Background Statement for SEMI Draft Document 6578

Revision to SEMI E10-0814^{E}
SPECIFICATION FOR DEFINITION AND MEASUREMENT OF EQUIPMENT RELIABILITY, AVAILABILITY, AND MAINTAINABILITY (RAM) AND UTILIZATION

NOTICE: This Background Statement is not part of the balloted item. It is provided solely to assist the recipient in reaching an informed decision based on the rationale of the activity that preceded the creation of this ballot.

NOTICE: For each Reject Vote, the Voter shall provide text or other supportive material indicating the reason(s) for disapproval (i.e., Negative[s]), referenced to the applicable section(s) and/or paragraph(s), to accompany the vote.

NOTICE: Recipients of this ballot are invited to submit, with their Comments, notification of any relevant patented technology, copyrighted items, or trademarks of which they are aware and to provide supporting documentation. In this context, 'patented technology' is defined as technology for which a patent has been issued or has been applied for. In the latter case, only publicly available information on the contents of the patent application is to be provided.

According to the SEMI Standards *Procedure Manual*, a Line-Item Ballot should include the Purpose, Scope, Limitations (if present), and Terminology (if present) sections, along with the full text of any section to which revisions are being balloted.

NOTICE: Additions are indicated by underline and deletions are indicated by ~~strikethrough~~.

Background

SEMI E10 is due for its mandatory five-year review. Below is a list of the types of changes included in this revision along with explanations/justifications as needed.

Scope

- **A. Various changes required to comply with the latest versions of the *Style Manual, Regulations*, and *Procedure Manual***: Many changes were made but with no actual intended changes from the original technical meaning. Please especially note the numerous verb changes to comply with *Style Manual* 4-5.
- **B. Various mostly editorial changes or very minor technical changes:** Many changes were made to improve wording consistency throughout the Document. One example is standardizing the use of 'equipment state' throughout when used to indicate one of the six basic equipment states vs. other uses of the term 'state' in the Document. Another example is to standardize on use of just 'substate' beginning in ¶ 6.1.3. Changed "suppliers of semiconductor manufacturing equipment by providing" to "suppliers of manufacturing equipment in the semiconductor and related industries by providing" in ¶ 1.1 to clarify the additional industry segments covered by SEMI to which E10 applies. Some existing terms used were not defined so the definitions from SEMI E149 were added. Various other, mostly editorial, changes were made to address grammar and consistency, but with no actual intended changes from the original technical meaning.
- **C. Mutual exclusivity of states and substates**: Please especially note the changes in ¶ 6.1.1 and the addition of ¶ 6.1.3.1.
- **D. Unscheduled Downtime State (UDT) definition correction/clarification**: Please especially note the changes in ¶ 5.2.67 and the addition of ¶ 6.1.9

E. **Improved handling of predictive maintenance conditions**: Some equipment/suppliers have added the capability to predict potential equipment failures before they occur based on monitoring and predictive models. This capability has now been specifically addressed. Please note that a potential effect of this change is that some previous unscheduled downtime will now be counted as scheduled downtime. This is analogous and more consistent with how the scheduled time for change of consumable material has been handled. Preventing failures (i.e., unscheduled downtime events) using scheduled downtime is considered more beneficial and less disruptive to manufacturing operations and less likely to cause scrapped units than unplanned failures. Please especially note the changes in § 6.1.8 and ¶ 5.2.52 along with the addition of ¶¶ 5.2.38-40.

F. **New metrics for subsystems**: A new category of reliability metrics, primarily intended for subsystems, beyond the current time-based and cycle-based metrics have been added for other 'work' factors (e.g., RF-hours for RF generators, pulse counts for pulse-based excimer lasers in exposure equipment). This increase in the scope of E10 addresses multiple requests the TF has received to provide more useful, official metrics for critical subsystems in several different types of equipment systems. Please especially note the changes and additions in ¶¶ 2.2, 2.3.1, 2.4, 5.2.17, 5.2.61, 5.2.62, 5.2.76, Table 3, 9.2, and 9.5 and §§ 10, Appendix 1, Appendix 2, and Related Information 2.

Review Information for Information Ballot

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SEMI Draft Document 6578

Revision to SEMI E10-0814[E]
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 May 12, 2014. Available at www.semiviews.org and www.semi.org in August 2014; originally published in 1986; previously published March 2012.~~

~~[E] This Standard was editorially modified in November 2015 to update patent information; SEMATECH Patent Application 12/749,169 is no longer valid.~~

~~**NOTICE:** This Document was completely rewritten in 2014.~~

1 Purpose

1.1 This Document establishes a common basis for communication between users and suppliers of ~~semiconductor~~ 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 The Document defines six mutually exclusive, basic equipment states ~~into which~~for all of the conditions and associated periods of time for an equipment system during and observation period~~must fall~~. One equipment state called the unscheduled downtime state (UDT) defines a 'failed' condition ~~state~~ for an equipment system. The measurement of equipment system reliability in this Document 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 multi-path cluster tool (MPCT), intended process sets (IPSs) of equipment modules, and MPCTs. This Document 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 Document defines basic metrics for:

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

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3 Limitations

3.1 Automated tracking of equipment states and performance is not within the scope of this Document, but is partially addressed by SEMI E58 (ARAMS) and SEMI E116 (EPT).

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. See Related Information 4 regarding the specific relationship between the SEMI E116 states and those needed by this Document.

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 system 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~~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 Document 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 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 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

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~~ 5.1.4 *E-MCBF*$_p$ — mean cycles between equipment-related failures during productive time

~~5.1.6~~ 5.1.5 *E-MCBF*$_u$ — mean cycles between equipment-related failures during uptime

~~5.1.7~~ 5.1.6 *E-MTBF*$_p$ — mean productive time between equipment-related failures

~~5.1.8~~ 5.1.7 *E-MTBF*$_u$ — mean uptime time between equipment-related failures

~~5.1.9~~ 5.1.8 *E-MTTR* — mean time to repair during equipment-related failures

~~5.1.10~~ 5.1.9 *ENG* — engineering state

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~~5.1.11~~ 5.1.10 *HPP* — homogeneous Poisson process

~~5.1.12~~ 5.1.11 *IPS* — intended process set

~~5.1.13~~ 5.1.12 *K* — key group

~~5.1.14~~ 5.1.13 *LCB* — lower confidence bound

~~5.1.15~~ 5.1.14 LN_2 — liquid nitrogen

~~5.1.16~~ 5.1.15 *MCBF* — mean cycles between failures

~~5.1.17~~ 5.1.16 $MCBF_p$ — mean cycles between failures during productive time

~~5.1.18~~ 5.1.17 $MCBF_u$ — mean cycles between failures during uptime

~~5.1.19~~ 5.1.18 MFD_p — mean failure duration for failures during productive time

~~5.1.20~~ 5.1.19 MFD_u — mean failure duration for failures during uptime

~~5.1.21~~ 5.1.20 *MPCT* — multi-path cluster tool

~~5.1.22~~ 5.1.21 *MTBF* — mean time between failures

~~5.1.23~~ 5.1.22 $MTBF_p$ — mean time between failures during productive time

~~5.1.24~~ 5.1.23 $MTBF_u$ — mean time between failures during uptime

~~5.1.25~~ 5.1.24 *MTOL* — mean time off-line

~~5.1.26~~ 5.1.25 *MTTPM* — mean time to [perform] preventive maintenance

~~5.1.27~~ 5.1.26 *MTTR* — mean time to repair

~~5.1.28~~ 5.1.27 *NST* — nonscheduled ~~time~~ state

~~5.1.29~~ 5.1.28 *OOS* — out of specification

~~5.1.30~~ 5.1.29 *PM* — preventive maintenance

~~5.1.31~~ 5.1.30 *PRD* — productive state

~~5.1.32~~ 5.1.31 *RAM* — reliability, availability, and maintainability

5.1.32 *RF* — radio frequency

5.1.33 *SBY* — standby state

5.1.34 *SDT* — scheduled downtime state

5.1.35 *SPCT* — single-path cluster tool

5.1.36 *TFR* — total failure rate

5.1.37 *UCB* — upper confidence bound

5.1.38 *UDT* — unscheduled downtime state

~~5.1.38~~ 5.1.39 *W* — work

5.2 *Definitions*

5.2.1 assembly — two or more component parts and/or subassemblies joined together to perform a specific function and capable of disassembly. [E149]

NOTE 2: 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.

~~5.2.1~~ 5.2.2 *availability* — the probability that the equipment system will be in a condition to perform its intended function when required.

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~~5.2.2~~ 5.2.3 *cluster tool* — an equipment system made up of multiple integrated processing equipment modules mechanically linked together. The equipment modules may or may not come from the same supplier.

~~5.2.3~~ 5.2.4 *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~~ 5.2.5 *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 2:~~NOTE 3: 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~~ 5.2.6 *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 3:~~NOTE 4: Life expectancy concept comes from SEMI E35.

~~5.2.6~~ 5.2.7 *continuous downtime event* — a downtime event starts when an equipment system transitions into a downtime state from an ~~nondowntime~~ uptime state or the nonscheduled state (NST). For example, a transition from the productive state (PRD) to a downtime state ~~is~~ starts a continuous downtime event.~~,~~ ~~but a~~A transition from a scheduled downtime state (SDT) to an unscheduled downtime state (UDT), or vice versa, ~~is not~~stays in a continuous downtime event.

