows operators to make adjustments, which improves program performance.

9.2.3 Operating Experience. When considering updating the RAM program, a RAM engineer should consult plant operators about their experience, and should review information posted on industry forums and in user groups. Review of operating experience may reveal new failure modes and causes that may apply to specific types or brands of equipment. Reviewing high-profile industry events at other plants may reveal new trends that may apply at the plant.

9.2.4 RAM Data. Industry, regulatory, and commercial data on reliability, availability, and maintainability (e.g., forced outage rate, demand equivalent forced outage rate) may be used to update the program.

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MANDATORY APPENDIX I
RAM PROCESS FLOWCHARTS

Figures I-1 through I-6 begin on the following page. The following acronyms are used in the figures:

CR = control room
DCS = distributed control system
EAMS = equipment asset management system
MEL = master equipment list
MWO = maintenance work order
O&M = operations and maintenance
PDA = personal digital assistant
RFCA = root cause failure analysis

Figure I-1 Overall Program Development

Assumptions: Traditional documents and other design tools have been developed (O&M manuals, drawings, functional descriptions, test instructions, etc.) to support the facility's design. An MEL has been developed. Components are classified by type and coded into an MEL. Every unique component in the plant design has a unique identifier code in the MEL.

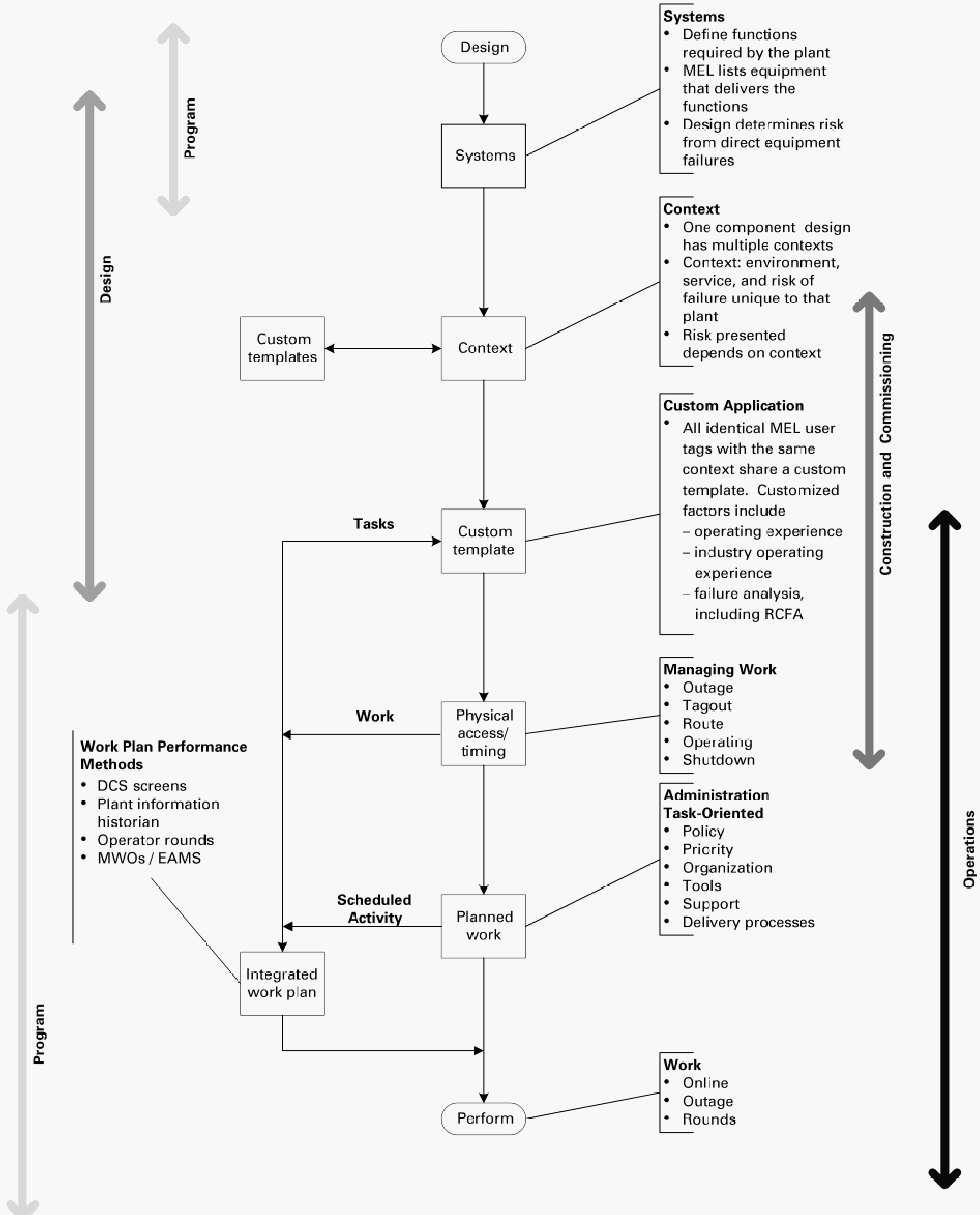


Figure I-2 Custom Template Development Framework

Assumptions: Traditional documents have been developed (O&M manuals, drawings, functional descriptions, test instructions, etc.) that support the replicated component's design. An MEL has been developed. Components have been classified and coded into the plant's MEL by type/subtype. Every component in the plant design has a unique identifier code in the MEL.

