

SEMI E10-0312

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 December 24, 2011. Available at www.semiviews.org and www.semi.org in March 2012; originally published in 1986; previously published March 2004.

NOTICE: This Document was completely rewritten in 2011.

1 Purpose

1.1 This Document establishes a common basis for communication between users and suppliers of semiconductor manufacturing equipment 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 The Document defines six mutually exclusive basic states into which all conditions and periods of time for an equipment system must fall. One state called unscheduled downtime defines a 'failed' state for an equipment system. The measurement of equipment system reliability in this Document concentrates on the relationship of equipment system failures to equipment system usage.

2.2 All metrics defined herein are applicable to equipment systems that include noncluster tools, single-path cluster tools (SPCTs), equipment modules within a multi-path cluster tool (MPCT), intended process sets (IPs) of equipment modules, and MPCTs. This Document defines a treatment of RAM measurement for MPCTs by first defining performance of IPs 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 IPs and MPCTs is defined.

2.3 This Document defines basic metrics for:

2.3.1 *Reliability* — Including mean time between failures and mean cycles between failures.

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, mean time to (perform) preventive maintenance, mean time offline, total failure rate, and impairment rate.

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

2.4 Supporting material included in this Document addresses concepts for measurement of MTBF uncertainty and 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 Document, but is addressed by SEMI E58 and SEMI E116.

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

3.3 This Document 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 may be 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 is addressed by SEMI E79.

3.5 This Document 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 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

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

5 Terminology

5.1 Abbreviations and Acronyms

5.1.1 *AMSAA* — Army Materials Systems Analysis Activity

5.1.2 *ARAMS* — Automated Reliability, Availability, and Maintainability Standard

5.1.3 *COO* — cost of ownership

5.1.4 *DT* — downtime

5.1.5 *E-MCBF_p* — mean cycles between equipment-related failures during productive time

5.1.6 *E-MCBF_u* — mean cycles between equipment-related failures during uptime

5.1.7 *E-MTBF_p* — mean productive time between equipment-related failures

5.1.8 *E-MTBF_u* — mean uptime time between equipment-related failures

5.1.9 *E-MTTR* — mean time to repair during equipment-related failures

5.1.10 *ENG* — engineering

5.1.11 *HPP* — homogeneous Poisson process

5.1.12 *IPS* — intended process set

5.1.13 *K* — key group

5.1.14 *LCB* — lower confidence bound

5.1.15 *LN₂* — liquid nitrogen

5.1.16 *MCBF_p* — mean cycles between failures during productive time

5.1.17 *MCBF_u* — mean cycles between failures during uptime

5.1.18 *MFD_p* — mean failure duration for failures during productive time

5.1.19 *MFD_u* — mean failure duration for failures during uptime

5.1.20 *MPCT* — multi-path cluster tool

5.1.21 *MTBF_p* — mean time between failures during productive time

5.1.22 *MTBF_u* — mean time between failures during uptime

- 5.1.23 *MTOL* — mean time off-line
- 5.1.24 *MTTPM* — mean time to [perform] preventive maintenance
- 5.1.25 *MTTR* — mean time to repair
- 5.1.26 *OOS* — out of specification
- 5.1.27 *PM* — preventive maintenance
- 5.1.28 *PRD* — productive
- 5.1.29 *SBY* — standby
- 5.1.30 *SDT* — scheduled downtime
- 5.1.31 *SPCT* — single-path cluster tool
- 5.1.32 *TFR* — total failure rate
- 5.1.33 *UCB* — upper confidence bound
- 5.1.34 *UDT* — unscheduled downtime

5.2 Definitions

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

5.2.2 *cluster tool* — an equipment system made up of multiple integrated equipment processing equipment modules mechanically linked together. The equipment modules may or may not come from the same supplier.

5.2.3 *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]

5.2.4 *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 1: 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.

5.2.5 *consumable part* — component part of the equipment that is consumed by the process operation of the equipment with a predictable life expectancy of less than one year. It requires periodic replacement to allow the equipment to perform its intended function.