~~5.2.7~~ 5.2.8 *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~~ 5.2.9 *downtime* ~~*(DT)*~~ — during an observation period, the accumulated ~~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.

5.2.10 *downtime event* — an initial equipment state transition event 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. A downtime event can be a transition into UDT from SDT or vice versa. A downtime event is neither an equipment substate transition within SDT nor an equipment substate transition within UDT.

~~5.2.9~~ 5.2.11 *downtime state* — the composite state of the scheduled downtime state (SDT) and the unscheduled downtime state (UDT).

~~5.2.10 *engineering time* — during an observation period, the accumulated time when the equipment system is in the engineering state (ENG).~~

5.2.12 *engineering state (ENG)* — the equipment state 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 system 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.

~~5.2.11~~ 5.2.13 *engineering time* — during an observation period, the accumulated time when the equipment system is in the engineering state (ENG).

~~5.2.12~~ 5.2.14 *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]

~~5.2.13~~ 5.2.15 *equipment module* — an indivisible entity within an equipment system. An equipment module may be either a nonprocessing equipment module or a processing equipment module.

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~~5.2.14~~ 5.2.16 *equipment-related failure* — any failure solely caused by the equipment (e.g., not an out-of-specification input).

~~5.2.15~~ 5.2.17 *equipment system* — a system of equipment generally capable of independently hosting units for processing, inspection, metrology, or support operations (e.g., transportation, storage, pump down) for which the independent tracking of performance (i.e., reliability, availability, and maintainability ~~(~~[RAM]~~)~~, utilization, productivity) is desired. This includes subsystems, noncluster tools, equipment modules, single-path cluster tools (SPCTs), intended process sets (IPSs) in multi-path cluster tools (MPCTs), and MPCTs.

~~5.2.16~~ 5.2.18 *failure* — a continuous instance of an unscheduled downtime state (UDT). A failure spans from the first 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. 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. An equipment system experiences at most one failure at a time; subsequent problems occurring during a failure are not counted as additional failure events.

~~5.2.17~~ 5.2.19 *failure event* — an initial equipment state transition event for an equipment system from an equipment state other than unscheduled downtime (UDT) to UDT. Failure events are used for establishing the count of failures in an observation period for applicable SEMI E10 metrics.

~~5.2.18~~ 5.2.20 *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]

~~5.2.19~~ 5.2.21 *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.

~~5.2.20~~ 5.2.22 *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.

~~5.2.21~~ 5.2.23 *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.

~~5.2.22~~ 5.2.24 *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.

~~5.2.23~~ 5.2.25 *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.

~~5.2.24~~ 5.2.26 *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.

~~5.2.25~~ 5.2.27 *manufacturing time* — the sum of productive time and standby time.

~~5.2.26~~ 5.2.28 *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.

~~5.2.27~~ 5.2.29 *noncluster tool* — an equipment system made up of only one processing equipment module.

~~5.2.28~~ 5.2.30 *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.

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~~5.2.29~~ 5.2.31 *nonprocessing equipment module* — an indivisible equipment entity 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.

~~5.2.30 *nonscheduled time* — during an observation period, the accumulated time when the equipment system is in the nonscheduled state (NST).~~

~~5.2.31~~ 5.2.32 *nonscheduled state (NST)* — the equipment state when the equipment system is not scheduled to be utilized in production.

5.2.33 *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).

~~5.2.32~~ 5.2.34 *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.

~~5.2.33~~ 5.2.35 *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.

~~5.2.34~~ 5.2.36 *operations time* — total time minus nonscheduled time.

~~5.2.35~~ 5.2.37 *operator* — any person who communicates locally with the equipment through the equipment's control panel.

5.2.38 *predictive model* — a predefined, documented set of conditions that have been determined to act as precursors to a failure event, which predict the need to schedule or plan preventive action to prevent a failure. Examples include approaching consumable part end of life, degraded performance but not yet at failure level, and known signal patterns occurring that indicates high probability of a future failures.

5.2.39 *preventive action* — a predefined preventive maintenance procedure (including equipment ramp-down and ramp-up), at scheduled intervals or based upon predictive models designed to reduce the likelihood of equipment failure during operation. Scheduled preventive maintenance may be based upon accumulated time, equipment usage (e.g., units, work), or equipment conditions (e.g., predictive models).

5.2.40 *preventive maintenance* — the performance of preventive actions (e.g., scheduled inspections, maintenance tasks) during a scheduled downtime state designed to reduce the likelihood of equipment failure during operation when it is performing its intended function (e.g., running production units). Also sometimes called scheduled maintenance. [E149]

~~5.2.36~~ 5.2.41 *preventive maintenance (PM) event* — a downtime event into a scheduled downtime state (SDT) where the SDT preventive maintenance equipment substate occurs before the equipment exits the scheduled downtime state (SDT).

~~5.2.37~~ 5.2.42 *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.

~~5.2.38~~ 5.2.43 *processing equipment module* — an indivisible production entity within an equipment system. Examples of processing equipment modules include processing chambers and processing stations.

~~5.2.39~~ 5.2.44 *product* — units produced during productive time (see unit).

~~5.2.40 *productive time* — during an observation period, the accumulated time the equipment system is in the productive state (PRD).~~

~~5.2.41~~ 5.2.45 *productive state (PRD)* — the equipment state in which the equipment system is performing its intended function.

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

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~~5.2.42~~ 5.2.47 *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.

~~5.2.43~~ 5.2.48 *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.

~~5.2.44~~ 5.2.49 *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.

~~5.2.45~~ 5.2.50 *reliability* — the probability that the equipment system will perform its intended function for a specified period of time.

~~5.2.46~~ 5.2.51 *scheduled downtime* — during an observation period, the accumulated time when the equipment system is in the scheduled downtime state (SDT).

~~5.2.47~~ 5.2.52 *scheduled downtime state (SDT)* — the equipment state when the equipment system is not ~~available~~ in a condition to perform its intended function due to scheduled or planned ~~downtime events~~activities or conditions. SDT includes any activities required to restore the equipment system to a condition where it can perform its intended function.

5.2.53 *scheduled maintenance* — see preventive maintenance. [E149]

~~5.2.48~~ 5.2.54 *shutdown* — the time required to put the equipment in a safe condition when entering a nonscheduled state (NST). It includes any procedures necessary to reach a safe condition. Shutdown is only included in NST.

~~5.2.49~~ 5.2.55 *single-path cluster tool (SPCT)* — a cluster tool in which all units follow only one process path.

~~5.2.50~~ 5.2.56 *specification (equipment operation)* — the documented set of intended functions including operating conditions as agreed upon between user and supplier.

~~5.2.51 *standby time* — during an observation period, the accumulated time the equipment system is in the standby state (SBY).~~

~~5.2.52~~ 5.2.57 *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.

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

~~5.2.53~~ 5.2.59 *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 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 NST.

~~5.2.54~~ 5.2.60 *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]

5.2.61 *subassembly* — two or more component parts joined together to perform a specific function and capable of disassembly. [E149]

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

~~5.2.55~~ 5.2.63 *supplier* — provider of equipment and related services to the user (e.g., unit manufacturer). Also called equipment vendor or original equipment manufacturer (OEM).

~~5.2.56~~ 5.2.64 *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).

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~~5.2.57~~ 5.2.65 *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~~ shall be accounted for and tracked accurately.

~~5.2.58~~ 5.2.66 *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 the nonscheduled state (NST).

~~5.2.59~~ 5.2.67 *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 [SBY] and nonscheduled [NST]) without special categorization.

~~5.2.60~~ 5.2.68 *unit* — any wafer, substrate, die, packaged die, or piece part thereof.

~~5.2.61~~ 5.2.69 *unscheduled downtime* — during an observation period, the accumulated time when the equipment system is in the unscheduled downtime state (UDT).

~~5.2.62~~ 5.2.70 *unscheduled downtime state (UDT)* — ~~any unplanned or unscheduled~~the equipment state ~~where an~~ when the equipment system ~~cannot~~ is not in a condition to perform its intended function due to unplanned or unscheduled activities or conditions. ~~Unscheduled downtime (~~UDT~~) starts when~~ includes any activities required to restore the equipment system ~~has experienced a failure event and lasts until it is restored~~ to a condition where it ~~may~~ can perform its intended function.

~~5.2.63~~ 5.2.71 *uptime* — during an observation period, the accumulated ~~the~~ time when the equipment system is in a condition to perform its intended function. ~~It~~ Uptime includes productive, standby, and engineering times, and does not include any portion of unscheduled downtime, scheduled downtime, or nonscheduled time.

5.2.72 *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).

~~5.2.64~~ 5.2.73 *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]

~~5.2.65~~ 5.2.74 *utilization* — the percentage of time the equipment system is performing its intended function during a specified observation~~time~~ period.

~~5.2.66~~ 5.2.75 *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.

5.2.76 *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 Document defines six, mutually exclusive, basic equipment states into which all equipment conditions and periods of time ~~must~~ shall fall. Any equipment system

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~~must~~ shall be in one and only one equipment~~SEMI E10~~ state at any point in time. One of these equipment states—unscheduled downtime (UDT)—represents the initial moment of an equipment system failure (i.e., a failure event) until its recovery from that failure event. Because an equipment system is in one and only one equipment~~SEMI E10~~ state at a time, an equipment system is subject to at most one failure at any point in 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 multi-path cluster tools (MPCTs), independent tracking of equipment~~SEMI E10~~ states is required for each equipment module in these equipment systems. These equipment modules may be in different equipment~~SEMI E10~~ 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 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 Document 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).~~;~~ ~~t~~These substates are required to support certain metrics and other examples for guidance.

