

SEMI E10-0422

SPECIFICATION FOR DEFINITION AND MEASUREMENT OF EQUIPMENT RELIABILITY, AVAILABILITY, AND MAINTAINABILITY (RAM) AND UTILIZATION

This Standard was technically approved by the Metrics Global Technical Committee. This edition was approved for publication by the global Audits and Reviews Subcommittee on September 7, 2021. Available at www.semiviews.org and www.semi.org in April 2022; originally published in 1986; previously published February 2021.

NOTICE: Paragraphs entitled ‘NOTE:’ are not an official part of this Standard or Safety Guideline and are not intended to modify or supersede the official Standard or Safety Guideline. These have been supplied by the global technical committee to enhance the usage of the Standard or Safety Guideline.

NOTICE: The section symbol (§) is used to reference a numbered section, paragraph, or header and all subordinate paragraphs, headers, and embedded material (i.e., EXCEPTIONs, lists) therein. The paragraph symbol (§) is used to reference a particular numbered paragraph and embedded material therein. When duplicated (i.e., §§ and §§) the symbols are used to reference more than one section or paragraph, respectively.

1 Purpose

1.1 This Specification establishes a common basis for communication between users and suppliers of manufacturing equipment in the semiconductor and related industries by providing a standardized methodology for measuring reliability, availability, and maintainability (RAM) and utilization performance of equipment in a manufacturing environment.

2 Scope

2.1 This Specification defines six mutually exclusive, basic equipment states for all of the conditions and associated periods of time for an equipment system during an observation period. One equipment state called the unscheduled downtime state (UDT) defines a ‘failed’ condition for an equipment system. The measurement of equipment system reliability in this Specification concentrates on the relationship between equipment system failures and equipment system usage.

2.2 All metrics defined herein are applicable to equipment systems that include subsystems, noncluster tools, single-path cluster tools (SPCTs), equipment modules within a multipath cluster tool (MPCT), intended process sets (IPSS) of equipment modules, and MPCTs. This Specification defines a treatment of RAM and utilization measurement for MPCTs by first defining performance of IPSS as a function of equipment module-level performance, then defining MPCT performance as a function of IPS performance. For each metric presented, any special handling required for IPSS and MPCTs is defined.

2.3 This Specification defines basic metrics for:

2.3.1 *Reliability* — Including mean time between failures (MTBF), mean cycles between failures (MCBF), and mean work between failures (MWBF).

2.3.2 *Availability* — Including total uptime, operational uptime, equipment-dependent uptime, and supplier-dependent uptime.

2.3.3 *Maintainability* — Including mean time to repair (MTTR), mean time to (perform) preventive maintenance (MTTPM), mean time offline (MTOL), total failure rate (TFR), and impairment rate.

2.3.4 *Utilization* — Including total utilization and operational utilization.

2.4 § 9 and Appendix 1 provide methods for the measurement of the uncertainty of the MTBF, MCBF, and MWBF metrics. § 10 and Appendix 2 provide methods to determine reliability growth and degradation.

NOTICE: SEMI Standards and Safety Guidelines do not purport to address all safety issues associated with their use. It is the responsibility of the users of the Documents to establish appropriate safety and health practices, and determine the applicability of regulatory or other limitations prior to use.

3 Limitations

3.1 Automated tracking of equipment states and performance is not within the scope of this Specification, but is partially addressed by SEMI E58 and SEMI E116.

NOTE 1: SEMI E58 is currently in Inactive Status and has not been updated to be consistent with and to support the later versions of SEMI E10. Refer to Related Information 4 regarding the specific relationship between the SEMI E116 states and those needed by this Specification.

3.2 The results of the calculations contained in this Specification are dependent on the operational conditions (e.g., specifications, processes, recipes, environment, maintenance strategies, human factors) for each user or equipment system type.

3.3 This Specification does not provide any guidance for assignment of responsibility for equipment system failures to user or supplier, except that certain downtime events and portions of downtime are distinguished as being related to the equipment or dependent on the supplier. Otherwise, the equipment states are determined by functional issues of the equipment system, independent of who performs the function.

3.4 The metrics defined herein do not address efficiency, productivity, diminished throughput, or capacity of equipment systems. Equipment efficiency and productivity are addressed by SEMI E79.

3.5 This Specification does not address the impact of RAM and utilization changes on cost or other performance metrics. The equipment cost of ownership (COO) Standard SEMI E35 provides the methodology for determining the impact of RAM and utilization changes on cost.

3.6 This Specification is intended to provide a concise treatment of basic reliability concepts of importance to equipment systems, as defined herein, and is not a comprehensive treatment of reliability theory in general.

4 Referenced Standards and Documents

4.1 SEMI Standards and Safety Guidelines

SEMI E30 — Specification for the Generic Model for Communications and Control of Manufacturing Equipment (GEM)

SEMI E35 — Guide to Calculate Cost of Ownership (COO) Metrics for Semiconductor Manufacturing Equipment

SEMI E58 — Automated Reliability, Availability, and Maintainability Standard (ARAMS): Concepts, Behavior, and Services

SEMI E79 — Specification for Definition and Measurement of Equipment Productivity

SEMI E116 — Specification for Equipment Performance Tracking

4.2 IEEE™ Documents¹

IRDS™ — International Roadmap for Devices and Systems™²

NOTICE: Unless otherwise indicated, all documents cited shall be the latest published versions.

5 Terminology

5.1 Abbreviations and Acronyms

5.1.1 *AI* — artificial intelligence

5.1.2 *AMSAA* — Army Materiel Systems Analysis Activity

5.1.3 *COO* — cost of ownership

5.1.4 *DM* — descriptive model

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- 5.1.5 *EF* — effectiveness factor
- 5.1.6 *E-MCBF_p* — mean cycles between equipment-related failures during productive time
- 5.1.7 *E-MCBF_u* — mean cycles between equipment-related failures during uptime
- 5.1.8 *E-MTBF_p* — mean productive time between equipment-related failures
- 5.1.9 *E-MTBF_u* — mean uptime time between equipment-related failures
- 5.1.10 *E-MTTR* — mean time to repair during equipment-related failures
- 5.1.11 *ENG* — engineering state
- 5.1.12 *HPP* — homogeneous Poisson process
- 5.1.13 *IPS* — intended process set
- 5.1.14 *K* — key group
- 5.1.15 *LCB* — lower confidence bound
- 5.1.16 *LN₂* — liquid nitrogen
- 5.1.17 *MCBF* — mean cycles between failures
- 5.1.18 *MCBF_p* — mean cycles between failures during productive time
- 5.1.19 *MCBF_u* — mean cycles between failures during uptime
- 5.1.20 *MFD_p* — mean failure duration for failures during productive time
- 5.1.21 *MFD_u* — mean failure duration for failures during uptime
- 5.1.22 *MPCT* — multipath cluster tool
- 5.1.23 *MTBF* — mean time between failures
- 5.1.24 *MTBF_p* — mean time between failures during productive time
- 5.1.25 *MTBF_u* — mean time between failures during uptime
- 5.1.26 *MTOL* — mean time off-line
- 5.1.27 *MTTPM* — mean time to [perform] preventive maintenance
- 5.1.28 *MTTR* — mean time to repair
- 5.1.29 *NHPP* — nonhomogeneous Poisson process
- 5.1.30 *NST* — nonscheduled state
- 5.1.31 *OOS* — out of specification
- 5.1.32 *PdM* — predictive maintenance
- 5.1.33 *PM* — preventive maintenance
- 5.1.34 *PRD* — productive state
- 5.1.35 *RAM* — reliability, availability, and maintainability
- 5.1.36 *RM* — reactive maintenance
- 5.1.37 *RxM* — prescriptive maintenance
- 5.1.38 *SBY* — standby state
- 5.1.39 *SDT* — scheduled downtime state
- 5.1.40 *SPCT* — single-path cluster tool
- 5.1.41 *TFR* — total failure rate

5.1.42 *UCB* — upper confidence bound

5.1.43 *UDT* — unscheduled downtime state

5.1.44 *U.S.* — United States of America

5.1.45 *W* — work

5.2 Definitions

5.2.1 *advanced notice model (ANM)* — a descriptive model that predicts a future failure event or performance degradation using a set of equipment system conditions that have been determined to act as predictors. Along with the prediction of the event, an ANM provides a prediction time element that includes an indication of how far in the future the failure is expected as well as an indication of the certainty of that prediction and the prediction horizon. The model could also predict the need for actions, such as scheduling preventive actions, to prevent the failure event or performance degradation. Examples of equipment system conditions include a consumable part approaching its end of life, degraded equipment system or component part performance that is not yet at failure level, and evidence of known signal patterns occurring that indicates high probability of a future failure.