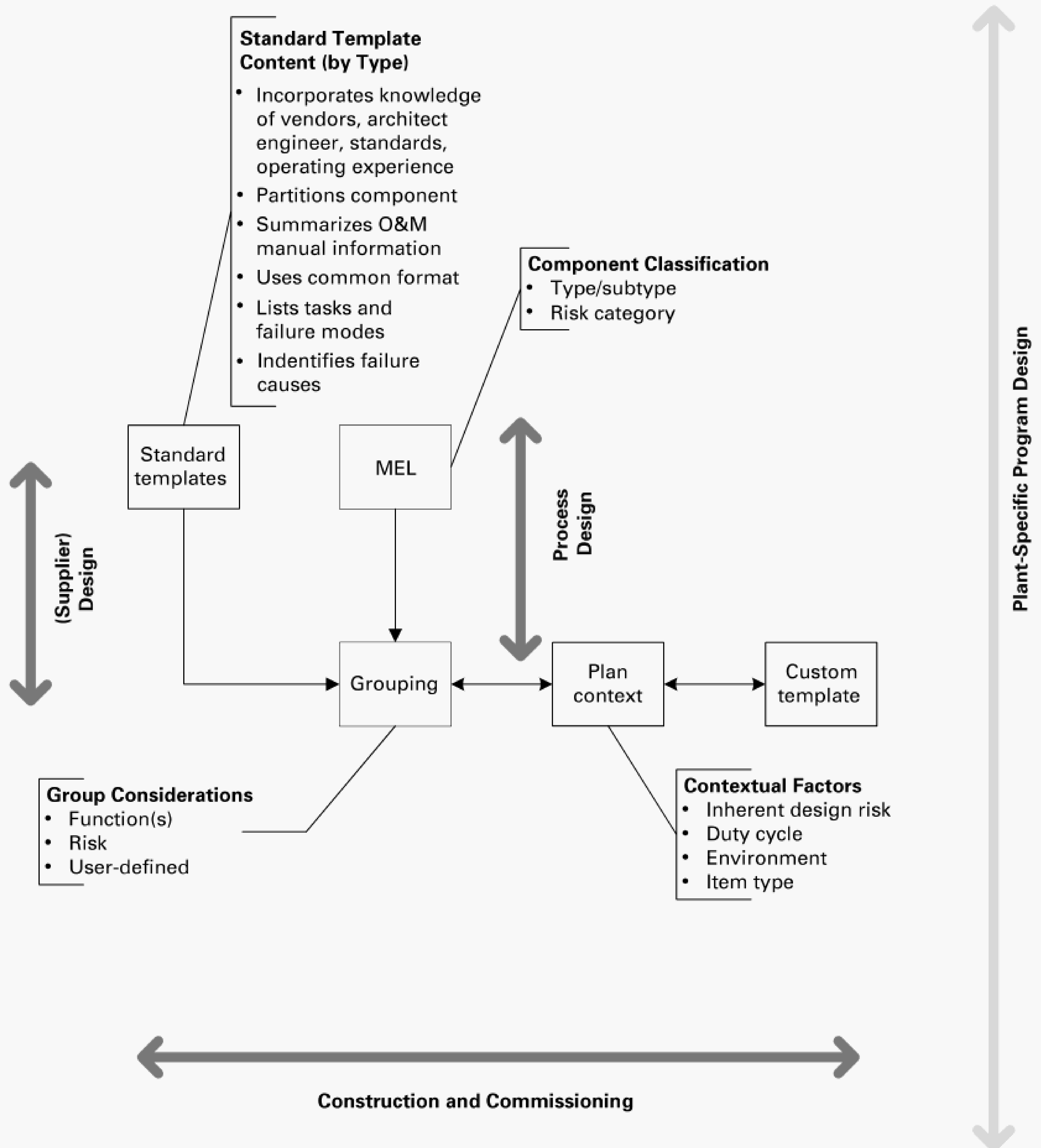


Figure I-3 Program Predevelopment

Assumptions: A traditional plant design has been developed, including performance requirements; functional requirements; systems; process and instrument drawings; supporting E, I, and M drawings; isometrics; vendor drawings; and literature. The plant design is controlled and available in historical traditional manner, albeit via Web applications (AutoCAD for drawings, PDFs for test documents, etc.).