NOTE 2: Life expectancy concept comes from SEMI E35.

5.2.6 *continuous downtime event* — a downtime event when an equipment system transitions into a downtime state from a nondowntime state. For example, a transition from the productive state to a downtime state is a continuous downtime event, but a transition from a scheduled downtime state to an unscheduled downtime state or vice versa is not a continuous downtime event.

5.2.7 *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.

5.2.8 *downtime (DT)* — the operations time when the equipment system is not in a condition, or is not available, to perform its intended function. Downtime includes scheduled downtime and unscheduled downtime.

5.2.9 *downtime event* — an initial state transition event either (1) into a scheduled downtime state from a state other than a scheduled downtime state or (2) into an unscheduled downtime state from a state other than an unscheduled

downtime state. A downtime event can be a transition into an unscheduled downtime state from a scheduled downtime state or vice versa. A downtime event is neither a substate transition within a scheduled downtime state nor a substate transition within an unscheduled downtime state.

5.2.10 *engineering time* — the time when the equipment system is in a condition to perform its intended function (no equipment or process problems exist), but is operated to conduct engineering experiments, especially where the usage of the equipment is not indicative of normal production.

5.2.11 *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]

5.2.12 *equipment module* — an indivisible entity within an equipment system. An equipment module may be either a nonprocessing equipment module or a processing equipment module.

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

5.2.14 *equipment system* — a system of equipment capable of independently hosting material for processing, inspection, metrology, transportation, or storage for which the independent tracking of reliability, availability, and maintainability (RAM) and utilization is desired. This includes noncluster tools, equipment modules, single-path cluster tools (SPCTs), intended process sets (IPSs) in multi-path cluster tools (MPCTs), and MPCTs.

5.2.15 *failure* — any unplanned or unscheduled event that changes an equipment system to a condition where it cannot perform its intended function. One or more component or subsystem failures, software or process recipe problems, facility or utility supply malfunctions, or human errors could cause an equipment system failure. In terms of SEMI E10 states, a failure is a downtime event into an unscheduled downtime state. Only the initial transition event to the unscheduled downtime state is a failure; subsequent problems occurring during a continuous unscheduled downtime are not counted as additional failures.

5.2.16 *host* — the factory computer system or an intermediate system that represents the factory and the operator to the equipment. [SEMI E116]

5.2.17 *intended function* — a manufacturing function that the equipment was built to perform. 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.

5.2.18 *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 multi-path 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.

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

5.2.20 *mainframe equipment module* — an individual abstract equipment module that may be used optionally in modeling a multi-path 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.

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

5.2.22 *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 adjustments, change of consumable material, software upgrades, repair, preventive maintenance (PM), etc., no matter who performs the task.

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

5.2.24 *multi-path 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.