NOTE 2: More sophisticated ANMs (e.g., artificial intelligence [AI] based) may also provide indications of the classification or source of the problem; recommendations on what to replace, repair, etc.; and recommendations to improve the equipment system's performance (e.g., improve its ability to perform its intended function, reveal why a particular problem or anomaly occurred in the process, extend the overall life of the equipment system).

5.2.2 *assembly* — two or more component parts and/or subassemblies joined together to perform a specific function and capable of being disassembled.

NOTE 3: The distinction between an assembly and subassembly should be determined by the individual application. An assembly in one instance may be a subassembly in another where it forms a portion of an assembly.

5.2.3 *availability* — the probability that the equipment system will be in a condition to perform its intended function when required.

5.2.4 *cluster tool* — an equipment system made up of multiple integrated processing equipment modules, with or without nonprocessing equipment modules, mechanically linked together. The equipment modules may or may not come from the same supplier.

5.2.5 *component part* — a constituent part, which can be separated from or attached to an assembly, not normally considered capable of independent operation. Also sometimes just called part. [SEMI E149]

5.2.6 *consumable material* — the material used by or in support of the equipment system at any time. Examples include gases (e.g., Ar, air), liquids (e.g., acids, solvents, ultrapure water, cooling water, mold compounds), solids (e.g., implant sources, bonding wire, lead frames). Examples do not include equipment component parts (e.g., consumable parts), support tools (e.g., carriers, probe cards), production substrates (e.g., wafers, die, assembly components), monitor/filler units (e.g., test wafers), and facility utilities (e.g., electricity, exhaust).

NOTE 4: Since the source of these consumable materials may vary from equipment to equipment, site to site, and company to company, this definition does not distinguish consumable materials based on the delivery method. For example, process cooling water may be provided by a dedicated heat exchanger for the equipment or by a facility distribution system, but it should be treated in a consistent manner.

5.2.7 *consumable part* — component part of the equipment that is used up, depleted, damaged, or destroyed by the process operation of the equipment with a predictable life expectancy (e.g., of less than one year) as agreed upon between the user and the supplier. It requires periodic replacement to allow the equipment to perform its intended function.

NOTE 5: Life expectancy concept comes from SEMI E35.

5.2.8 *continuous downtime event* — an event that starts when an equipment system transitions into a downtime state from an uptime state or the nonscheduled state (NST) and ends when an equipment system transitions from a downtime state. For example, a transition from the productive state (PRD) to a downtime state starts a continuous downtime event. A continuous downtime event continues through state transitions from a scheduled downtime state (SDT) to an unscheduled downtime state (UDT) or vice versa.

5.2.9 *cycle* — one complete operational sequence (including unit load and unload) of processing, manufacturing, or testing steps for an equipment system or subsystem. In equipment systems that process units individually, the number of cycles equals the number of units processed. In equipment systems that process units in batches, the number of cycles equals the number of batches processed.

5.2.10 *descriptive model (DM)* — a model describing a possible future condition that may require intervention. The model could also predict the need for actions, such as scheduling preventive actions, to prevent an undesirable future condition.

5.2.10.1 *Discussion* — A DM does not have to be predictive. It could be a simple model monitoring a parameter for a threshold boundary check or it could be a more complicated model that looks for conditions that are not always directly evident (e.g., fault detection analysis on a chamber's pump down time to determine variations within the desired range, even if recent individual pump down times do not indicate a trend).

5.2.11 *downtime* — during an observation period, the accumulated time when the equipment system is not in a condition to perform its intended function. Downtime includes scheduled downtime and unscheduled downtime.

5.2.12 *downtime event* — an event that starts with an equipment state transition either (1) into a scheduled downtime state (SDT) from an equipment state other than SDT or (2) into an unscheduled downtime state (UDT) from an equipment state other than UDT and ends when an equipment system transitions to any other equipment state. For example, a transition into UDT from SDT, or vice versa, starts a downtime event. A downtime event does not start or end with an equipment substate transition within SDT or within UDT.

5.2.13 *downtime state* — the composite state of the scheduled downtime state (SDT) and the unscheduled downtime state (UDT).

5.2.14 *engineering state (ENG)* — the equipment state when the equipment system is in a condition to perform its intended function, but is operated to conduct engineering experiments, especially where the usage of the equipment system during ENG is not indicative of normal production. ENG includes any activities required to restore the equipment system to a condition where it may perform its intended function.

5.2.15 *engineering time* — during an observation period, the accumulated time when the equipment system is in the engineering state (ENG).

5.2.16 *equipment* — the combination of hardware and software required to perform an operation or activity (e.g., processing, transporting, storing), including all direct auxiliary support or peripheral equipment (e.g., vacuum pumps, heat exchangers, effluent/exhaust treatment equipment). [SEMI E149]

5.2.17 *equipment module* — an indivisible entity within an equipment system that if separated into individual parts is not capable of performing its portion of the intended function of the equipment system. An equipment module may be either a nonprocessing equipment module or a processing equipment module.

5.2.18 *equipment-related failure* — any failure caused solely by the equipment (e.g., not an out-of-specification input).

5.2.19 *equipment system* — a system of equipment generally capable of independently accommodating units for processing, inspection, metrology, or support operations (e.g., transportation, storage, pump down) or subsystem for which the independent tracking of performance (i.e., reliability, availability, and maintainability [RAM], utilization, productivity) is desired. Equipment systems include subsystems, noncluster tools, equipment modules, single-path cluster tools (SPCTs), intended process sets (IPs) in multipath cluster tools (MPCTs), and MPCTs.

5.2.20 *failure* — a continuous instance of downtime starting from a transition to the unscheduled downtime state (UDT). A failure spans from the transition event (i.e., a failure event) to UDT from an equipment state other than UDT to the next transition to an equipment state other than UDT or SDT. One or more component or subsystem failures, software or process recipe problems, facility or utility supply malfunctions, safety errors (e.g., open interlock), or human errors could cause a failure. An equipment system experiences at most one failure at a time; subsequent problems occurring during a failure are not counted as additional failure events.

5.2.21 *failure event* — an event that starts with an equipment state transition for an equipment system from an equipment state other than unscheduled downtime (UDT) to UDT and ends when an equipment system transitions to any other equipment state except SDT. Failure events are used for establishing the count of failures in an observation period for applicable SEMI E10 metrics.

5.2.22 *host* — the factory computer system or an intermediate system that represents the factory and the user to the equipment or other lower level control system. [SEMI E168]

5.2.23 *intended function* — a manufacturing function that the equipment was built to perform within specified operating conditions agreed upon between the user and the supplier. This includes transport functions for transport equipment and measurement functions for metrology equipment, as well as process functions such as physical vapor deposition and wire bonding. The period of time equipment is performing its intended function includes equipment initialization and reaching base operating environmental conditions (e.g., temperature, pressure). Complex equipment may have more than one intended function.

5.2.24 *intended process set (IPS)* — a predetermined set of equipment modules that is used to achieve a process and is specified by the user for equipment operation. A multipath cluster tool (MPCT) may have one or more such intended process sets (IPSs). An IPS may include alternative equipment modules at one or more steps of the process. An IPS may therefore contain one or many process paths.

5.2.25 *key group (K)* — a subset of equipment modules that are common to all intended process sets (IPSs) in a multipath cluster tool (MPCT) where the failure of K is sufficient to cause a failure of all IPSs and hence the MPCT. K may include a mainframe equipment module.

5.2.26 *mainframe equipment module* — an individual abstract equipment module that may be used in modeling a multipath cluster tool (MPCT) to represent functionality of the equipment system at large rather than for an individual equipment module. Examples include shared computing resources, information services like recipe download, and power and gas distribution.

5.2.27 *maintainability* — the probability that the equipment system will be retained in, or restored to, a condition where it can perform its intended function within a specified period of time.

5.2.28 *maintenance* — the act of sustaining equipment in or restoring it to a condition to perform its intended function. Maintenance refers to function, not an organization; it includes any necessary activities (e.g., adjustments, change of consumable material, software upgrades, repair, preventive maintenance [PM]), no matter who performs the task.

5.2.29 *manufacturing time* — the sum of productive time and standby time.

5.2.30 *multipath cluster tool (MPCT)* — a cluster tool in which the units visit a subset of the equipment modules in sequences that vary from unit to unit.

5.2.31 *noncluster tool* — an equipment system made up of only one processing equipment module.

5.2.32 *nonconsumable part* — component part of the equipment that is not normally used up, depleted, damaged, or destroyed by the process operation of the equipment. It may require replacement (e.g., due to a failure) with another component part to allow equipment to perform its intended function.

5.2.33 *nonprocessing equipment module* — an equipment module within an equipment system that supports the movement or conditioning of units through the equipment system. Examples of nonprocessing equipment modules include robotic handlers, load/unload locks, and prealigners.

5.2.34 *nonscheduled state (NST)* — the equipment state when the equipment system is not in the productive state (PRD), standby state (SBY), engineering state (ENG), scheduled downtime state (SDT), or unscheduled downtime state (UDT).