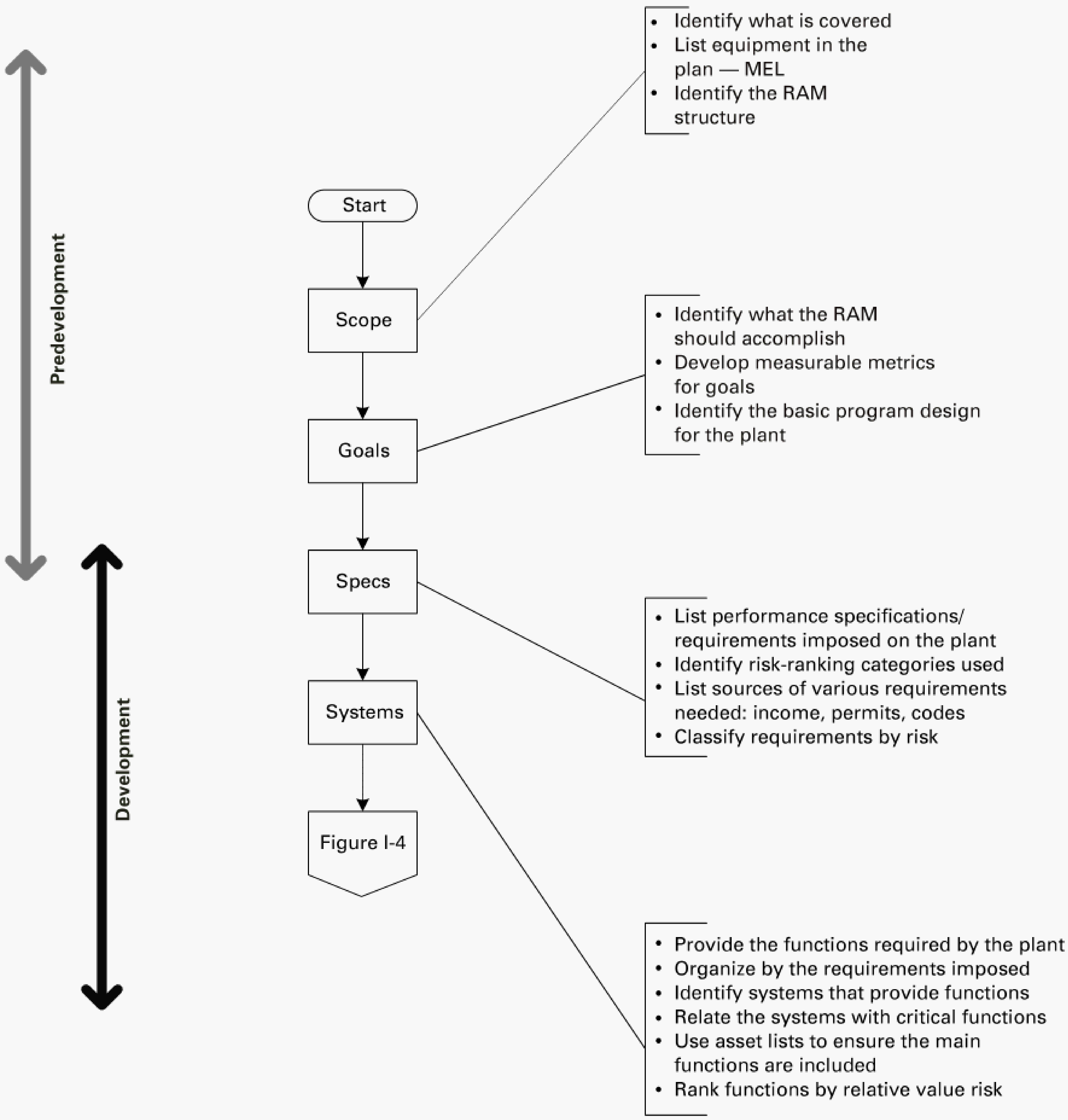


Figure I-4 Program Development

Assumptions: The program standardizes around similar components with standard templates to develop common activities that address functional needs of the equipment separate from (outside) the plant. Using the MEL, the program replicates those templates based on functional needs in different instances in the plant based on context, generating custom templates for groups of identically worked equipment that share a common work approach.