6.1.3.1 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.

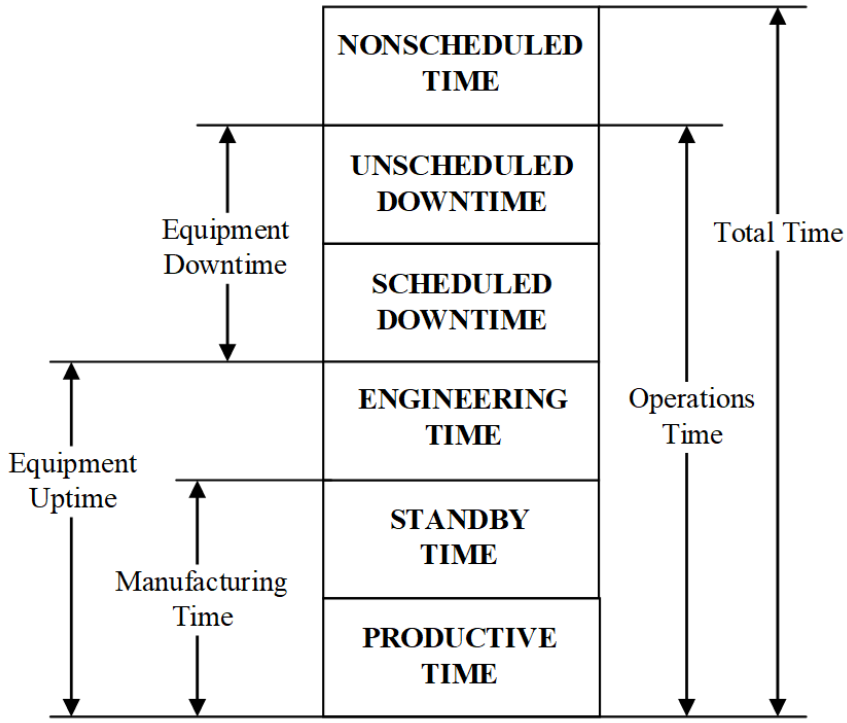

Figure 1
Equipment Time/State Stack Chart

6.1.4 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 Document. The activities and conditions associated with the basic equipment states and substates are described in the following sections.

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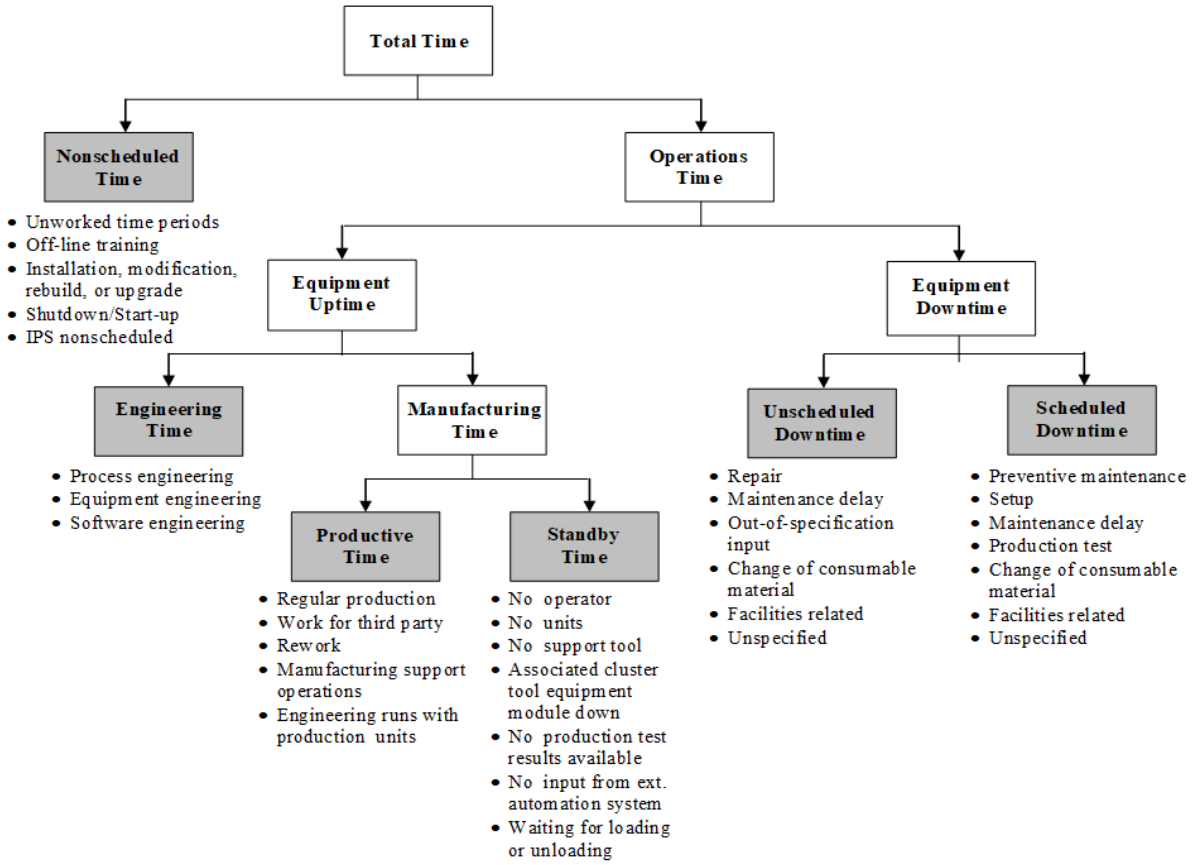

Figure 2
Equipment Time/State Hierarchy

6.1.5 *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~~an~~ equipment system is in PRD is called productive time. This Document does not define or require mutually exclusive substates for PRD, but PRD does include 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)

6.1.5.1 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 4:~~NOTE 5: Relative to the SEMI E30 (GEM) 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 (EPT) 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 (ARAMS), PRD here is intended to be synonymous with the ARAMS productive state. See Related Information 4 for more details.

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6.1.6 *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~~an~~ equipment system is in SBY is called standby time. This Document does not define or require mutually exclusive substates for SBY, but SBY does include 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

6.1.7 *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~~an~~ equipment system is in ENG is called engineering time. This Document does not define or require mutually exclusive substates for ENG, but ENG does include 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 State (SDT)* — The equipment state when the equipment system is not ~~available~~ in a condition to perform its intended function due to scheduled or planned activities or conditions~~downtime events~~. These activities or conditions~~events~~ may be based upon accumulated time, equipment usage (e.g., units, work), or equipment conditions (e.g., predictive models). During an observation period, the accumulated time when the~~an~~ equipment system is in SDT is ~~also~~ called scheduled downtime. SDT 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 5:~~NOTE 6: The substates SDT preventive maintenance; 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. See §§ 8.3.3 and 8.3.4.

6.1.8.1 *SDT Preventive Maintenance* — SDT substate that includes the following procedures as specified by the supplier as part of a preventive maintenance (PM) program:

- *Preventive Action* — A predefined preventive maintenance procedure (including equipment ramp-down and ramp-up), at scheduled intervals or based upon predictive models~~,~~ designed to reduce the likelihood of equipment

failure during operation. Scheduled preventive maintenance ~~intervals~~ may be based upon accumulated time, equipment usage (e.g., units, work), or equipment conditions (e.g., predictive models).

- *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 6:~~NOTE 7: 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* — 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 7:~~NOTE 8: Equipment suppliers are responsible for recommending procedures for conversion. Users are obligated to identify any deviation from the recommended procedures.

~~NOTE 8:~~NOTE 9: 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.

6.1.8.3 *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 substate may occur at any point during SDT.

6.1.8.4 *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 may occur at any point during SDT. 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* — 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.

6.1.8.6 *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.

6.1.8.7 *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)

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- Facility connections (e.g., power, cooling water, facility gases, exhaust, liquid nitrogen [LN_2])
- Communications links with other equipment or host computers

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

6.1.9 *Unscheduled Downtime State (UDT)* — The equipment~~unplanned or unscheduled~~ state when~~re~~ ~~an~~ the equipment system ~~cannot~~ is not in a condition to perform its intended function due to unplanned or unscheduled activities or conditions. UDT starts when the equipment system has experienced a failure event and lasts until it is restored to a condition where it ~~may~~ can perform its intended function. During an observation period, the accumulated time ~~an~~ when the equipment system is in UDT is ~~also~~ called unscheduled downtime.

6.1.9.1 A continuous instance of UDT is called a failure. A failure spans from the first 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.

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

6.1.9.3 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 9:~~NOTE 10: 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. See §§ 8.3.3 and 8.3.4.

6.1.9.4 *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. 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.

6.1.9.5 *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.

6.1.9.6 *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. UDT maintenance delay substates may occur at any point during UDT.

6.1.9.7 *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 an unscheduled downtime state. UDT maintenance delay substates may also be due to an administrative decision to leave the equipment down and postpone maintenance.

6.1.9.8 *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)

6.1.9.9 *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.

6.1.9.10 *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, LN_2)
- Communications links with other equipment or host

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

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

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

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

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

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

6.1.10.4 *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.

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

6.1.10.6 *IPS Nonscheduled* — IPS equipment system is not the current IPS or among the IPSs currently scheduled to be utilized in production. See § 7.4.6.1 for more details on the IPS ~~nonscheduled state~~NST.

~~NOTE 10:~~NOTE 11: 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.