5.2.35 *nonscheduled time* — during an observation period, the accumulated time when the equipment system is in the nonscheduled state (NST). NST includes any activities required to restore the equipment system to a condition where it can perform its intended function, but no activities that would normally be tracked in the productive state (PRD), engineering state (ENG), scheduled downtime state (SDT), or unscheduled downtime state (UDT).

5.2.36 *nonsupplier* — an acting agent of relevance to an equipment system other than the primary equipment supplier used for classifying the source of maintenance delay. Examples include the user (operator or host) as well as agents that provide parts, materials, information, or other resources to an equipment system such as in-house maintenance personnel, independent third-party maintenance personnel, and independent third-party suppliers.

5.2.37 *observation period* — a specified continuous interval of calendar time (e.g., 72 hours, 6 weeks, 3 months, 1 quarter, 90 days) during which equipment system performance is tracked.

5.2.38 *operations time* — the time when the equipment system is in the productive (PRD), standby (SBY), engineering (ENG), scheduled downtime (SDT), and unscheduled downtime (UDT) states (i.e., total time minus nonscheduled time).

5.2.39 *operator* — any person who communicates locally with the equipment through the equipment's control panel.

5.2.40 *predictive maintenance (PdM)* — preventive maintenance (PM) actions that are scheduled based upon results from an advanced notice model (ANM) calculation.

5.2.41 *prescriptive maintenance (RxM)* — specific preventive maintenance (PM) action(s) to perform that may include predefined procedures or predictive maintenance recommended by an advanced notice model (ANM). Depending on the complexity of the predefined procedures or the ANM, the recommended PM action(s) may change based on the specific set of conditions.

5.2.42 *preventive maintenance (PM)* — the performance of PM actions during a scheduled downtime state designed to reduce the likelihood of equipment system failure or performance degradation during operation. PM may be scheduled based upon accumulated time, equipment system usage, equipment system conditions, or outputs of a descriptive model (DM) or an advanced notice model (ANM). One type of PM is sometimes called scheduled maintenance.

NOTE 6: Scheduled maintenance does not include scheduled corrective actions.

5.2.43 *preventive maintenance (PM) action* — a predefined PM procedure (including equipment ramp-down and ramp-up), which could be scheduled at intervals or based upon advanced notice models designed to reduce the likelihood of equipment system failure during operation.

5.2.44 *preventive maintenance (PM) event* — a downtime event into a scheduled downtime state (SDT) where the SDT PM equipment substate occurs before the equipment exits the scheduled downtime state (SDT).

5.2.45 *process path* — a specific set of equipment modules a unit passes through for which each equipment module is unique and has no alternative equipment modules.

5.2.46 *processing equipment module* — an equipment module within an equipment system. Examples of processing equipment modules include chambers and stations that provide functions for processing, metrology, inspection, testing, and packaging of units.

5.2.47 *product* — units produced during productive time (refer to unit).

5.2.48 *productive state (PRD)* — the equipment state in which the equipment system is performing its intended function.

5.2.49 *productive time* — during an observation period, the accumulated time when the equipment system is in the productive state (PRD).

5.2.50 *ramp-down* — the portion of a maintenance procedure required to prepare the equipment for hands-on work. It includes any necessary activities (e.g., purging, cool-down, warm-up, software backup, storing dynamic values [e.g., parameters, recipes]). Ramp-down occurs only in the scheduled downtime and unscheduled downtime states.

5.2.51 *ramp-up* — the portion of a maintenance procedure required, after the hands-on work is completed, to return the equipment to a condition where it can perform its intended function. It includes any necessary activities (e.g., pump down, warm-up, stabilization periods, initialization routines, software load, restoring dynamic values [e.g., parameters, recipes], control system reboot). It does not include equipment or process test time. Ramp-up occurs only in the scheduled downtime and unscheduled downtime states.

5.2.52 *reactive maintenance (RM)* — the performance of corrective actions necessary to restore an equipment system that has experienced an unexpected failure event.

5.2.53 *recipe* — the preplanned and reusable portion of the set of instructions, settings, and parameters under control of a processing agent that determines the processing environment experienced by the units in the entire equipment system (i.e., processing equipment modules and nonprocessing equipment modules). Recipes may be subject to change between runs or processing cycles.

5.2.54 *reliability* — the probability that the equipment system will perform its intended function for a specified period of time.

5.2.55 *scheduled downtime* — during an observation period, the accumulated time when the equipment system is in the scheduled downtime state (SDT).

5.2.56 *scheduled downtime state (SDT)* — the equipment state when the equipment system is not in a condition to perform its intended function due to scheduled activities or conditions. SDT includes any activities required to restore the equipment system to a condition where it can perform its intended function.

5.2.57 *scheduled maintenance* — refer to preventive maintenance (PM).

5.2.58 *shutdown* — the time required to put the equipment in a safe condition when entering a nonscheduled state (NST). It includes time for any necessary activities to reach a safe condition. Shutdown occurs only in NST.

5.2.59 *single-path cluster tool (SPCT)* — a cluster tool in which all units follow only one process path.

5.2.60 *specification (equipment operation)* — the documented set of intended functions including operating conditions as agreed upon between user and supplier.

5.2.61 *standby state (SBY)* — the equipment state, other than the nonscheduled state (NST), when the equipment system is in a condition to perform its intended function and consumable materials and facilities are available, but the equipment system is not operated.

5.2.62 *standby time* — during an observation period, the accumulated time when the equipment system is in the standby state (SBY).

5.2.63 *start-up* — the time required for equipment to achieve a condition where it can perform its intended function, when leaving a nonscheduled state (NST). It includes time for any necessary activities (e.g., pump down, warm-up, cool-down, stabilization periods, initialization routines, software load, restoring dynamic values [e.g., parameters, recipes], control system reboot). Start-up only occurs in NST.

5.2.64 *state* — a static set of conditions and associated behavior. While all of its conditions are met, the state is current (active). Behavior within a given state includes the response to various stimuli. [SEMI E58]

NOTE 7: Within the scope of this Specification, the term ‘state’ generally refers to one of the following six basic equipment states defined in SEMI E10: productive (PRD), standby (SBY), engineering (ENG), scheduled downtime (SDT), unscheduled downtime (UDT), and nonscheduled (NST).

5.2.65 *subassembly* — two or more component parts joined together to perform a specific function and capable of being disassembled.

5.2.66 *subsystem* — an integrated structure of component parts, subassemblies, and assemblies capable of performing, in aggregate, one or more specific functions within an equipment. [SEMI E149]

5.2.67 *supplier* — provider of equipment and related services to the user (e.g., unit manufacturer). Also called equipment vendor or original equipment manufacturer (OEM).

5.2.68 *support tool* — a tool that, although not part of the equipment, is required by and becomes integral with it during the course of normal operation (e.g., cassette, wafer carrier, probe card, computerized controller/monitor).

5.2.69 *total time* — all time (at the rate of 24 hours/day, 7 days/week) during the observation period. In order to have a valid representation of total time, all six basic equipment states shall be accounted for and tracked accurately.

5.2.70 *training (off-line)* — the time required for the instruction of personnel in the operation and/or maintenance of equipment done outside of operations time. Off-line training occurs only in the nonscheduled state (NST).

5.2.71 *training (on-the-job)* — the instruction of personnel in the operation and/or maintenance of equipment performed during the course of normal work functions. On-the-job training typically does not interrupt operation or maintenance activities and can therefore occur in any equipment state (except standby [SBY] and nonscheduled [NST]) without special categorization.

5.2.72 *unit* — any wafer, substrate, die, packaged die, or similar piece part.

5.2.73 *unscheduled downtime* — during an observation period, the accumulated time when the equipment system is in the unscheduled downtime state (UDT).

5.2.74 *unscheduled downtime state (UDT)* — the equipment state when the equipment system is not in a condition to perform its intended function due to unplanned or unscheduled activities or conditions. UDT includes any activities required to restore the equipment system to a condition where it can perform its intended function.

5.2.75 *uptime* — during an observation period, the accumulated time when the equipment system is in a condition to perform its intended function. Uptime includes productive, standby, and engineering times, and does not include any portion of unscheduled downtime, scheduled downtime, or nonscheduled time.

5.2.76 *uptime state* — the composite state when the equipment system is in a condition to perform its intended function. It includes the productive state (PRD), standby state (SBY), and the engineering state (ENG), and does not include any portion of the downtime state (DT) or the nonscheduled state (NST).

5.2.77 *user* — any entity interacting with the equipment, either locally as an operator or remotely via the host. From the equipment's viewpoint, both the operator and the host represent the user. [SEMI E58]

5.2.78 *utilization* — the percentage of time the equipment system is performing its intended function during a specified observation period.

5.2.79 *verification run* — a single cycle of the equipment (using units or no units) used to establish that it is performing its intended function within specifications.