- 5.2.25 *noncluster tool* — an equipment system made up of only one processing equipment module.
- 5.2.26 *nonconsumable part* — component part of the equipment that is not normally consumed 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.
- 5.2.27 *nonprocessing equipment module* — an indivisible equipment entity that supports the movement or conditioning of units through the equipment. Examples of nonprocessing equipment modules include robotic handlers, load/unload locks, and prealigners.
- 5.2.28 *nonscheduled time* — the time when the equipment system is not scheduled to be utilized in production.
- 5.2.29 *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.
- 5.2.30 *observation period* — a specified continuous interval of calendar time (e.g., 72 hours, 6 weeks, 3 months, 1 quarter, past 90 days) during which equipment system performance is tracked.
- 5.2.31 *operations time* — total time minus nonscheduled time.
- 5.2.32 *operator* — any person who communicates locally with the equipment through the equipment's control panel.
- 5.2.33 *preventive maintenance (PM) event* — a downtime event into a scheduled downtime (SDT) state where the SDT preventive maintenance substate occurs before the equipment exits the scheduled downtime state.
- 5.2.34 *processing equipment module* — an indivisible production entity within an equipment system. Examples of processing equipment modules include processing chambers and processing stations.
- 5.2.35 *process path* — a specific set of modules a unit passes through for which each module is unique and has no alternative modules.
- 5.2.36 *product* — units produced during productive time (see unit).
- 5.2.37 *productive time* — the time in which the equipment system is performing its intended function.
- 5.2.38 *ramp-down* — the portion of a maintenance procedure required to prepare the equipment for hands-on work. It includes purging, cool-down, warm-up, software backup, storing dynamic values (e.g., parameters, recipes), etc. Ramp-down is only included in scheduled downtime and unscheduled downtime.
- 5.2.39 *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 pump down, warm-up, stabilization periods, initialization routines, software load, restoring dynamic values (e.g., parameters, recipes), control system reboot, etc. It does not include equipment or process test time. Ramp-up is only included in scheduled downtime and unscheduled downtime.
- 5.2.40 *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 seen by the units. Recipes may be subject to change between runs or processing cycles.
- 5.2.41 *reliability* — the probability that the equipment will perform its intended function, within stated conditions, for a specified period of time.
- 5.2.42 *scheduled downtime* — the time when the equipment system is not available to perform its intended function due to planned downtime events.
- 5.2.43 *shutdown* — the time required to put the equipment in a safe condition when entering a nonscheduled state. It includes any procedures necessary to reach a safe condition. Shutdown is only included in nonscheduled time.
- 5.2.44 *single-path cluster tool (SPCT)* — a cluster tool in which all units follow only one process path.
- 5.2.45 *specification (equipment operation)* — the documented set of intended functions within stated conditions for equipment operation as agreed upon between user and supplier.

5.2.46 *standby time* — the time, other than nonscheduled time, 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.

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

5.2.48 *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]

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

5.2.50 *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).

5.2.51 *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 must be accounted for and tracked accurately.

5.2.52 *training (off-line)* — the instruction of personnel in the operation and/or maintenance of equipment done outside of operations time. Off-line training is only included in nonscheduled time.

5.2.53 *training (on-the-job)* — the instruction of personnel in the operation and/or maintenance of equipment done during the course of normal work functions. On-the-job training typically does not interrupt operation or maintenance activities and can therefore be included in any equipment state (except standby and nonscheduled) without special categorization.

5.2.54 *unit* — any wafer, substrate, die, packaged die, or piece part thereof.

5.2.55 *unscheduled downtime* — the time from when the equipment system has experienced a failure until equipment is restored to a condition where it may perform its intended function.

5.2.56 *uptime* — the time when the equipment system is in a condition to perform its intended function. It includes productive, standby, and engineering time, and does not include any portion of downtime or nonscheduled time.

5.2.57 *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.

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

5.2.59 *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.

5.3 Symbols

5.3.1 *Ai* — alternative equipment module.

5.3.2 *Li* — load lock i.

5.3.3 *M* — equipment module.

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 performance (e.g., RAM metrics), this Document defines six basic equipment states into which all equipment conditions and periods of time must fall. Any equipment system must be in one and only one SEMI E10 state at any point in time. Any equipment system must be subject to at most one failure at any point in time regardless of the number of underlying constituent problems contributing to or arising from that failure.

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 Figure 1 is a stack chart of the six basic equipment states. These basic equipment states can be divided into as many substates as are required to achieve the equipment tracking resolution that a manufacturing operation desires. This Document makes no attempt to list all possible substates, but does give some that are required to support certain metrics and other examples for guidance.