6.1.10.7 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.

6.1.10.8 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) ~~must~~ shall be tracked in either SDT or UDT.

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

~~NOTE 11:~~NOTE 12: 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 $MCBF_p$.

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

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

6.3.2 *Continuous Downtime Event* — A downtime event starts when an equipment system transitions into a downtime state from an uptime ~~nondowntime~~ state or the nonscheduled state (NST). For example, a transition from PRD to a downtime state ~~is~~starts a continuous downtime event.~~,~~ ~~but a~~A transition from SDT to UDT, or vice versa, ~~is not~~ stays in 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* — For a noncluster tool, an SPCT, or an individual equipment module, a PM event is a downtime event into SDT where the SDT preventive maintenance 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 initial equipment state transition event for an equipment system from an equipment state other than UDT to UDT. A failure event is a downtime event transitioning into UDT. For a noncluster tool, an SPCT, or an individual equipment module, a failure event ~~may~~ also ~~be~~ 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 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 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 12:~~NOTE 13: 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.

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6.4 *Tracking Requirements for Subsets of Downtime* — For each observation period, aside from aggregating the time in each equipment~~SEMI E10~~ 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 noncluster tool, an SPCT, or an individual equipment module, PM time is the sum of all time in the substate SDT preventive maintenance. 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 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 preventive maintenance, 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 13:~~NOTE 14: 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 14:~~NOTE 15: 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 multi-path cluster tool (MPCT) RAM and utilization performance. While 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 ~~may~~ 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.

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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~~SEMI E10~~ 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 ~~may~~ 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 the key group is sufficient to cause a failure of all IPSs and hence the entire MPCT. A key group may include the mainframe equipment module if one is tracked for the MPCT. By accurately modeling a key group and leveraging it in calculations, substantial redundant calculations are avoided. Furthermore, understanding which equipment modules belong to the key group 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' ~~must~~ shall be defined in terms of the intended function of the entire IPS/MPCT. For example, an IPS/MPCT cycle ~~may~~ 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 ~~may~~ can change and ~~must~~ shall be evaluated. For the metrics in this Document, 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.

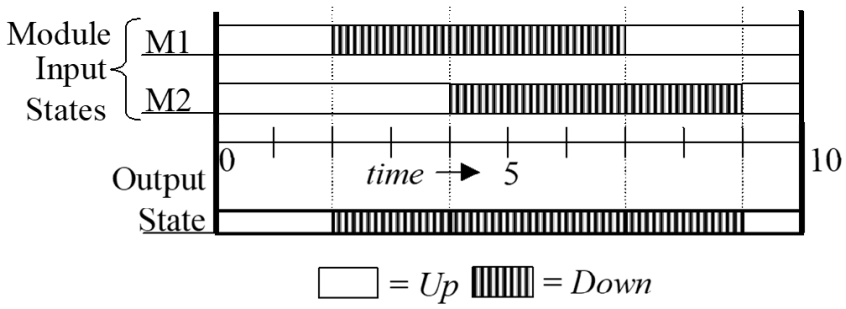

Figure 3
Equipment Module Set Output State as a Function of Individual Equipment Module Input States

7.4.4 Temporal mapping ~~may~~ can be performed as each event is generated and received by a SEMI E10-compliant equipment performance tracking system. Temporal mapping also ~~may~~ 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~~SEMI E10~~ state to be evaluated. For PRD, ~~only~~ at least one processing equipment module ~~must~~ 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 15:~~NOTE 16: 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~~SEMI E10~~ States for an IPS* — This section provides the logical flow for determining the equipment~~SEMI E10~~ state of an IPS based on the equipment~~SEMI E10~~ 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.

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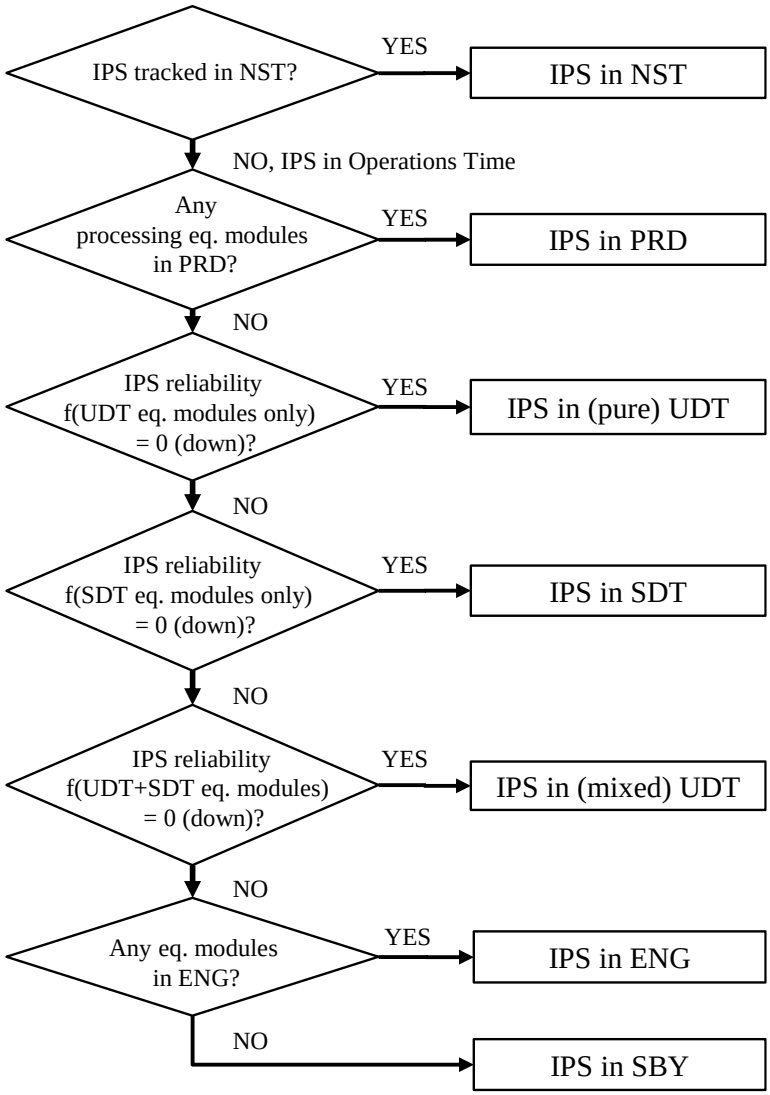

Figure 4
Temporal Mapping of Equipment Module Equipment~~SEMI E10~~ States to an IPS Equipment~~SEMI E10~~ State

7.4.6.1 First, an IPS as a whole ~~must~~ shall be tracked in either NST or in operations time. Any IPS that is not scheduled to be utilized in production shall be tracked in NST.

~~NOTE 16:~~NOTE 17: 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.

7.4.6.2 Next, if the IPS is not tracked in NST and if any processing equipment module in the IPS is in PRD, then the IPS is in PRD. If a processing equipment module in PRD belongs to more than one IPS that is not tracked in NST, then all such IPSs are in PRD.

~~NOTE 17:~~NOTE 18: Nonprocessing equipment modules, such as wafer handling equipment modules, are not considered when determining PRD for an IPS.

7.4.6.3 Otherwise, based on the reliability function of equipment module equipment states for an IPS, if an IPS is in a downtime state due only to equipment modules in UDT, then the IPS is in UDT.

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~~NOTE 18:~~NOTE 19: Both processing equipment modules and nonprocessing equipment modules are considered in the reliability function for the IPS.

~~NOTE 19:~~NOTE 20: For an IPS, the failure of an equipment module ~~may~~ can ~~or may not~~ result, in some cases but not others, in a failure of the entire IPS depending on the reliability function for that IPS.

~~NOTE 20:~~NOTE 21: When the IPS is in a downtime state due only to equipment modules in UDT, the IPS may ~~be said to~~ be in a 'pure' UDT.

7.4.6.4 Otherwise, based on the reliability function of equipment module equipment states for an IPS, if an IPS is in a downtime state due only to equipment modules in SDT, then the IPS is in SDT.

7.4.6.5 Otherwise, based on the reliability function of equipment module equipment states for an IPS, if an IPS is in a downtime state due to equipment modules in both UDT and SDT, then the IPS is in UDT.

~~NOTE 21:~~NOTE 22: When the IPS is not in 'pure' UDT or in SDT, but is 'down' due to equipment modules in both SDT and UDT, the IPS ~~is~~ may ~~said to~~ be in a 'mixed' UDT.

7.4.6.6 Otherwise, if at least one equipment module in the IPS is in ENG, then the IPS is in ENG.

~~NOTE 22:~~NOTE 23: Both processing equipment modules and nonprocessing equipment modules are considered when determining ENG for an IPS.

7.4.6.7 Otherwise, the IPS is in SBY. SBY means that the IPS is not tracked in NST, no processing equipment modules are in PRD, the IPS is not 'down' (from equipment modules in either SDT or UDT), and no equipment modules are in ENG. If all equipment modules of an IPS are in SBY, the IPS is in SBY. However, there are other combinations of equipment module equipment states for which an IPS ~~may~~ can also be in SBY.

7.4.7 *Temporal Mapping of the Six Basic Equipment~~SEMI E10~~ States for an MPCT* — This section presents the logical flow for determining the equipment~~SEMI E10~~ state of an MPCT as a function of the equipment~~SEMI E10~~ states of its constituent IPSs as determined in § 7.4.6. Figure 5 illustrates this logical flow.