5.2.80 *work (W)* — any measurable value; other than units, cycles, or time; that can be used to measure equipment reliability or to schedule maintenance activities (e.g., laser pulses, kilowatt-hours, liters filtered).

5.3 Symbols

5.3.1 *Ai* — alternative equipment module.

5.3.2 *Li* — load lock i.

5.3.3 *Mi* — equipment module i.

5.3.4 *P* — mainframe equipment module.

5.3.5 *PMj* — processing equipment module j.

5.3.6 *r* — number of failures.

5.3.7 *Si* — serial equipment module.

5.3.8 *T* — transport equipment module.

6 Equipment States and Tracking Requirements

6.1 Equipment States

6.1.1 To measure equipment system performance (e.g., RAM metrics), this Specification defines six, mutually exclusive, basic equipment states into which all equipment conditions and periods of time shall fall. Any equipment system shall be in one and only one equipment state at any period of time. One of these equipment states—unscheduled downtime (UDT)—represents the time period when an equipment system failure (i.e., a failure event) occurs until its recovery from that failure event. Because an equipment system is in one and only one equipment state at a time, an equipment system is subject to at most one failure at any period of time, regardless of the number of underlying problems contributing to or arising from that failure.

6.1.1.1 For certain equipment systems called intended process sets (IPSS) and multipath cluster tools (MPCTs), independent tracking of equipment states is required for each equipment module in these equipment systems. These equipment modules may be in different equipment states at the same time, and they may experience failures independently from each other.

6.1.2 The equipment states are determined by function, not by organization. Any given maintenance procedure, for example, is classified the same way no matter who performs it (e.g., an operator, a production technician, a maintenance technician, a process engineer).

6.1.3 An equipment state transition can be initiated by a human or an automated process. Examples of a human initiating an equipment state transition include an operator identifying a failure has occurred or a maintenance

technician starting PM. Examples of an automated process initiating an equipment state transition include equipment detecting a failure event has occurred or the host initiating a state change for PM based on input from an ANM.

6.1.4 Figure 1 is a stack chart of the six basic equipment states. These basic equipment states can be divided into as many equipment substates (hereinafter substates) as are required to achieve the equipment tracking resolution that a manufacturing operation desires. This Specification makes no attempt to list all possible substates, but does define mutually exclusive substates for the scheduled downtime state (SDT) and the unscheduled downtime state (UDT). These substates are required to support certain metrics and other examples for guidance.

6.1.4.1 Besides the substates defined to support certain metrics and other examples for guidance, users may define additional substates (e.g., based on the list of key activities listed as being included for each equipment state) and higher resolution of substates within substates. It is highly recommended that these user-defined substates be mutually exclusive to avoid double-counting of time if they are used in additional user-defined equations.

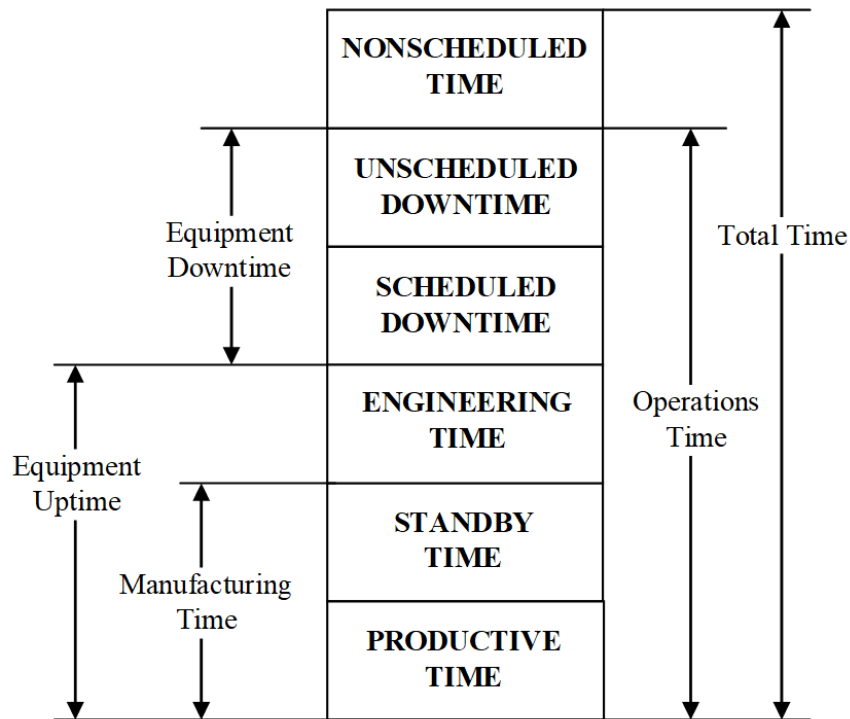


Figure 1
Equipment Time/State Stack Chart

6.1.5 Key activities and conditions associated with the basic equipment states and substates are given in Figure 2. The accumulated time in equipment states and substates are used in the metrics in this Specification. The activities and conditions associated with the basic equipment states and substates are described in the following sections.

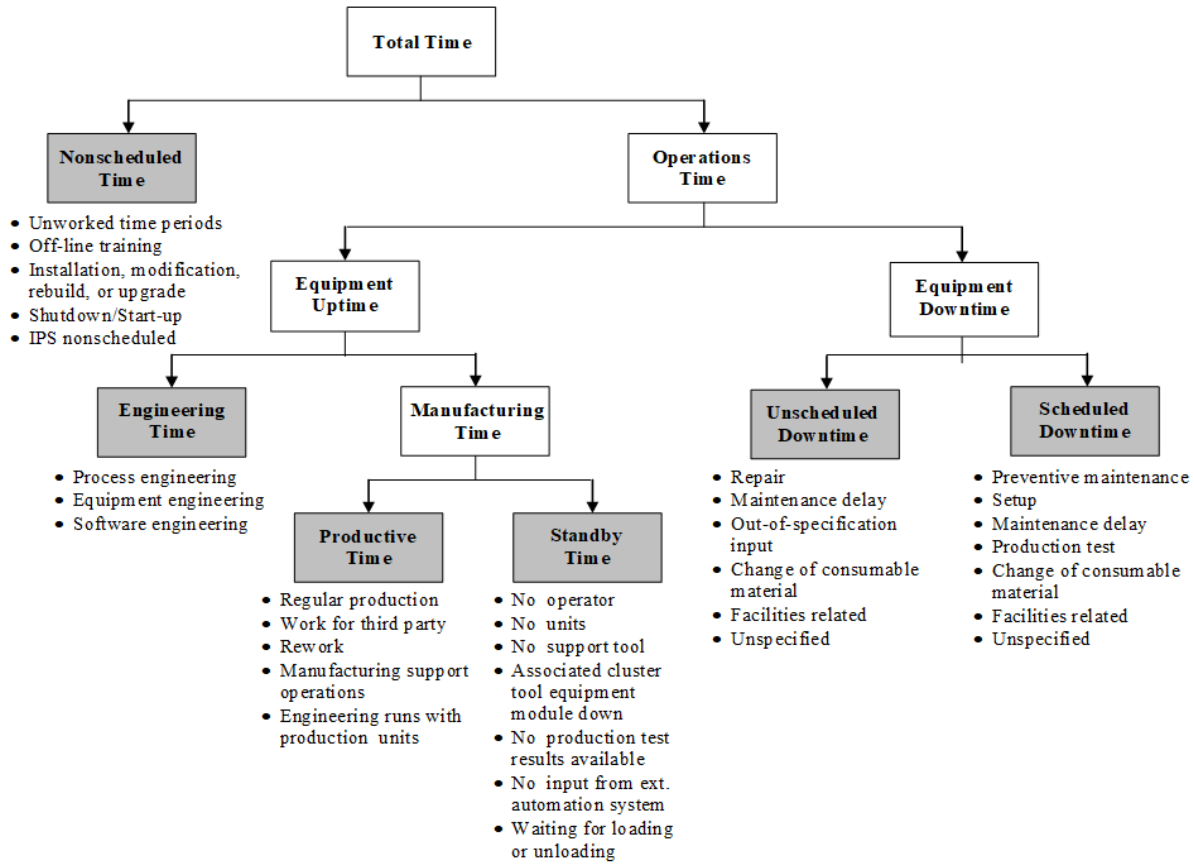


Figure 2
Equipment Time/State/Activity Hierarchy

6.1.6 *Productive State (PRD)* — The equipment state in which the equipment system is performing its intended function, where the intended function includes performing within the specified operating conditions for which the equipment system was built and configured. During an observation period, the accumulated time when the equipment system is in PRD is called productive time. This Specification does not define or require mutually exclusive substates for PRD, but PRD does include time periods for the following activities:

- Regular production (including loading and unloading of units internal to the equipment and conventional recipe download)
- Work for a third party
- Rework
- Manufacturing support operations (e.g., processing test units to support other processes or equipment)
- Engineering runs done in conjunction with production units (e.g., split lots, new applications)

6.1.6.1 For some equipment systems, the primary intended function may include performing other types of activities. Examples include equipment systems used primarily for process development and laboratory testing support equipment such as a transmission electron microscope. For these types of equipment systems, PRD is used to track when they are performing their primary intended function instead of ENG.