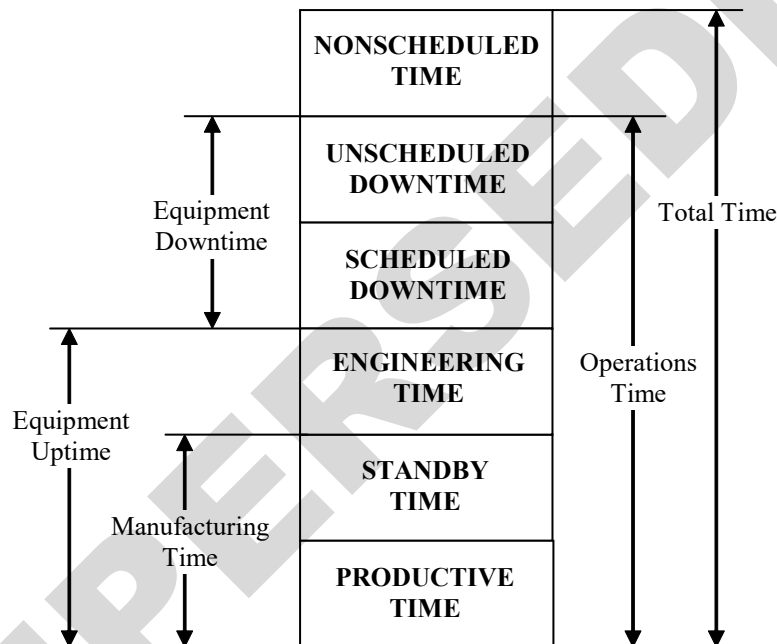


Figure 1
Equipment State Stack Chart

6.1.4 Key blocks of time associated with the basic states and substates are given in Figure 2. These blocks of time are used in the RAM equations given later in this Document. The blocks of time associated with the basic states and substates are described in the following sections.