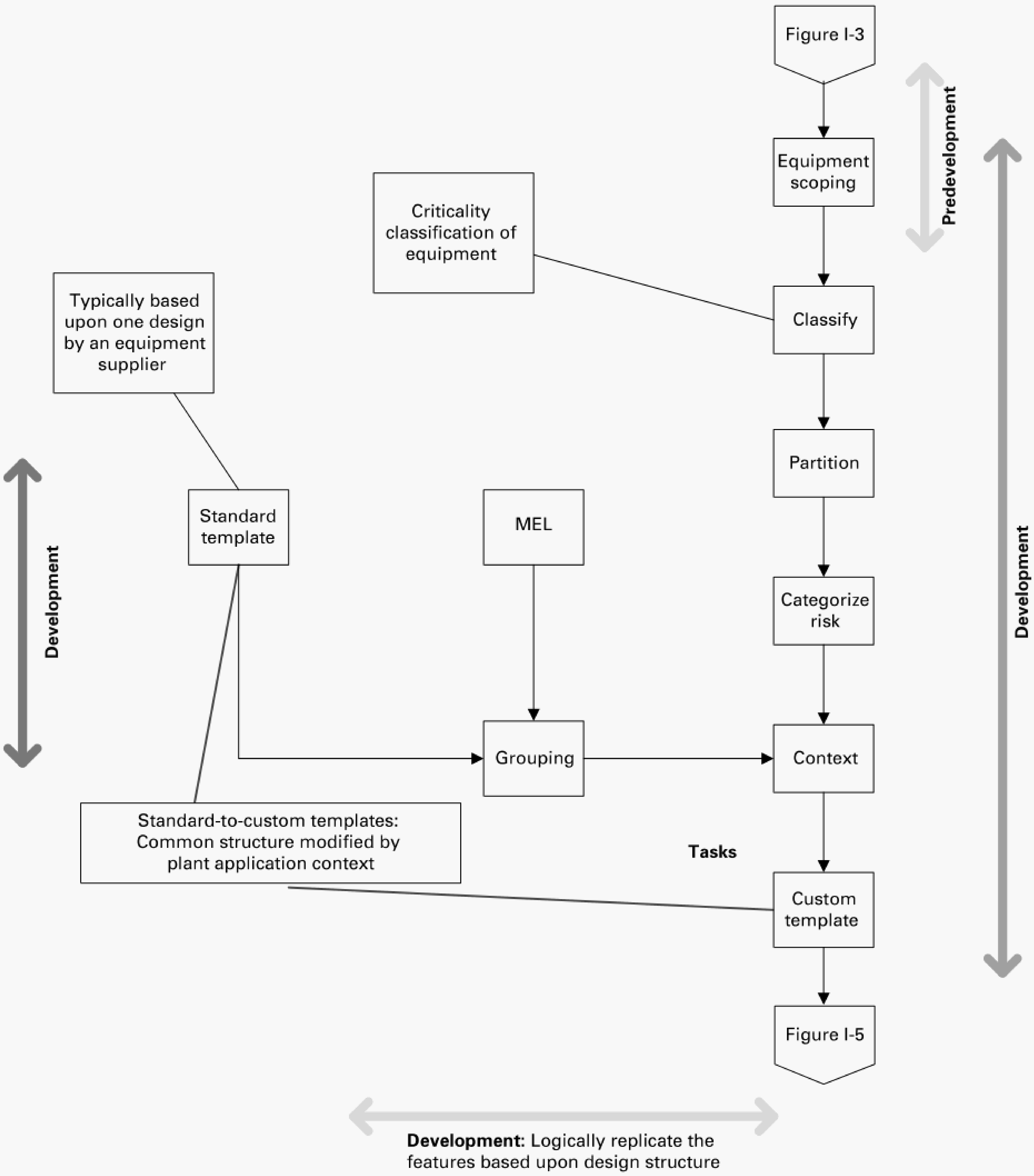


Figure I-5 Program Implementation

Assumptions: The program standardizes work by component tags as MWOs and rounds to perform discrete task activities that address equipment functional needs in the actual plant. Based on the MEL, the program replicates work based on templates organized by trade skill.