6.1.6.2 Support activities such as heating, cooling, purging, pump down, cleaning, etc., that are specified as part of production recipes shall be specifically included in PRD. However, similar support activities that are not specified as part of production recipes shall be specifically excluded from PRD.

NOTE 8: Relative to the SEMI E30 processing state model, PRD includes all of the ‘executing’ state and portions of the ‘setup’ state such as loading and unloading. Relative to the SEMI E116 equipment module states, PRD includes all time in ‘busy’ states during SEMI E10 manufacturing time where the SEMI E116 task type is either ‘process’ or ‘support.’ Relative to SEMI E58, PRD here is intended to be synonymous with the SEMI E58 productive state. Refer to Related Information 4 for more details.

6.1.7 Standby State (SBY) — The equipment state, other than the nonscheduled state (NST), when the equipment system is in a condition to perform its intended function and consumable materials and facilities are available, but the equipment system is not operated. During an observation period, the accumulated time when the equipment system is in SBY is called standby time. This Specification does not define or require mutually exclusive substates for SBY, but SBY does include time periods for the following activities:

- No operator available (e.g., breaks, lunches, meetings)
- No units available (e.g., no units due to lack of available support equipment, such as metrology equipment)
- No support tool (e.g., wafer carrier, probe card)
- Associated cluster tool equipment module down
- No production test results available for review
- No input from external automation systems (e.g., host)
- Waiting for loading or unloading

6.1.8 Engineering State (ENG) — The equipment state when the equipment system is in a condition to perform its intended function (i.e., no equipment or process problems exist), but is operated to conduct engineering experiments, especially where the usage of the equipment system is not indicative of normal production and may be asked to perform outside specified operating conditions. Failures under such extreme conditions should not be considered to arise from PRD. During an observation period, the accumulated time when the equipment system is in ENG is called engineering time. This Specification does not define or require mutually exclusive substates for ENG, but ENG does include time periods for the following activities:

- Process engineering (e.g., process characterization)
- Equipment engineering (e.g., equipment evaluation)
- Software engineering (e.g., software qualification)

6.1.9 Scheduled Downtime State (SDT) — The equipment state when the equipment system is not in a condition to perform its intended function due to scheduled, PM downtime events. PM is the performance of PM actions during SDT designed to reduce the likelihood of equipment system failure or performance degradation during operation. PM may be scheduled based upon accumulated time, equipment system usage (e.g., quantity of units, quantity of work), equipment system conditions (e.g., reduced pressure threshold reached), or ANMs. One type of PM is sometimes called scheduled maintenance.

NOTE 9: Scheduled maintenance does not include scheduled corrective actions that address unscheduled downtime events.

6.1.9.1 An ANM is a model that predicts a future failure event or performance degradation using a set of equipment system conditions that have been determined to act as predictors. Along with the prediction of the event, the model provides an indication of how far in the future the failure is expected as well as an indication of the certainty of that prediction and the prediction horizon. The model could also predict the need for actions, such as scheduling PM actions, to prevent the failure event or performance degradation. Examples of equipment system conditions include a consumable part approaching its end of life, degraded equipment system or component part performance that is not yet at failure level, and evidence of known signal patterns occurring that indicates high probability of a future failure.

NOTE 10: More sophisticated ANMs (e.g., AI based) may also provide indications of the classification or source of the problem; recommendations on what to replace, repair, etc.; and recommendations to improve the equipment system’s performance (e.g., improve its ability to perform its intended function, reveal why a particular problem or anomaly occurred in the process, extend the overall life of the equipment system).

6.1.9.2 Predictive maintenance (PdM) is PM actions that are scheduled based upon results from an ANM calculation.

6.1.9.3 Prescriptive maintenance (RxM) is specific PM action(s) to perform that may include predefined procedures or PdM recommended by an ANM. Depending on the complexity of the predefined procedures or the ANM, the

recommended PM action(s) may change based on the specific set of conditions. Refer to Figure 3 for the relationships between PM, PdM, RxM, and reactive maintenance (RM).

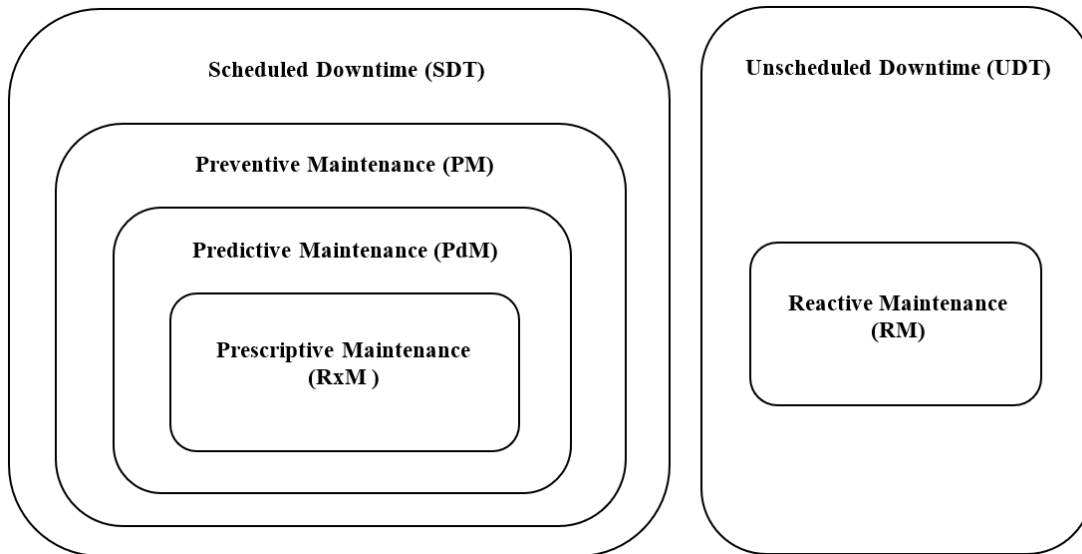


Figure 3
Relationships Between PM, PdM, RxM, and RM

6.1.9.4 During an observation period, the accumulated time when the equipment system is in SDT is called scheduled downtime. SDT is divided into the following mutually exclusive substates:

- SDT PM
- SDT setup
- SDT maintenance delay, supplier
- SDT maintenance delay, nonsupplier
- SDT production test
- SDT change of consumable material
- SDT facilities related
- SDT unspecified

NOTE 11: The substates SDT PM; SDT setup; SDT maintenance delay, supplier; and SDT change of consumable material are required to support accurate supplier-dependent and equipment-dependent metrics. Other SDT substates are not used in these metrics. Refer to §§ 8.3.3 and 8.3.4.

6.1.9.5 *SDT PM* — SDT substate that includes the following activities as specified by the supplier as part of a PM program:

- *PM Action* — A predefined PM procedure (including equipment ramp-down and ramp-up), which could be scheduled at intervals or based upon an ANM designed to reduce the likelihood of equipment failure during operation. Scheduled PM may be based upon accumulated time, equipment usage (e.g., units, work), or equipment conditions.
- *Equipment Test* — The operation of equipment after preventive action to demonstrate equipment functionality (e.g., chamber reaches base pressure, units transfer without problem, gas flow is correct, plasma ignites, source reaches specified power).

- *Verification Run* — The processing and evaluation of units after preventive action to establish that the equipment is performing its intended function within specifications.

NOTE 12: Equipment suppliers should recommend a PM program to achieve a predetermined equipment performance level. Users should identify any deviation from the recommended program if they expect the supplier to meet or improve that performance level.

NOTE 13: If, during PM, the user chooses to perform additional maintenance, qualifications, or other activities that are not part of the procedure recommended by the supplier, then the downtime required for such additional activities should not be counted towards the supplier-dependent scheduled downtime unless the user shows that they are necessary to ensure that the equipment system is capable of performing its intended function within specifications. The SDT unspecified substate is recommended for use to track this additional time separately.

6.1.9.6 *SDT Setup* — SDT substate that includes the following activities related to a setup as specified by the supplier:

- *Conversion* — The procedure to complete an equipment alteration (hardware and/or software) necessary to accommodate a change in process, unit type, package configuration, etc., as part of normal production processing (excluding permanent modifications, rebuilds, and upgrades). Examples include parameter (e.g., beam current, temperature, gas flow) adjustment and handler adjustment.
- *Equipment Test* — The operation of equipment after conversion to demonstrate equipment functionality (e.g., chamber reaches base pressure, units transfer without problem, gas flow is correct, plasma ignites, source reaches specified power).
- *Verification Run* — The processing and evaluation of units after conversion to establish that equipment is performing its intended function within specifications.