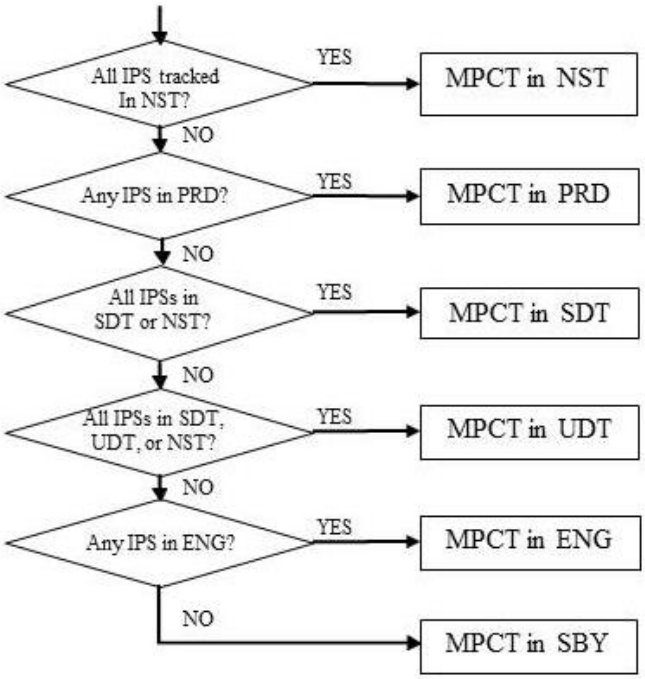

Figure 5
Temporal Mapping of IPS Equipment~~SEMI E10~~ States to an MPCT Equipment~~SEMI E10~~ State

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7.4.7.1 If all IPSs within an MPCT are in NST, then the MPCT is in NST. If an MPCT uses only one IPS at a time, then only one IPS shall be scheduled to be utilized in production at any given time. Any IPSs tracked in operations time shall remain in operations time until a different IPS or IPSs is (are) tracked in operations time, or until the entire MPCT is intended to be in nonscheduled time. Unless the entire MPCT is intended to be in nonscheduled time, at least one IPS ~~must~~ shall be tracked in operations time.

7.4.7.2 Otherwise, if any IPS in the MPCT is in PRD, then the MPCT is in PRD.

~~NOTE 23:~~NOTE 24: The degree to which an IPS or MPCT is efficient when in PRD is addressed by SEMI E79.

7.4.7.3 Otherwise, if all IPSs within an MPCT are in SDT or NST, then the MPCT is in SDT. Equivalently, if all IPSs tracked in operations time are in SDT, then the MPCT is in SDT.

7.4.7.4 Otherwise, if all IPSs in an MPCT are in SDT, UDT, or NST, then the MPCT is in UDT. Equivalently, if all IPSs tracked in operations time are in SDT or UDT, but not all IPSs tracked in operations time are SDT, then the MPCT is in UDT.

~~NOTE 24:~~NOTE 25: For MPCTs, the failure of an equipment module can~~may or may not~~ result, in some cases but not others, in a failure of the entire MPCT depending on its definition of IPSs. A failure occurs on the MPCT when none of the IPSs that are tracked in operations time can perform its intended function.

7.4.7.5 Otherwise, if any IPS in the MPCT is ENG, then the MPCT is in ENG.

7.4.7.6 Otherwise, the MPCT is in SBY. SBY that not all of the IPSs are in NST, none of the IPSs (hence none of the processing equipment modules) are in PRD, not all of the IPSs tracked in operations time are in a downtime state, and none of the IPSs are in ENG. If all IPSs that are tracked in operations time are in SBY, then the MPCT is in SBY. However, there are other combinations of IPSs equipment states for which the MPCT can~~may~~ be in SBY (e.g., one IPS is in SDT and one IPS is in SBY).

7.4.8 *Temporal Mapping of SDT Substates and SDT Events for IPS/MPCT Metrics* — This section presents the logical flow for assigning substates within SDT to both IPSs and MPCTs. Figure 6 illustrates this logical flow.

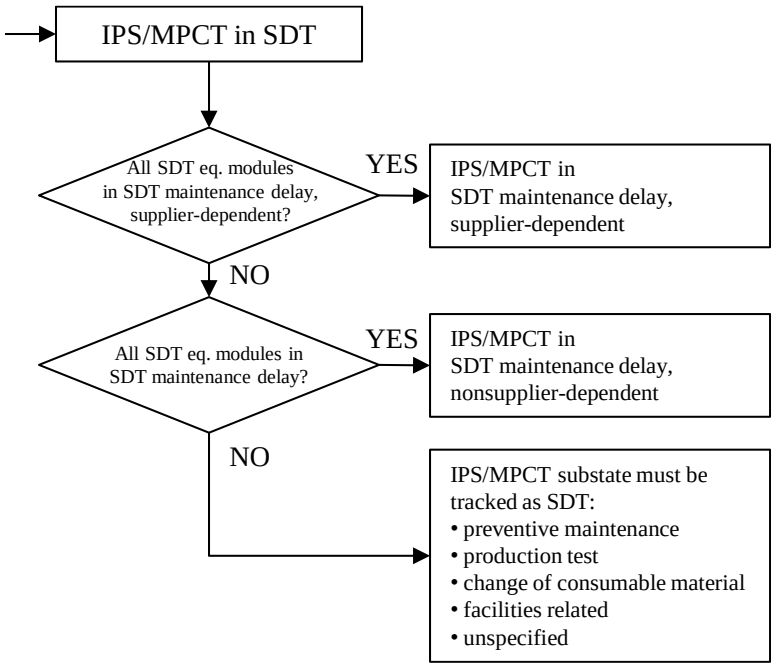

Figure 6
SDT Substates for IPSs and MPCTs

7.4.8.1 For an IPS/MPCT in SDT, for any point in time where all equipment modules in SDT are in the substate SDT maintenance delay, supplier-dependent, then the IPS or MPCT is in the substate SDT maintenance delay, supplier-dependent.

7.4.8.2 Otherwise, for any point in time where all equipment modules in SDT are in either of the substates SDT maintenance delay, supplier-dependent or SDT maintenance delay, nonsupplier-dependent, then the IPS/MPCT is in the substate SDT maintenance delay, nonsupplier-dependent. If any equipment modules in SDT are in a substate other than one of the SDT maintenance delay substates, then the IPS/MPCT is not in one of the SDT maintenance delay substates.

7.4.8.3 For an IPS/MPCT in SDT that is not in a SDT maintenance delay substate, the SDT substate ~~must~~ shall be dispositioned and tracked for the IPS/MPCT in the same manner as for an individual equipment module, noncluster tool, or SPCT. If a clear and defensible disposition of the SDT substate cannot be made, then the IPS/MPCT is in the SDT, unspecified substate.

7.4.8.4 This Document does not define a concept of a PM event for an IPS/MPCT as a whole; PM events are considered only at the equipment module level in the metric MTTPM.

7.4.9 *Temporal Mapping of UDT Substates and UDT Events for IPS and MPCT Metrics* — This section presents the logical flow for assigning substates within UDT to IPS or MPCTs. Figure 7 illustrates this logical flow.

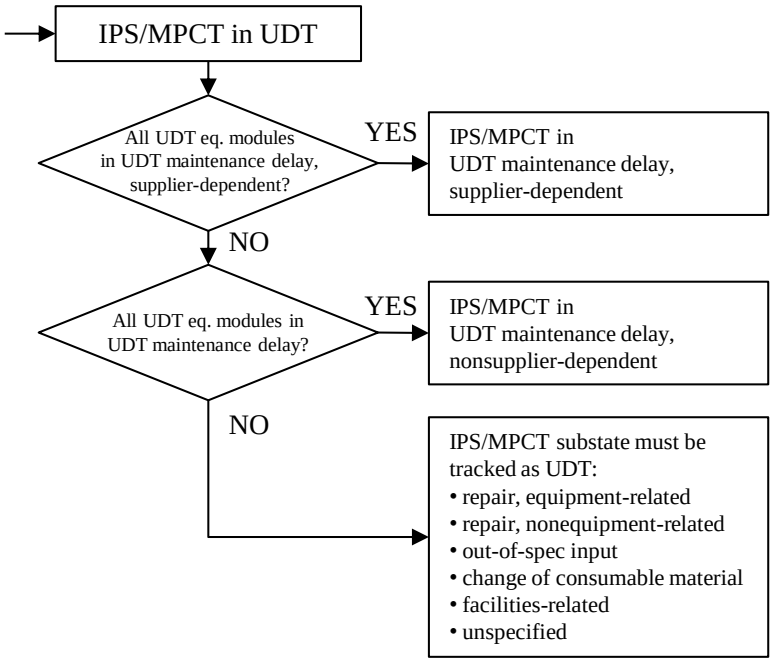

Figure 7
UDT Substates for IPSs and MPCTs

7.4.9.1 For an IPS/MPCT in UDT, for any point in time where all equipment modules in UDT are in the substate UDT maintenance delay, supplier-dependent, then the IPS/MPCT is in the substate UDT maintenance delay, supplier-dependent.

7.4.9.2 Otherwise, for any point in time where all equipment modules in ~~a~~ UDT ~~state~~ are in the substate UDT maintenance delay, but not all equipment modules in ~~a~~ UDT ~~state~~ are in the substate UDT maintenance delay, supplier-dependent, then the IPS/MPCT is in the substate UDT maintenance delay, nonsupplier-dependent.