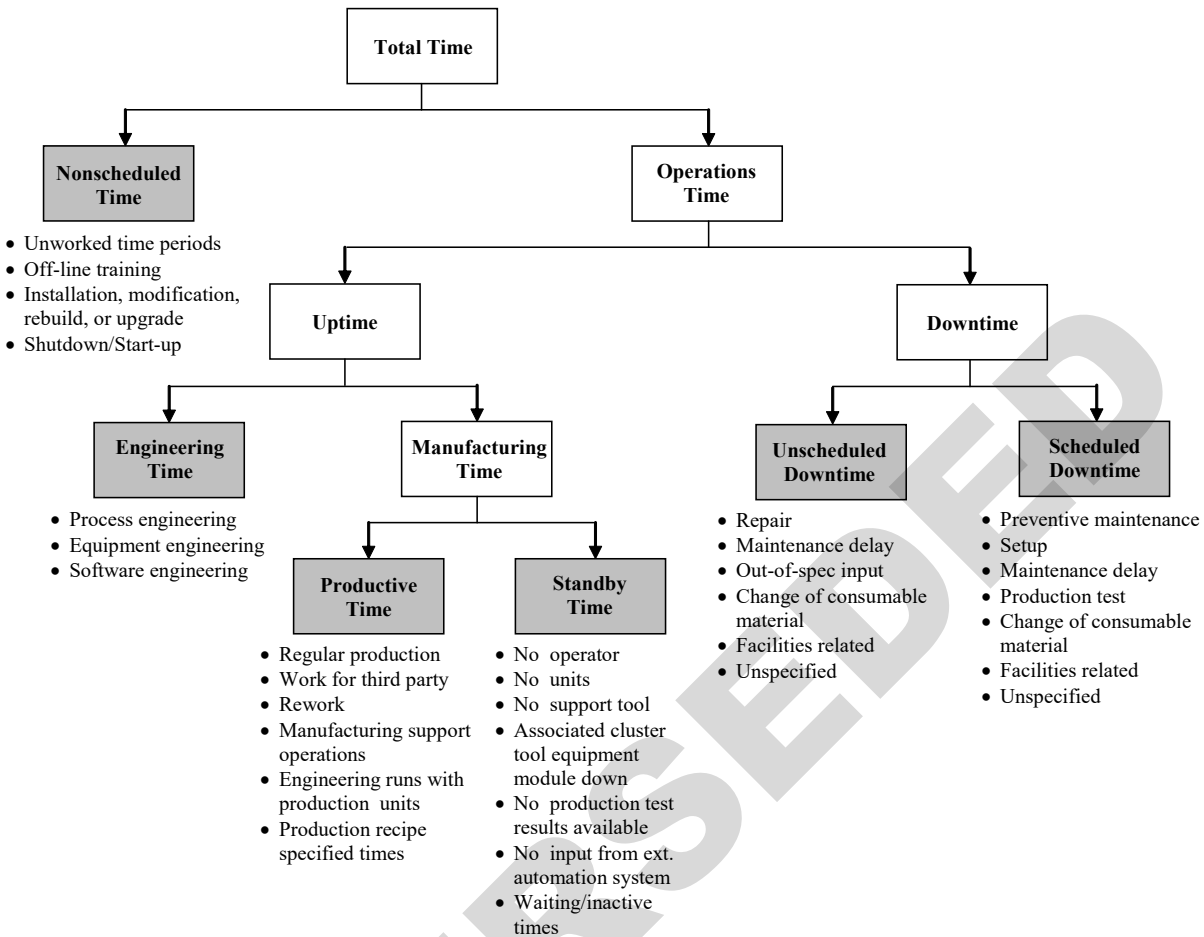


Figure 2
Equipment State Hierarchy

6.1.5 Productive (PRD) State — The time (productive time) in which the equipment system is performing its intended function. The productive state includes the following activities:

- Regular production (including loading and unloading of units internal to the equipment and 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)

6.1.5.1 Times for heating, cooling, purging, pump down, cleaning, etc., that are specified as part of production recipes shall be specifically included in productive time. However, similar times that are not specified as part of production recipes shall be specifically excluded from productive time.

NOTE 3: Productive state events may be derived from SEMI E58 (ARAMS) state change data or SEMI E116 (EPT) equipment module BUSY state events where the equipment system is known to be in a 'manufacturing' state and the SEMI E116 task type is either "Process" or "Support."

6.1.6 Standby (SBY) State — The time (standby time), other than nonscheduled time, 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. The standby state includes 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., cassette, 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 times or inactive times, including waiting for load and waiting for unload

6.1.7 Engineering (ENG) State — The time (engineering time) when the equipment system is in a condition to perform its intended function (no equipment or process problems exist), but is operated to conduct engineering experiments, especially where the usage of the equipment is not indicative of normal production. Failures under such extreme conditions should not be considered to arise from the productive state. The engineering state includes the following activities:

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

6.1.8 Scheduled Downtime (SDT) State — The time (scheduled downtime) when the equipment system is not available to perform its intended function due to planned downtime events. These events may be based upon time, equipment usage, or equipment conditions. Scheduled downtime is divided into the following mutually exclusive substates:

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

NOTE 4: The substates SDT preventative maintenance; SDT setup; SDT maintenance delay, supplier; and SDT change of consumables are required to support accurate supplier-dependent and equipment-dependent metrics. Other SDT substates are not used in these metrics. See §§ 8.3.3 and 8.3.4.

6.1.8.1 SDT Preventive Maintenance — The time for the following procedures as specified by the supplier:

- **Preventive Action** — A predefined maintenance procedure (including equipment ramp-down and ramp-up), at scheduled intervals (e.g., consumable part replacement), designed to reduce the likelihood of equipment failure during operation. Scheduled intervals may be based upon time, equipment usage, 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 5: Equipment suppliers are responsible for recommending a PM program to achieve a predetermined equipment performance level. Users are obligated to identify any deviation from the recommended program if they expect the supplier to meet or improve that performance level.

6.1.8.2 *SDT Setup* — The time for the following activities related to a setup as specified by the supplier:

- *Conversion* — The time required 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 6: Equipment suppliers are responsible for recommending procedures for conversion. Users are obligated to identify any deviation from the recommended procedures.

NOTE 7: Recipe download activities that are unusual or infrequent, that have especially significant impact on equipment time, or that require significant manual intervention should be tracked as conversions under SDT setup time. Recipe download activities that are regular, automated functions of processing should be tracked under productive time.