NOTE 14: Equipment suppliers should recommend procedures for conversion. Users should identify any deviation from the recommended procedures.

NOTE 15: Recipe download activities that are unusual or infrequent, that have especially significant durations, or that require significant manual intervention should be tracked as conversions under SDT setup. Recipe download activities that are regular, automated functions of processing should be tracked in PRD.

6.1.9.7 *SDT Maintenance Delay, Supplier* — SDT substate where the equipment cannot perform its intended function because it is waiting for supplier personnel, supplier-controlled parts, supplier-controlled consumable materials, or supplier-controlled information such as test results. An SDT maintenance delay, supplier substate may occur at any point during SDT.

6.1.9.8 *SDT Maintenance Delay, Nonsupplier* — SDT substate where the equipment cannot perform its intended function because it is waiting for nonsupplier personnel, nonsupplier-controlled parts, nonsupplier-controlled consumable material, or nonsupplier-controlled information such as test results. An SDT maintenance delay substate, nonsupplier may occur at any point during SDT. An SDT maintenance delay substate, nonsupplier may also be due to an administrative decision to leave the equipment down and postpone maintenance.

6.1.9.9 *SDT Production Test* — SDT substate for the scheduled interruption of equipment uptime for evaluation of units, as defined in the user specifications for equipment operation, to confirm that the equipment is performing its intended function within specifications. It does not include testing that can be done in parallel with, or transparent to, the running of production, and it does not include any testing done following a PM, setup, or repair procedure. It also does not include waiting for test results.

6.1.9.10 *SDT Change of Consumable Material* — SDT substate for the scheduled interruption of equipment uptime to change consumable material. It does not include delays in obtaining the consumable material, which are included in either SDT maintenance delay, supplier or SDT maintenance delay, nonsupplier.

6.1.9.11 *SDT Facilities-Related* — SDT substate when the equipment cannot perform its intended function solely as a result of scheduled out-of-specification facilities. Any scheduled downtime required by the facilities listed below shall be included in the SDT facilities-related substate. For example, if otherwise unnecessary PM actions are needed as a result of a scheduled facilities change, upgrade, or repair, all activities required to return the equipment to a condition where it can perform its intended function are included in the SDT facilities-related substate. The facilities include:

- Environmental (e.g., temperature, humidity, vibration, particle count)
- Facility connections (e.g., power, cooling water, facility gases, exhaust, liquid nitrogen [LN₂])

- Communications links with other equipment or host computers

6.1.9.12 *SDT Unspecified* — The substate for any scheduled downtime that is not specifically tracked under one of the above substates.

6.1.10 *Unscheduled Downtime State (UDT)* — The equipment state when the equipment system is not in a condition to perform its intended function due to unplanned or unscheduled activities or conditions. The equipment system transitions into UDT when it experiences a failure event and transitions out of UDT when it is restored to a condition where it can perform its intended function. In some cases, the equipment system may transition into UDT for a reason other than experiencing a failure event (e.g., to continue a repair on a previous failure that was temporarily delayed to perform PM). During an observation period, the accumulated time when the equipment system is in UDT is called unscheduled downtime.

NOTE 16: When the equipment system transitions into UDT for a reason other than experiencing a failure event, it is typically due to a previous decision to change the equipment state out of UDT to more accurately reflect the state that it should be in (e.g., changing from UDT to NST when the equipment system is not scheduled to be used in production, changing from UDT to PRD to allow some production to be run even when the equipment system is not completely capable of performing all of its intended function). Therefore, this transition to UDT should not create additional failure counts used in some of the metrics.

6.1.10.1 A continuous instance of UDT is called a failure. A failure spans from the transition event, called a failure event, to UDT from an equipment state other than UDT to the next transition to an equipment state other than UDT.

6.1.10.2 Failure events are used for all metrics requiring a count of failures. Transitions between substates of UDT are not counted as additional failures.

6.1.10.3 UDT is divided into the following mutually exclusive substates:

- UDT repair, equipment-related
- UDT repair, nonequipment-related
- UDT maintenance delay, supplier
- UDT maintenance delay, nonsupplier
- UDT out-of-specification input
- UDT change of consumable material
- UDT facilities-related
- UDT unspecified

NOTE 17: The substates UDT repair; equipment-related; UDT maintenance delay, supplier; and UDT change of consumable material are required to support accurate supplier-dependent and equipment-dependent metrics. Other UDT substates are not used in these metrics. Refer to §§ 8.3.3 and 8.3.4.

6.1.10.4 *UDT Repair, Equipment-Related* — The unscheduled downtime substate in which the equipment is being actively repaired to bring it back to an uptime state in response to a failure whose responsibility is assigned to the supplier or equipment. Reactive maintenance (RM) is the performance of corrective actions necessary to restore an equipment system that has experienced an unexpected failure event. Repairs include the following activities:

- *Diagnosis* — The procedure to identify the source of an equipment problem or failure.
- *Corrective Action* — The maintenance procedure (e.g., component part replacement, equipment self-correction or autocorrection, equipment ramp-down and ramp-up, rebooting, resetting, recycling, restarting, reverting to a previous software version) to address an equipment system failure and return the equipment system to a condition where it can perform its intended function.
- *Equipment Test* — The operation of equipment after corrective action to demonstrate equipment functionality (e.g., chamber reaches base pressure, units transfer without problem, gas flow is correct, plasma ignites, source reaches specified power).
- *Verification Run* — The processing and evaluation of units after corrective action to establish that the equipment is performing its intended function within specifications.

6.1.10.5 UDT Repair, Nonequipment-Related — UDT substate in which the equipment is being actively repaired to bring it back to an uptime state in response to a failure whose responsibility is not assigned to the supplier or equipment. Repairs include the following activities:

- *Diagnosis* — The procedure to identify the source of an equipment problem or failure.
- *Corrective Action* — The maintenance procedure (e.g., component part replacement, equipment self-correction or autocorrection, equipment ramp-down and ramp-up, rebooting, resetting, recycling, restarting, reverting to a previous software version) to address an equipment system failure and return the equipment system to a condition where it can perform its intended function.
- *Equipment Test* — The operation of equipment after corrective action to demonstrate equipment functionality (e.g., chamber reaches base pressure, units transfer without problem, gas flow is correct, plasma ignites, source reaches specified power).
- *Verification Run* — The processing and evaluation of units after corrective action to establish that the equipment is performing its intended function within specifications.

6.1.10.6 UDT Maintenance Delay, Supplier — UDT substate during which the equipment cannot perform its intended function because it is waiting for supplier personnel, supplier-controlled parts, supplier-controlled consumable material, or supplier-controlled information such as test results. A UDT maintenance delay substate, supplier may occur at any point during UDT.

6.1.10.7 UDT Maintenance Delay, Nonsupplier — UDT substate during which the equipment cannot perform its intended function because it is waiting for nonsupplier personnel, nonsupplier-controlled parts, nonsupplier-controlled consumable materials, or nonsupplier-controlled information such as test results. UDT maintenance delay substates may occur at any point during UDT. A UDT maintenance delay substate, nonsupplier may also be due to an administrative decision to leave the equipment down and postpone maintenance.

6.1.10.8 UDT Out-of-Specification (OOS) Input — UDT substate in which the equipment cannot perform its intended function solely as a result of problems created by OOS or faulty inputs. Any unscheduled downtime resulting from the inputs listed below being OOS shall be included in UDT OOS input downtime. For example, if a prober/tester system requires a repair as a result of an intermittent probe card short, then all downtime incurred prior to identifying the problem is recategorized as UDT OOS input downtime. The inputs include the following:

- Support tools (e.g., warped cassettes or wafer carriers, faulty probe cards, defective reticles)
- Units (e.g., upstream process problems, warped wafers, contaminated wafers, warped lead frames)
- Test data (e.g., metrology equipment out of calibration, misread charts, erroneous data interpretation/entry)
- Consumable materials (e.g., contaminated acid, leaky target bond, degraded photo resist, degraded mold compound)
- Incorrect host or other equipment input (e.g., wrong recipe)

6.1.10.9 UDT Change of Consumable Material — UDT substate in which there is an unscheduled interruption of equipment uptime to change consumable material. It may involve a failure directly related to the consumable material, or it may involve a change of consumable material that is necessitated by an unrelated failure. It does not include delays in obtaining the consumable material, which are included in either UDT maintenance delay, supplier or UDT maintenance delay, nonsupplier.