7.4.9.3 If any equipment modules in ~~a~~ UDT ~~state~~ are not in a UDT maintenance delay substate, then the IPS/MPCT is not in a UDT maintenance delay substate. For an IPS/MPCT not in a UDT maintenance delay substate, the UDT substate ~~must~~ shall be dispositioned and tracked for the IPS/MPCT in the same manner as for an individual equipment

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module, noncluster tool, or SPCT. If a clear and defensible disposition of the UDT substate cannot be made, then the IPS/MPCT is in the substate UDT unspecified.

7.4.9.4 For a failure event for an IPS/MPCT, if any equipment module is in the substate UDT equipment-related repair before the IPS/MPCT exits UDT, then the failure event is also an equipment-related failure.

7.5 *Modeling Reliability Functions for Intended Process Sets*

7.5.1 An IPS 'up/down' state is modeled as a network flow through the unique equipment modules that comprise the IPS. If there is 'connectivity' through the IPS network, then the IPS is 'up'; otherwise it is 'down'. The equipment modules in an IPS network have series and parallel relationships that determine the connectivity through the network. Mathematically, each equipment module and each IPS has a state value equal to 1 when the module is 'up' and 0 when the module is 'down'. For example,

$$Mi = \{1 \text{ if module i is up, } 0 \text{ if module i is down}\} \quad (1)$$

7.5.2 Depending on the particular invocation of a reliability function for an IPS, $Mi = 1$ may apply for only UDT equipment modules, for only SDT equipment modules, or for SDT and UDT equipment modules together. These variations are used in the IPS ~~SEMI E10~~ state logic to determine different conditions for which an IPS ~~may~~ can be considered 'up' or 'down'.

7.5.3 The process steps within an IPS have a mutually serial relationship (i.e., if connectivity is not possible through any single step, then connectivity is not possible through the network). This is illustrated in Figure 8. The IPS state value for serial constituents is calculated as the product of the constituent state values (e.g., $IPS = \Pi_{i=1 \text{ to } 4}\, Si = S1 \times S2 \times S3 \times S4$).

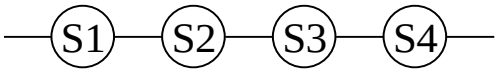


Figure 8
Serial Process Steps within an IPS

7.5.4 At any general process step, S_x, the set of alternative equipment modules, Ai (if any are present), have a mutually parallel relationship (i.e., if any one of the alternative equipment modules is up, then connectivity through that step is still possible). This is illustrated in Figure 9. The state value through this step is calculated as:

$$IPS = 1 - \Pi_{i=1 \text{ to } 3}\,(1 - Ai) \quad (2)$$

$$= 1 - [(1 - A1) \times (1 - A2) \times (1 - A3)] \quad (3)$$

7.5.5 If any alternative equipment module is 'up' ($Ai = 1$), then the expression in the square brackets evaluates to 0, and the IPS state value evaluates to 1, or 'up'. If all of the alternative equipment modules are 'down', then the expression in the square brackets evaluates to 1, and the IPS state value evaluates to 0, or 'down'.

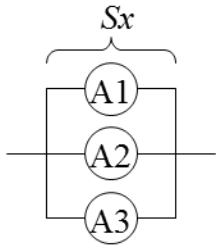
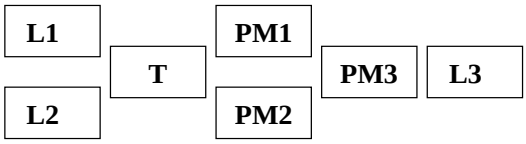


Figure 9
Parallel Alternative Equipment Modules at a Process Step

7.5.6 All IPSs in an MPCT can contain a single 'key group' (K), where the state of the key group affects the state of all IPSs. The key group is a subset of equipment modules that appears in every IPS in the MPCT regardless of any process differentiation. The key group may include sets of alternative equipment modules such as multiple load locks or multiple cooling stations. If this key group is down, then all IPSs in the MPCT (and, consequently, the entire MPCT) is down.

7.5.6.1 The example shown in Figure 10 is an MPCT with seven equipment modules used in a single IPS, IPS1. L1 and L2 are load lock equipment modules that are used to load units into the MPCT. A single transport arm, T, performs all point-to-point transportation. The first processing equipment module visited by any unit is either PM1 or PM2, after which every unit visits PM3. Lastly, L3 is a load lock that is used to unload units from the MPCT. Any other issues affecting the MPCT at large are allocated to an additional abstract mainframe equipment module, P (not shown).



Li = Load Lock i, i = 1, 2, 3
PMj = Processing Equipment Module j, j = 1, 2, 3
T = Transport Equipment Module

Figure 10
MPCT Equipment Modules, Example 1

7.5.6.2 The key group, K, as shown in Figure 11, includes the three load locks and the transport that are the common support equipment modules for this MPCT used by all IPSs in the MPCT. The mainframe equipment module, P, is also included in the key group. And since all units visit PM3 regardless of the IPS, PM3 is also included in the key group.

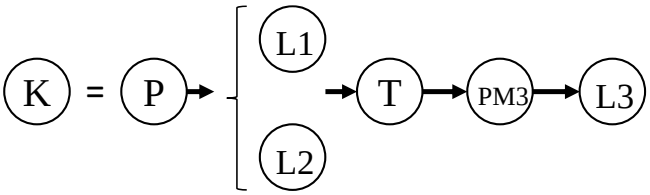


Figure 11
Example, Defining Equipment Modules in a Key Group

7.5.6.3 The reliability function for the key group, K, is $K = P \times [1 - (1 - L1) \times (1 - L2)] \times T \times PM3 \times L3$, where P, L1, L2, T, L3, and PM3 are 1 if 'up' and 0 if 'down'. The equivalent truth table for this logic is shown in Table 1.

Table 1 Truth Table for Key Group, Example 1

P	*L1*	*L2*	*T*	*PM3*	*L3*	*K*
1	1	1	1	1	1	1
1	1	0	1	1	1	1
1	0	1	1	1	1	1
else						0

7.5.6.4 IPS1 uses the key group and either processing equipment module PM1 or PM2, as shown in Figure 12.

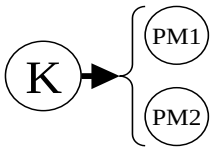


Figure 12
IPS Example

7.5.6.5 The reliability function for *IPS1* = K × [1 − (1 − PM1) × (1 − PM2)], where K, PM1, and PM2 are 1 if 'up' and 0 if 'down'. The equivalent truth table is shown in Table 2:

Table 2 Truth Table for the State Function, Example 1

K	*PM1*	*PM2*	*IPS1*
1	1	1	1
1	1	0	1
1	0	1	1
else			0

8 RAM and Utilization Measurement

8.1 *Observation Periods for Metrics*

8.1.1 To calculate metrics, an observation period shall be specified and agreed upon by the user and the supplier. Appendix 1 ¶ A1-2.9 provides some guidance on establishing the observation period time needed to demonstrate a desired mean time between failures (MTBF) at a given confidence level.

8.1.2 For any equipment system, the following rules shall be followed to ensure that over multiple observation periods, neither downtime events nor downtime is ever double-counted.

8.1.2.1 The count of downtime events including failure events that occur during the observation period are included in all applicable metrics regardless of when the related downtime state is exited. The count of downtime events that occur before the observation period are not included in metrics even if the related downtime state is exited during or after the observation period.

8.1.2.2 Downtime time that occurs during the observation period is counted in all applicable metrics regardless of the start time or end time of the downtime state. For a downtime event that occurs prior to the observation period, the portion of downtime time that occurs within the observation period is still counted. Hence, an observation period can~~may~~ have associated downtime time without a downtime event occurring during that observation period.

8.1.3 Observation periods shall be specified of appropriate duration so that divide-by-zero errors for metrics are unlikely.

8.1.3.1 For the equipment reliability metrics defined in § 8.2, the possibility exists of having the case of zero failures, zero downtime events, etc. in the denominators resulting in a divide-by-zero error, especially for shorter observation periods or highly reliable equipment. In these cases, the single-value point estimates for these metrics cannot be calculated and are therefore undefined. However, a lower confidence bound (LCB) estimate can still be calculated (see § 9.6), but an upper confidence bound (UCB) estimate cannot.

8.1.3.2 For the equipment maintainability metrics defined in § 8.4, the possibility exists of having the case of zero PM events, zero repair events, or zero downtime events in the denominators resulting in a divide-by-zero error, especially for shorter observation periods, low maintenance equipment, or highly reliable equipment. In these cases, the singe-value point estimates for these metrics cannot be calculated and are therefore undefined. For these metrics calculating LCB and UCB estimates is not appropriate (see § 9.4).

~~NOTE 25:~~NOTE 26: Related Information 2 provides an example MPCT usage scenario including calculations of all metrics.

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8.2 *Equipment Reliability* — Measurement of the equipment's ability to perform its intended function for a specified period of time, without failure. For IPSs and MPCTs, all of the metrics in this section ~~will~~ shall be based on the temporal mapped equipment states for the IPSs and MPCTs as defined in § 7.