6.1.8.3 *SDT Maintenance Delay, Supplier* — The time during which 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 substate may occur at any point during a scheduled downtime state.

6.1.8.4 *SDT Maintenance Delay, Nonsupplier* — The time 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. An SDT maintenance delay substate may occur at any point during a scheduled downtime state. An SDT maintenance delay substate may also be due to an administrative decision to leave the equipment down and postpone maintenance.

6.1.8.5 *SDT Production Test* — The time (production test downtime) 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 the time while waiting for test results.

6.1.8.6 *SDT Change of Consumable Material* — The time for the scheduled interruption of equipment uptime to change consumable material. It does not include delays in obtaining the consumable material.

6.1.8.7 *SDT Facilities-Related* — The time (scheduled facilities-related downtime) 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 time required to return the equipment to a condition where it can perform its intended function is 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

6.1.8.8 *SDT Unspecified* — Any scheduled downtime that is not specifically tracked under one of the above substates.

6.1.9 *Unscheduled Downtime (UDT) State* — The time from when the equipment system has experienced a failure until equipment is restored to a condition where it may perform its intended function.

6.1.9.1 A continuous instance of unscheduled downtime is called a failure. A failure spans from the first transition to unscheduled downtime from a state other than unscheduled downtime to the next transition to a state other than unscheduled downtime.

6.1.9.2 A ‘failure onset event’ is the first transition to the unscheduled downtime state from a state other than unscheduled downtime. The failure onset event shall be used for all metrics requiring a count of failures. Transitions between substates of unscheduled downtime are not failure onset events and shall not be counted as additional failures.

6.1.9.3 Equipment-related failures are a subset of all failures whose causes and/or responsibilities are assigned to the supplier. The remaining failures are nonequipment-related failures.

6.1.9.4 The unscheduled downtime state 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-spec input
- UDT change of consumable material
- UDT facilities-related
- UDT unspecified

NOTE 8: The substates UDT repair; equipment-related; UDT maintenance delay, supplier; and UDT change of consumables are required to support accurate supplier-dependent and equipment-dependent metrics. Other UDT substates are not used in these metrics. See §§ 8.3.3 and 8.3.4.

6.1.9.5 *UDT Repair, Equipment-Related* — The unscheduled downtime substate in which the equipment is being actively repaired to bring it back to a productive state in response to a failure that is assigned to the supplier. Complete repair time includes the following activities:

- *Diagnosis* — The procedure of identifying the source of an equipment problem or failure.
- *Corrective Action* — The maintenance procedure (including equipment ramp-down and ramp-up, rebooting, resetting, recycling, restarting, reverting to a previous software version, etc.) employed to address an equipment failure (e.g., component part replacement) and return the equipment 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.

6.1.9.6 *UDT Repair, Nonequipment-Related* — The unscheduled downtime substate in which the equipment is being actively repaired to bring it back to a productive state in response to a failure that is not assigned to the supplier. Complete repair time includes the following activities:

- *Diagnosis* — The procedure of identifying the source of an equipment problem or failure.
- *Corrective Action* — The maintenance procedure (including equipment ramp-down and ramp-up, rebooting, resetting, recycling, restarting, reverting to a previous software version, etc.) employed to address an equipment failure (e.g., component part replacement) and return the equipment 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.

6.1.9.7 UDT Maintenance Delay, Supplier — The unscheduled downtime substate during which 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. UDT maintenance delays may occur at any point during unscheduled downtime.

6.1.9.8 UDT Maintenance Delay, Nonsupplier — The unscheduled downtime 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. An UDT maintenance delay substate may occur at any point during an unscheduled downtime state. A UDT maintenance delay substate may also be due to an administrative decision to leave the equipment down and postpone maintenance.