6.1.10.10 UDT Facilities-Related — UDT substate in which equipment cannot perform its intended function as the result of an unscheduled facilities failure. Any unscheduled downtime resulting from a failure of the facilities listed below shall be included in the UDT facilities-related substate. For example, if an otherwise unnecessary cryopump regeneration is needed as a result of an unscheduled 15-minute power outage, then all activities required to return the equipment to a condition where it can perform its intended function is included in the UDT facilities-related substate. Facilities-related issues include the following:

- Environmental (e.g., temperature, humidity, vibration, particle count, electromagnetic interference)
- Facility connections (e.g., power, cooling water, facility gases, exhaust, LN₂)

- Communications links with other equipment or host

6.1.10.11 *UDT Unspecified* — The substate for any unscheduled downtime that is not specifically tracked under one of the above substates.

6.1.11 *Nonscheduled State (NST)* — The equipment state when the equipment system is not scheduled to be used in production. During an observation period, the accumulated time when the equipment system is in NST is called nonscheduled time. This Specification does not define or require mutually exclusive substates for NST, but NST does include time periods for the following activities:

- Unworked Time Periods
- Off-Line Training
- Equipment Installation
- Equipment Modification
- Shutdown/Start-up
- IPS Nonscheduled (for IPS equipment systems only)

6.1.11.1 *Unworked Time Periods* — Shifts, weekends, holidays, facilities shutdowns, etc. out of the production schedule.

6.1.11.2 *Off-Line Training* — Equipment system is operated exclusively for training purposes that does not result in any productive output.

6.1.11.3 *Equipment Installation* — Equipment system is out of the production schedule due to initial installation.

6.1.11.4 *Equipment Modification* — Equipment system is out of the production schedule due to modification, rebuild, or upgrade (hardware or software) that is not accommodated by the regular PM schedule.

6.1.11.5 *Shutdown/Start-Up* — Equipment system is out of the production schedule due to equipment shutdown and start-up.

6.1.11.6 *IPS Nonscheduled* — IPS equipment system is not the current IPS or among the IPSs currently scheduled to be used in production. Refer to ¶ 7.4.6.1 for more details on the IPS NST.

NOTE 18: By tracking inactive IPSs in NST, productive time is more accurately attributed to active IPSs, directly affecting metrics for IPSs involving productive time. To the extent that multiple IPSs are simultaneously active and have shared processing equipment modules, productive time cannot be accurately attributed to individual IPSs, and metrics for IPSs involving productive time may be less useful.

6.1.11.7 NST includes any qualification activities required to bring the equipment system to a condition where it can perform its intended function after any nonscheduled activities like those listed above.

6.1.11.8 Any maintenance done to the equipment system cannot be counted in NST, since all maintenance (including automatic maintenance routines such as a programmed cryopump regeneration) shall be tracked in either SDT or UDT.

6.1.11.9 By the same convention, any production or engineering work (including an unattended operation that may shut itself off ‘after hours’) shall be tracked in either PRD or ENG.

NOTE 19: NST is intended for omission of strategically unworked periods from total time and should be generally predetermined in a long-term production schedule. In general, random moment-to-moment periods of idling between productive periods should be tracked in SBY rather than NST. The only notable exception may be for particularly agile MPCTs that frequently switch IPSs (e.g., from lot-to-lot), where tracking inactive IPSs in NST aids in the accurate attribution of productive time to active IPSs.

6.2 *Tracking Requirements for Equipment Cycles* — For support of certain SEMI E10 metrics, counts of equipment cycles are also required for each observation period. A cycle is one complete operational sequence (including unit load and unload) of processing, manufacturing, or testing steps for an equipment system or subsystem. In equipment systems that process units individually, the number of cycles equals the number of units (e.g., wafers) processed. In equipment systems that process units in batches, the number of cycles equals the number of batches processed.

6.2.1 *Count of Equipment Cycles During Productive Time* — The count of equipment cycles during productive time is used in the metric $MCBF_p$.

6.2.2 Count of Equipment Cycles During Uptime — The count of equipment cycles during productive time plus the count of equipment cycles during engineering time. By definition of equipment states, there shall be no equipment cycles during standby time. The count of equipment cycles during uptime is used in the metric $MCBF_u$.

6.3 Tracking Requirements for Downtime Events — For each observation period, aside from aggregating the time in each equipment state and/or substate, downtime events for each equipment system shall be tracked and classified for use in SEMI E10 metrics.

6.3.1 Downtime Event — A downtime event is an event that starts with an equipment state transition either (1) into SDT from an equipment state other than SDT or (2) into UDT from an equipment state other than UDT and ends when an equipment system transitions to any other equipment state. For example, a transition into UDT from SDT, or vice versa, starts a downtime event. A downtime event does not start or end with an equipment substate transition within SDT or within UDT.

6.3.2 Continuous Downtime Event — A continuous downtime event is an event that starts when an equipment system transitions into a downtime state from an uptime state or the nonscheduled state (NST) and ends when an equipment system transitions from a downtime state. For example, a transition from PRD to a downtime state starts a continuous downtime event. A continuous downtime event continues through state transitions from SDT to UDT or vice versa. The count of continuous downtime events is used in the metric mean time off line (MTOL).

6.3.3 PM Event — For a subsystem, noncluster tool, an SPCT, or an individual equipment module, a PM event is a downtime event into SDT where the SDT PM substate occurs before the equipment exits SDT; PM events for an IPS/MPCT are the aggregate set of PM events of its constituent equipment modules. The count of PM events is used in the metric mean time to PM (MTTPM).

6.3.4 Failure Event — A failure event is an event that starts with an equipment state transition for an equipment system from an equipment state other than UDT to UDT and ends when an equipment system transitions to any other equipment state except SDT. A failure event is a downtime event transitioning into UDT. For a subsystem, noncluster tool, an SPCT, or an individual equipment module, a failure event also is classified as a repair event if a repair substate occurs before the equipment exits UDT; repair events for an IPS/MPCT are the aggregate set of repair events of its constituent equipment modules. Failure events are classified as follows:

6.3.4.1 Failure During Productive Time — A failure event from PRD. This includes failures that occur while attempting the transition into PRD. The count of failures during productive time is used in the metrics $MTBF_p$ and $MCBF_p$.

6.3.4.2 Failure During Uptime — A failure event from PRD, SBY, or ENG. This includes failures that occur while attempting the transition into those equipment states. The count of failures during uptime is used in the metrics $MTBF_u$ and $MCBF_u$.

6.3.4.3 Equipment-Related Failure During Productive Time — A failure event from PRD where the UDT repair time, equipment-related substate occurs before the equipment system exits the UDT related to the failure event. The count of equipment-related failures during productive time is used in the metrics $E-MTBF_p$ and $E-MCBF_p$.

6.3.4.4 Equipment-Related Failure During Uptime — A failure event from PRD, SBY, or ENG where the UDT repair time, equipment-related substate occurs before the equipment exits the UDT related to the failure event. The count of equipment-related failures during uptime is used in the metrics $E-MTBF_u$ and $E-MCBF_u$.

6.3.4.5 Equipment-Related Repair Event — For a subsystem, noncluster tool, an SPCT, or an individual equipment module, an equipment-related repair event is a failure event where the UDT repair time, equipment-related substate occurs before the equipment system exits UDT. For an IPS/MPCT, the count of equipment-related repair events used in these metrics is the aggregate count of equipment module-level equipment-related repair events. The count of equipment-related repair events is used in the metrics MTTR and E-MTTR.

6.3.4.6 Nonequipment-Related Repair Event — For a subsystem, noncluster tool, an SPCT, or an individual equipment module, a nonequipment-related repair event is a failure event where the UDT repair time, nonequipment-related substate occurs—and the UDT repair time, equipment-related substate does not occur—before the equipment exits UDT. For an IPS/MPCT, the count of nonequipment-related repair events used in this metric is the aggregate count of equipment module-level nonequipment-related repair events. The count of nonequipment-related repair events is used in the metric MTTR.

NOTE 20: It is legitimate to have ‘repairless’ failures that contain neither of the substates UDT repair time, nonequipment-related substate or the UDT repair time, equipment-related.

6.4 Tracking Requirements for Subsets of Downtime — For each observation period, aside from aggregating the time in each equipment state, certain metrics require aggregated time in subsets of both scheduled downtime and unscheduled downtime. These subsets are defined by the downtime substates and by the classification of related downtime events.

6.4.1 Unscheduled Downtime for Failures During Productive Time — The sum of all time in UDT related to failure events from PRD. This includes time for failures that occur immediately after the transition into PRD. The sum of unscheduled downtime for failures during productive time is used in the metric MFD_p .

6.4.2 Unscheduled Downtime for Failures During Uptime — The sum of all time in UDT related to failure events from PRD, SBY, and ENG. This includes time for failures that occur immediately after the transition into those equipment states. The sum of unscheduled downtime for failures during uptime is used in the metric MFD_u .

6.4.3 PM Time — For a subsystem, noncluster tool, an SPCT, or an individual equipment module, PM time is the sum of all time in the substate SDT PM. For an IPS/MPCT, PM time is the aggregate time for all equipment modules in the IPS/MPCT. PM time is used in the metric MTTPM.