8.2.1 *Mean Time Between Failures Calculations*

8.2.1.1 $MTBF_u$ — Mean uptime between failures; the average equipment system uptime that the equipment was capable of performing its intended function between failures; uptime divided by the number of failures during that time. Only uptime is included in this calculation. Failures that occur coincident with an attempt to change from NST or SDT to an uptime state are included in this calculation.

$$MTBF_u = \frac{uptime}{\#\ of\ failures\ during\ uptime} \tag{4}$$

8.2.1.2 MFD_u — Mean failure duration for failures during uptime; unscheduled downtime for failures during uptime divided by the number of failures during uptime.

$$MFD_u = \frac{unscheduled\ downtime\ for\ failures\ during\ uptime}{\#\ of\ failures\ during\ uptime} \tag{5}$$

8.2.1.3 $E\text{-}MTBF_u$ — Mean uptime time between equipment-related failures; the average equipment system uptime that the equipment was capable of performing its intended function between these equipment-related failures; uptime divided by the number of equipment-related failures during that time. Only uptime is included in this calculation. Equipment-related failures that occur coincident with an attempt made to change from NST or SDT to an uptime state are included in this calculation.

$$E\text{-}MTBF_u = \frac{uptime}{\#\ of\ equipment\text{-}related\ failures\ during\ uptime} \tag{6}$$

8.2.1.4 $MTBF_p$ — Mean productive time between failures; the average time the equipment performed its intended function between failures; productive time divided by the number of failures during that time. Only productive time is included in this calculation. Failures that occur when an attempt is made to change from any equipment state other than UDT to PRD are included in this calculation.

$$MTBF_p = \frac{productive\ time}{\#\ of\ failures\ during\ productive\ time} \tag{7}$$

8.2.1.5 MFD_p — Mean failure duration for failures during productive time; unscheduled downtime for failures during productive time divided by the number of failures during productive time.

$$MFD_p = \frac{unscheduled\ downtime\ for\ failures\ during\ productive\ time}{\#\ of\ failures\ during\ productive\ time} \tag{8}$$

8.2.1.6 $E\text{-}MTBF_p$ — Mean productive time between equipment-related failures; the average time the equipment performed its intended function between equipment-related failures; productive time divided by the number of equipment-related failures during that time. Only productive time is included in this calculation. Equipment-related failures that occur when an attempt is made to change from any equipment state other than UDT to PRD are included in this calculation.

$$E\text{-}MTBF_p = \frac{productive\ time}{\#\ of\ equipment\text{-}related\ failures\ during\ productive\ time} \tag{9}$$

8.2.2 *Mean Cycles Between Failures Calculations*

8.2.2.1 $MCBF_u$ — Mean cycles between failures during uptime; the average number of equipment cycles between failures during uptime.

$$MCBF_u = \frac{equipment\ cycles\ during\ uptime}{\#\ of\ failures\ during\ uptime} \tag{10}$$

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8.2.2.2 *E-MCBF$_u$* — Mean cycles between equipment-related failures during uptime; the average number of equipment cycles between equipment-related failures during uptime.

$$E\text{-}MCBF_u = \frac{\textit{equipment cycles during uptime}}{\textit{\# of equipment-related failures during uptime}} \quad (11)$$

8.2.2.3 *MCBF$_p$* — Mean cycles between failures during productive time; the average number of equipment cycles between failures during productive time.

$$MCBF_p = \frac{\textit{equipment cycles during productive time}}{\textit{\# of failures during productive time}} \quad (12)$$

8.2.2.4 *E-MCBF$_p$* — Mean cycles between equipment-related failures during productive time; the average number of equipment cycles between equipment-related failures during productive time.

$$E\text{-}MCBF_p = \frac{\textit{equipment cycles during productive time}}{\textit{\# of equipment-related failures during productive time}} \quad (13)$$

8.2.3 Mean Work Between Failures Calculations

NOTE 27: These metrics are intended primarily to support subsystem performance measurement where time and/or cycles may not be the only optimum factors. Examples of subsystems and their work include radio-frequency (RF) generators (kilowatt-hours), pulse-based lasers (pulse counts), filtration systems (liters), etc.

8.2.3.1 *MWBF$_u$* — Mean work between failures during uptime; the average work between failures during uptime.

$$MWBF_u = \frac{\textit{equipment work during uptime}}{\textit{\# of failures during uptime}} \quad (14)$$

8.2.3.2 *E-MWBF$_u$* — Mean work between equipment-related failures during uptime; the work between equipment-related failures during uptime.

$$E\text{-}MWBF_u = \frac{\textit{equipment work during uptime}}{\textit{\# of equipment-related failures during uptime}} \quad (15)$$

8.2.3.3 *MWBF$_p$* — Mean work between failures during productive time; the average work between failures during productive time.

$$MWBF_p = \frac{\textit{equipment work during productive time}}{\textit{\# of failures during productive time}} \quad (16)$$

8.2.3.4 *E-MWBF$_p$* — Mean work between equipment-related failures during productive time; the average work between equipment-related failures during productive time.

$$E\text{-}MWBF_p = \frac{\textit{equipment work during productive time}}{\textit{\# of equipment-related failures during productive time}} \quad (17)$$

8.3 *Equipment Availability* — The probability that the equipment will be in a condition to perform its intended function when required. For IPSs and MPCTs, all of the metrics in this section ~~will~~ shall be based on the temporal mapped equipment states for the IPSs and MPCTs as defined in § 7.

8.3.1 *Total Uptime* — The percentage of time the equipment is in a condition to perform its intended function during total time.

$$\textit{total uptime (\%)} = \frac{\textit{uptime} \times 100}{\textit{total time}} \quad (18\cancel{5})$$

8.3.2 *Operational Uptime* — The percentage of time the equipment is in a condition to perform its intended function during the period of operations time and disregarding nonscheduled time.

$$\textit{operational uptime (\%)} = \frac{\textit{uptime} \times 100}{\textit{operations time}} \quad (19\cancel{5})$$

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8.3.3 *Equipment-Dependent Metrics* — The performance of the equipment based solely on equipment merit and disregarding the effect of user and supplier maintenance delays. Equipment-dependent metrics depend on the following three fundamental quantities, each expressed in units of time:

$$\textit{equipment-dependent scheduled downtime} = \begin{array}{l} \textit{SDT preventive maintenance} \\ + \textit{SDT setup} \\ + \textit{SDT change of consumable material} \end{array} \qquad (20\cancel{16})$$

$$\textit{equipment-dependent unscheduled downtime} = \begin{array}{l} \textit{UDT repair, equipment-related} \\ + \textit{UDT change of consumable material} \end{array} \qquad (21\cancel{7})$$

$$\textit{equipment-dependent operations time} = \begin{array}{l} \textit{uptime} \\ + \textit{equipment-dependent scheduled downtime} \\ + \textit{equipment-dependent unscheduled downtime} \end{array} \qquad (22\cancel{18})$$

~~NOTE 26:~~NOTE 28: SDT production test is presumed to be dictated primarily by user policy and is excluded from equipment dependence.

~~NOTE 27:~~NOTE 29: SDT unspecified and UDT unspecified are not clearly associated with equipment dependence and are excluded.

8.3.3.1 *Equipment-Dependent Uptime* — The percentage of equipment-dependent operations time the equipment is in a condition to perform its intended function based solely on equipment merit.

$$\textit{equipment-dependent uptime (\%)} = \frac{\textit{uptime} \times 100}{\textit{equipment-dependent operations time}} \qquad (23\cancel{19})$$

8.3.3.2 *Equipment-Dependent Scheduled Downtime* — The percentage of equipment-dependent operations time the equipment is not in a condition~~available~~ to perform its intended function due to equipment-dependent SDT events such as PM events.

$$\textit{equipment-dependent scheduled downtime (\%)} = \frac{\textit{equipment-dependent scheduled downtime} \times 100}{\textit{equipment-dependent operations time}} \qquad (24\cancel{0})$$

8.3.3.3 *Equipment-Dependent Unscheduled Downtime* — The percentage of equipment-dependent operations time the equipment is not in a condition~~available~~ to perform its intended function due to equipment-dependent UDT events.

$$\textit{equipment-dependent unscheduled downtime (\%)} = \frac{\textit{equipment-dependent unscheduled downtime} \times 100}{\textit{equipment-dependent operations time}} \qquad (25\cancel{1})$$

~~NOTE 28:~~NOTE 30: Equipment-dependent uptime (%) + equipment-dependent scheduled downtime (%) + equipment-dependent unscheduled downtime (%) = 100%.

8.3.4 *Supplier-Dependent Metrics* — The performance of the equipment based solely on equipment merit and supplier maintenance delays and disregarding the effect of user maintenance delays. Supplier-dependent metrics depend on the following three fundamental quantities:

$$\textit{supplier-dependent scheduled downtime} = \begin{array}{l} \textit{equipment-dependent scheduled downtime} \\ + \textit{supplier maintenance delay SDT} \end{array} \qquad (26\cancel{2})$$

$$\textit{supplier-dependent unscheduled downtime} = \begin{array}{l} \textit{equipment-dependent unscheduled downtime} \\ + \textit{supplier maintenance delay UDT} \end{array} \qquad (27\cancel{3})$$

$$\textit{supplier-dependent operations time} = \begin{array}{l} \textit{uptime} \\ + \textit{supplier-dependent scheduled downtime} \\ + \textit{supplier-dependent unscheduled downtime} \end{array} \qquad (28\cancel{4})$$

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8.3.4.1 *Supplier-Dependent Uptime* — The percentage of supplier-dependent operations time the equipment is in a condition to perform its intended function based solely on equipment merit and supplier maintenance delays.

$$\textit{supplier-dependent uptime (\%)} = \frac{\textit{uptime} \times 100}{\textit{supplier-dependent operations time}} \qquad (29\cancel{5})$$

8.3.4.2 *Supplier-Dependent Scheduled Downtime* — The percentage of supplier-dependent operations time the equipment is not in a condition~~available~~ to perform its intended function due to SDT events, such as PM events.

$$\textit{supplier-dependent scheduled downtime (\%)} = \frac{\textit{supplier-dependent scheduled downtime} \times 100}{\textit{supplier-dependent operations time}} \qquad (30\cancel{26})$$

8.3.4.3 *Supplier-Dependent Unscheduled Downtime* — The percentage of supplier-dependent operations time the equipment is not in a condition~~available~~ to perform its intended function due to UDT events.

$$\textit{supplier-dependent unscheduled downtime (\%)} = \frac{\textit{supplier-dependent unscheduled downtime} \times 100}{\textit{supplier-dependent operations time}} \qquad (31\cancel{27})$$

~~NOTE 29:~~NOTE 31: Supplier-dependent uptime (%) + supplier-dependent scheduled downtime (%) + supplier-dependent unscheduled downtime (%) = 100%.