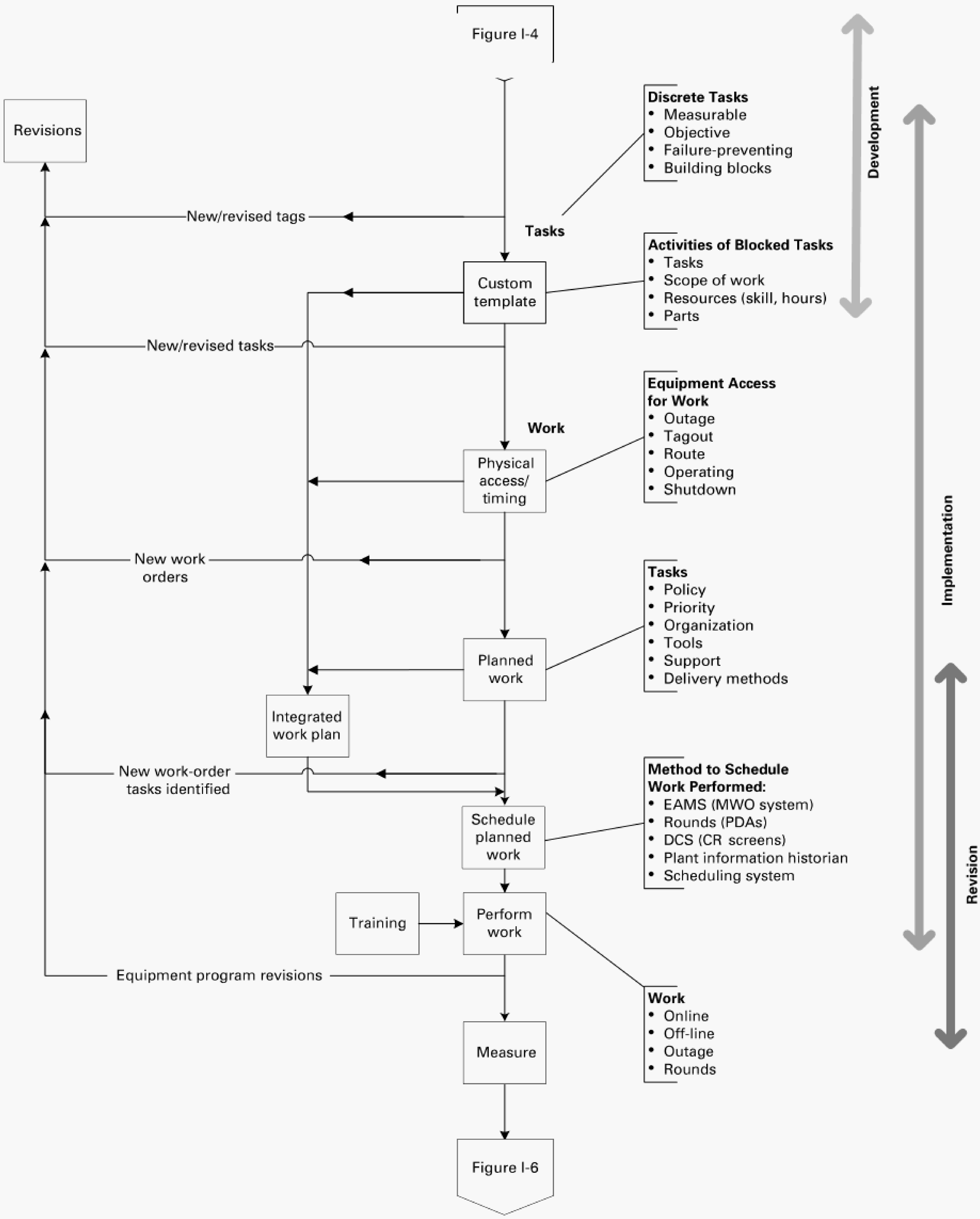
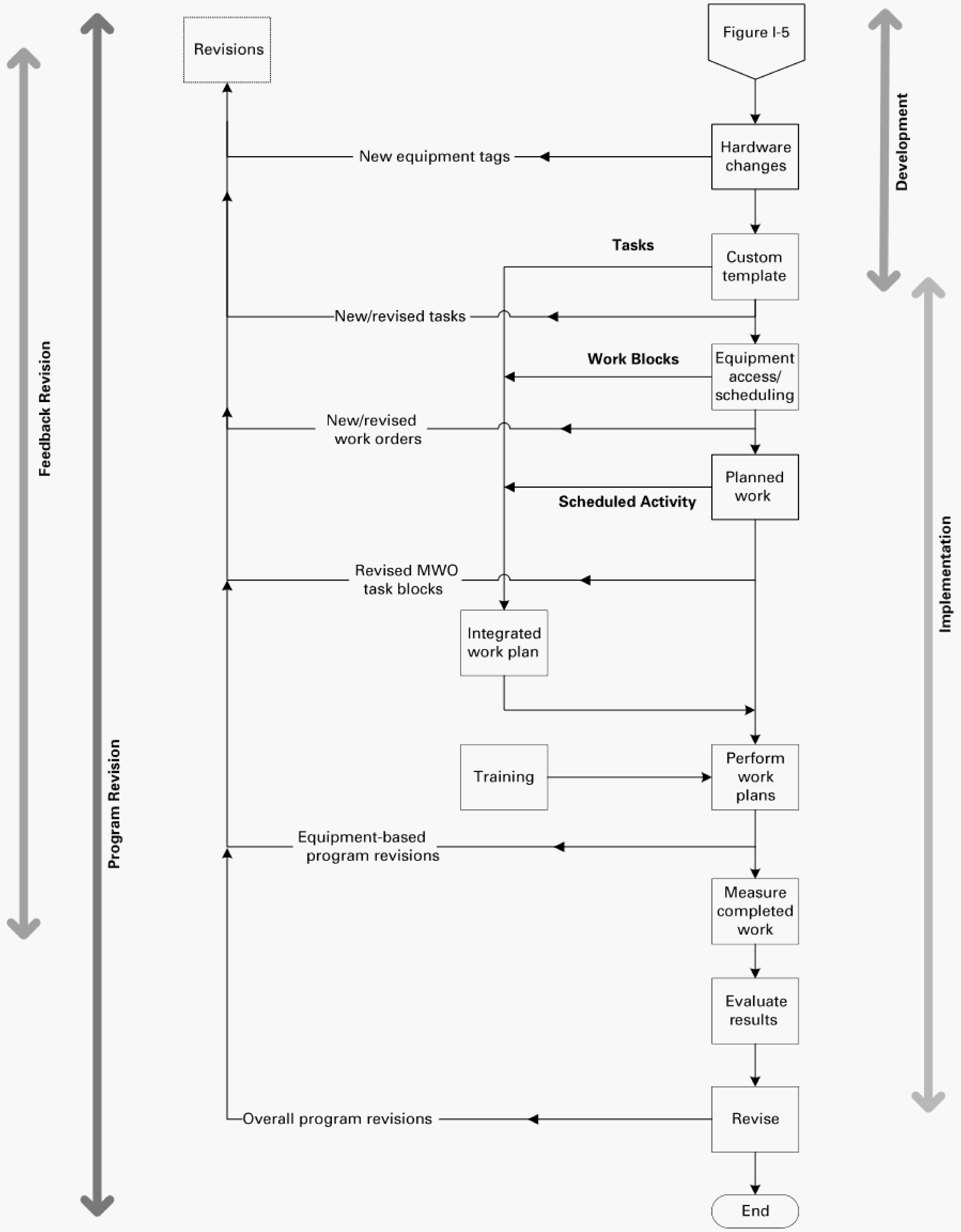


Figure I-6 Program Revisions

Assumptions: Revisions can occur at any time and place in the process to reflect lessons learned, designer/supplier product updates and plant modification, and/or redesign occurring over the plant's lifetime. Improved diagnostic technologies change monitoring approaches. Materials and treatments affect optimum task performance frequencies.



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