6.4.4 Repair Time for Equipment-Related Failures — For a subsystem, noncluster tool, an SPCT, or an individual equipment module, repair time for equipment-related failures is the sum of all time in the substate UDT repair, equipment-related. For an IPS/MPCT, repair time for equipment-related failures is the aggregate time for all equipment modules in the IPS/MPCT. Repair time for equipment-related failures is used in the metrics MTTR and E-MTTR.

6.4.5 Repair Time for Nonequipment-Related Failures — The sum of all time in substate the UDT repair, nonequipment-related is used in the metric MTTR.

6.4.6 Equipment-Dependent Scheduled Downtime — The sum of all time in the substates SDT PM, SDT setup, and SDT change of consumable material. This quantity is used in the metrics equipment-dependent uptime (%), equipment-dependent scheduled downtime (%), and equipment-dependent unscheduled downtime (%).

NOTE 21: The SDT production test substate is presumed to be primarily dictated by user policy and is excluded from equipment dependence. The SDT unspecified substate is not clearly associated with equipment dependence and is excluded.

6.4.7 Equipment-Dependent Unscheduled Downtime — The sum of all time in the substates UDT repair, equipment-related and UDT change of consumable material. This quantity is used in the metrics equipment-dependent uptime (%), equipment-dependent scheduled downtime (%), and equipment-dependent unscheduled downtime (%).

NOTE 22: The UDT unspecified substate is not clearly associated with equipment dependence and is excluded.

6.4.8 Supplier-Dependent Scheduled Downtime — The sum of equipment-dependent scheduled downtime (from ¶ 6.4.6) and all time in the substate SDT maintenance delay, supplier. This quantity is used in the metrics supplier-dependent uptime (%), supplier-dependent scheduled downtime (%), and supplier-dependent unscheduled downtime (%).

6.4.9 Supplier-Dependent Unscheduled Downtime — The sum of equipment-dependent unscheduled downtime (from ¶ 6.4.7) and all time in the substate UDT maintenance delay, supplier. This quantity is used in the metrics supplier-dependent uptime (%), supplier-dependent scheduled downtime (%), and supplier-dependent unscheduled downtime (%).

7 Additional Concepts and Tracking Requirements for IPSs and MPCTs

7.1 This section presents additional concepts and tracking requirements for intended process set (IPS) and multipath cluster tool (MPCT) RAM and utilization performance. While subsystems, noncluster tools, single-path cluster tools (SPCTs), and individual equipment modules are either entirely ‘up’ (i.e., in one of the uptime states) or entirely ‘down’ (i.e., in one of the downtime states), MPCTs are more likely to have a combination of some ‘up’ equipment modules and some ‘down’ equipment modules. An MPCT can be ‘up’ although individual equipment modules or IPSs within the MPCT are ‘down’.

7.2 *Intended Process Set (IPS) Concepts*

7.2.1 An IPS is a particular subset of equipment modules within an MPCT that is used to satisfy a subset of processes intended to be performed by the MPCT. An MPCT may have one IPS, a few IPSs, or many IPSs.

7.2.2 At each process step, an IPS may be comprised of a unique equipment module or a set of several alternative equipment modules. How the user defines each IPS determines which equipment modules are required for that IPS to be ‘up’ or ‘down’.

7.2.3 The equipment state of the IPSs in an MPCT determines the equipment state of the MPCT. If all of the IPSs in an MPCT are ‘down’, then the MPCT is down. If any IPS in the MPCT is ‘up’, then the MPCT is up.

7.2.4 In order to evaluate MPCT RAM and utilization metrics, the IPSs shall be predetermined for the MPCT. It is important to differentiate between process sets that are possible on a given MPCT configuration and ‘intended’ process sets that are specified by the user for equipment operation. Two instances of the same MPCT, as offered by the supplier, may have different definitions of IPSs based on how the user intends to apply the MPCTs. Also, for a given MPCT, the user may change the specified set of IPSs over time to meet changing process needs.

7.3 *Equipment Module Tracking Requirements*

7.3.1 All metrics for IPSs and MPCTs are calculated as functions of equipment module-level data only and require complete tracking of equipment state data for all equipment modules that are components of IPSs within the MPCT.

7.3.2 Equipment modules in IPSs can include both processing equipment modules and nonprocessing equipment modules (e.g., handlers, load locks, carrier ports). An individual equipment module may belong to one IPS, several IPSs, or all IPSs for an MPCT.

7.3.3 Certain behavior or functionality that affects the MPCT ‘at large’ and is not clearly attributed to a processing equipment module or nonprocessing equipment module can be modeled under an abstract mainframe equipment module. Example items to model in a mainframe equipment module include shared computing resources, information services like recipe download, and power and gas distribution.

7.3.4 A key group (K) is a subset of equipment modules that are common to all IPSs in an MPCT where the failure of K is sufficient to cause a failure of all IPSs and hence the entire MPCT. K may include the mainframe equipment module if one is tracked for the MPCT. By accurately modeling K and leveraging it in calculations, substantial redundant calculations are avoided. Furthermore, understanding which equipment modules belong to K is crucial in understanding and improving overall equipment system reliability and availability.

7.3.5 *Count of Equipment Cycles* — For an IPS/MPCT a ‘cycle’ shall be defined in terms of the intended function of the entire IPS/MPCT. For example, an IPS/MPCT cycle can be defined in terms of units, where one unit passing through the entire IPS/MPCT counts as one cycle, even if not all equipment modules were visited by the particular unit.

7.4 *Temporal Mapping of IPS and MPCT Equipment States*

7.4.1 The method of temporal mapping—or mapping over time—defined in this section is used to generate a history of IPS/MPCT equipment states based on the equipment states of individual equipment modules. IPS equipment states are determined as a function of equipment module equipment states, and MPCT equipment states are determined as a function of IPS equipment states.

7.4.2 Temporal mapping provides an output equipment state history for an IPS/MPCT as a function of input equipment state histories from associated process sets and equipment modules. For each event when at least one of the equipment modules changes equipment state, the equipment states of the IPS and/or MPCT can change and shall be evaluated. For the metrics in this Specification, MPCT and IPS equipment state histories are generated as functions of equipment module equipment state histories on an event-by-event basis in chronological order. The metrics themselves are calculated as functions of these generated output equipment state histories.

7.4.3 Figure 3 presents an example of a simple temporal mapping where equipment module states and a desired output state change from ‘up’ and ‘down’ over time. The input states for two equipment modules, M1 and M2, are shown over the observation period $t = 0$ to $t = 10$. An output state is mapped temporally as a function of the equipment module states, where if either equipment module is ‘down’ or both equipment modules are ‘down’, then the output state is ‘down’. The set of transition events to evaluate for the output state history is the union set of the transition events for the input state histories: $t = 0$, $t = 2$, and $t = 7$ for M1 and $t = 0$, $t = 4$, and $t = 9$ for M2.

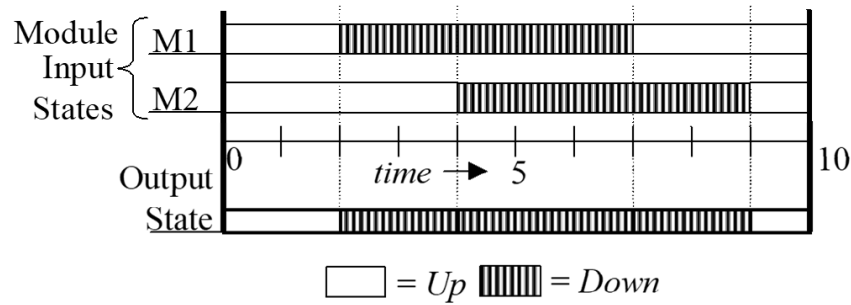


Figure 4
Equipment Module Set Output State as a Function of Individual Equipment Module Input States

7.4.4 Temporal mapping can be performed as each event is generated and received by a SEMI E10-compliant equipment performance tracking system. Temporal mapping also can be performed in batch mode at report time. Regardless, a logic function is applied at each input equipment state transition event to derive an output equipment state value as a function of the input equipment state values.

7.4.5 There are different types of temporal mapping depending on the target equipment state to be evaluated. For PRD, at least one processing equipment module shall be in PRD for the IPS or MPCT to be in PRD. For downtime states, a more complicated reliability function defined in § 7.5 is required to determine the output equipment state.

NOTE 23: Related Information 2 provides an example MPCT scenario including temporal mapping of IPSs and MPCT.

7.4.6 *Temporal Mapping of the Six Basic Equipment States for an IPS* — This section provides the logical flow for determining the equipment state of an IPS based on the equipment states of its constituent equipment modules and on a direct designation of NST for the IPS as a whole. Figure 4 illustrates this logical flow.