6.1.9.9 UDT Out-of-Specification (OOS) Input — The unscheduled downtime 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 required by the inputs listed below shall be included in UDT OOS input downtime. For example, if a prober/tester system is put down for repair as a result of an intermittent probe card short, all downtime incurred prior to identifying the problem is recategorized as UDT OOS input downtime. The inputs include:

- Support tools (e.g., warped cassettes or wafer carriers, faulty probe cards, defective reticles)
- Unit (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)

6.1.9.10 UDT Change of Consumable Material — The unscheduled downtime substate in which there is an unscheduled interruption of equipment uptime to change consumable material. This 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.

6.1.9.11 UDT Facilities-Related — The unscheduled downtime substate in which equipment cannot perform its intended function as the result of an unscheduled facilities failure. Any unscheduled downtime required by 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, all time required to return the equipment to a condition where it can perform its intended function is included in the UDT facilities-related substate. The facilities include:

- 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

6.1.9.12 UDT Unspecified — Any unscheduled downtime that is not specifically tracked under one of the above substates.

6.1.10 Nonscheduled (NST) State — The state in which the equipment system is not scheduled to be utilized in production. Nonscheduled time includes the following activities:

- Unworked Time Periods
- Off-Line Training
- Equipment Installation
- Equipment Modification
- NST IPS (IPS equipment systems only)

6.1.10.1 Unworked Time Periods — Shifts, weekends, holidays, facilities shutdowns, etc. out of the production schedule. Each unworked time period includes time for equipment shutdown and start-up.

6.1.10.2 *Off-line Training* — Operation of the equipment exclusively for training purposes that does not result in any other productive output.

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

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

6.1.10.5 *NST IPS* — For an IPS equipment system that is not the IPS or among the IPSs currently scheduled to be utilized in production. See § 7.4.6.1 for more details on IPS nonscheduled time.

NOTE 9: By designating IPSs in the NST IPS substate, productive time is more accurately attributed to individual IPSs. To the extent that multiple IPSs are simultaneously scheduled to be utilized in production, productive time cannot be attributed to individual IPSs. This attribution has a direct effect on the results for all IPS metrics involving productive time.

6.1.10.6 The nonscheduled state includes any qualification time required to bring the equipment to a condition where it can perform its intended function after one of these activities.

6.1.10.7 Any maintenance done to equipment cannot be counted in the nonscheduled state, since all maintenance (including automatic maintenance routines such as a programmed cryopump regeneration) must be tracked in either a scheduled downtime or an unscheduled downtime state.

6.1.10.8 By the same convention, any production or engineering work (including an unattended operation that may shut itself off ‘after hours’) must be tracked in either a productive or an engineering state.

NOTE 10: Nonscheduled time is intended for omission of strategically unworked periods from total time and should be generally predetermined in a long-term production schedule. The only notable exception may be nonscheduled IPS time for particularly agile MPCTs that frequently switch IPS perhaps from lot-to-lot. In general, random moment-to-moment periods of idling between productive periods should be tracked in the standby state rather than the nonscheduled state.

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 SEMI E10 states, there should 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 SEMI E10 state and/or substate, downtime events for each equipment system must be tracked and classified for use in SEMI E10 metrics.

6.3.1 *Downtime Event* — A downtime event is an initial state transition event either (1) into a scheduled downtime state from a state other than a scheduled downtime state or (2) into an unscheduled downtime state from a state other than an unscheduled downtime state. A downtime event can be a transition into an unscheduled downtime state from a scheduled downtime state or vice versa. A downtime event is neither a substate transition within a scheduled downtime state nor a substate transition within an unscheduled downtime state.

6.3.2 *Continuous Downtime Event* — A downtime event when equipment transitions into a downtime state from a nondowntime state. For example, a transition from the productive state to a downtime state is a continuous downtime event, but a transition from a scheduled downtime state to an unscheduled downtime state or vice versa is not a continuous downtime event. The count of continuous downtime events is used in the metric mean time off line (MTOL).

6.3.3 *Preventive Maintenance (PM) Event* — A downtime event into a scheduled downtime state where the SDT preventive maintenance substate occurs before the equipment exits the scheduled downtime state. The count of PM events is used in the metric mean time to PM (MTTPM).