8.4 *Equipment 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.

8.4.1 The metrics in this section apply to all equipment systems. For IPSs and MPCTs, all of the metrics in this section ~~will~~ shall be treated as the equipment module-level aggregate in both the numerator and denominator.

8.4.1.1 *MTTPM* — Mean time to PM; the average time to complete a PM and return the equipment to a condition where it can perform its intended function; the sum of all PM time (elapsed time, not necessarily total man hours) incurred during a specified time period (including equipment and process test time, but not including maintenance delay downtime), divided by the number of PM events during that period.

$$\textit{MTTPM} = \frac{\textit{SDT preventive maintenance}}{\textit{\# of PM events}} \qquad (32\cancel{8})$$

8.4.1.2 *MTTR* — Mean time to repair; the average time to correct a failure and return the equipment to a condition where it can perform its intended function; the sum of all repair time (elapsed time not necessarily total man hours) incurred during a specified time period (including equipment and process test time, but not including maintenance delay downtime), divided by the number of repair events during that period.

$$\textit{MTTR} = \frac{\textit{UDT repair, equipment-related} + \textit{UDT repair, nonequipment-related}}{\textit{\# of equipment-related repair events} + \textit{\# of nonequipment-related repair events}} \qquad (33\cancel{29})$$

8.4.1.3 *E-MTTR* — Mean time to repair during equipment-related failures; the average time to correct an equipment-related failure and return the equipment to a condition where it can perform its intended function; the sum of all equipment-related failure repair time (elapsed time, not necessarily total man hours) incurred during a specified time period (including equipment and process test time, but not including maintenance delay downtime), divided by the number of equipment-related repair events during that period.

$$\textit{E-MTTR} = \frac{\textit{UDT repair, equipment-related}}{\textit{\# of equipment-related repair events}} \qquad (34\cancel{0})$$

8.4.1.4 *MTOL* — Mean time off-line; the average time equipment is not ~~available~~ in a condition to perform its intended function due to scheduled downtime and unscheduled downtime combined. MTOL is the sum of all downtime (including maintenance delay time) divided by the number of continuous downtime events during an observation period.

$$\textit{MTOL} = \frac{\textit{scheduled downtime} + \textit{unscheduled downtime}}{\textit{\# of continuous downtime events}} \qquad (35\cancel{1})$$

8.4.2 The metrics in this section have equipment system total time as the denominator, even for IPSs or MPCTs. Unique to the metrics in this section, the numerators are defined as particular equipment module-level aggregates of

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failures counts and unscheduled downtime. For an equipment system that is not an IPS or MPCT, the numerators are simply the failure count and unscheduled downtime for the equipment system.

8.4.2.1 *Total Failure Rate (TFR)* — The rate of equipment module-level failures versus equipment system total time reflecting the potentially negative effect of equipment system complexity. The numerator is the aggregate count of equipment module-level failures. The denominator is equipment system total time; it is not aggregated. The denominator is limited to calendar time; hence, an equipment system with fewer equipment modules ~~may~~ can reflect better performance with this metric than an equipment system with more equipment modules (where equipment modules in both equipment systems have roughly the same failure performance). Calculated in this way, TFR is not a reciprocal of any MTBF metrics in this Document.

$$TFR = \frac{\#\ of\ equipment\ module\text{-}level\ failures}{equipment\ system\ total\ time} \qquad (36\cancel{2})$$

8.4.2.2 *Impairment Time (%)* — A percentage of unscheduled downtime versus total time reflecting the potentially negative effect of equipment system complexity. The numerator is a temporal mapping of all periods of time in an observation period when at least one equipment module is UDT. The denominator is the equipment system total time, which is not aggregated. It is limited to calendar time; hence, an equipment system with fewer equipment modules ~~may~~ can naturally be expected to reflect better performance than an equipment system with more equipment modules (where equipment modules in both equipment systems have roughly the same failure performance). Calculated in this way, impairment time is in no way analogous to MTTR, MTOL, or other downtime performance metrics in this Document.

$$impairment\ time\ (\%) = \frac{time\ when\ at\ least\ one\ equipment\ module\ is\ in\ unscheduled\ down \times 100}{equipment\ system\ total\ time} \qquad (37\cancel{3})$$

8.5 *Equipment Utilization* — The percentage of time the equipment is performing its intended function during a specified time period. For IPSs and MPCTs, all of the metrics in this section ~~will~~ shall be based on the temporal mapped equipment states for the IPSs and MPCT as defined in § 7.

~~NOTE 30:~~NOTE 32: 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~~ can be less useful.

8.5.1 *Total Utilization (%)* — The percentage of productive time during total time. This calculation is intended to reflect bottom-line equipment utilization.

$$total\ utilization\ (\%) = \frac{productive\ time \times 100}{total\ time} \qquad (38\cancel{4})$$

8.5.2 *Operational Utilization (%)* — The percentage of productive time during operations time. This calculation is intended to be used for equipment utilization comparisons between operations with different work shift configurations, since it does not include nonscheduled time.

$$operational\ utilization\ (\%) = \frac{productive\ time \times 100}{operations\ time} \qquad (39\cancel{5})$$

8.6 *Metrics Summary Tables*

8.6.1 *Reliability Metrics* — For IPSs and MPCTs, input to metrics shall be~~is~~ based on temporal equipment mapped states per § 7.

Table 3 Reliability Metrics

Metric	*Formula*	*Paragraph Reference*
$MTBF_u$ — Mean uptime time between failures	(uptime) / (# of failures during uptime)	8.2.1.1
MFD_u — Mean failure duration for failures during uptime	(unscheduled downtime for failures during uptime) / (# of failures during uptime)	8.2.1.2

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Metric	*Formula*	*Paragraph Reference*
E-MTBF$_u$ — Mean uptime time between equipment-related failures	(uptime) / (# of equipment-related failures during uptime)	8.2.1.3
MTBF$_p$ — Mean productive time between failures	(productive time) / (# of failures during productive time)	8.2.1.4
MFD$_p$ — Mean failure duration for failures during productive time	(unscheduled downtime for failures during productive time) / (# of failures during productive time)	8.2.1.5
E-MTBF$_p$ — Mean productive time between equipment-related failures	(productive time) / (# of equipment-related failures during productive time)	8.2.1.6
MCBF$_u$ — Mean cycles between failures during uptime	(equipment cycles during uptime) / (# of failures during uptime)	8.2.2.1
E-MCBF$_u$ — Mean cycles between equipment-related failures during uptime	(equipment cycles during uptime) / (# of equipment-related failures during uptime)	8.2.2.2
MCBF$_p$ — Mean cycles between failures during productive time	(equipment cycles during productive time) / (# of failures during productive time)	8.2.2.3
E-MCBF$_p$ — Mean cycles between equipment-related failures during productive time	(equipment cycles during productive time) / (# of equipment-related failures during productive time)	8.2.2.4
MWBFu — Mean work between failures during uptime	(equipment work during uptime) / (# of failures during uptime)	8.2.2.1
E-MWBFu — Mean work between equipment-related failures during uptime	(equipment work during uptime) / (# of equipment-related failures during uptime)	8.2.2.2
MWBFp — Mean work between failures during productive time	(equipment work during productive time) / (# of failures during productive time)	8.2.2.3
E-MWBFp — Mean works between equipment-related failures during productive time	(equipment work during productive time) / (# of equipment-related failures during productive time)	8.2.2.4

8.6.2 *Availability Metrics* — For all IPSs and MPCTs, input to metrics shall be~~is~~ based on temporal mapped equipment states per § 7.

Table 4 Availability Metrics

Metric	*Formula*	*Paragraph Reference*
total uptime (%)	(uptime × 100) / (total time)	8.3.1
operational uptime (%)	(uptime × 100) / (operations time)	8.3.2
equipment-dependent uptime (%)	(uptime × 100) / (equipment-dependent operations time)	8.3.3.1
equipment-dependent scheduled downtime (%)	(equipment-dependent scheduled downtime × 100) / (equipment-dependent operations time)	8.3.3.2
equipment-dependent unscheduled downtime (%)	(equipment-dependent unscheduled downtime × 100) / (equipment-dependent operations time)	8.3.3.3
supplier-dependent uptime (%)	(uptime × 100) / (supplier-dependent operations time)	8.3.4.1
supplier-dependent scheduled downtime (%)	(supplier-dependent scheduled downtime × 100) / (supplier-dependent operations time)	8.3.4.2
supplier-dependent unscheduled downtime (%)	(supplier-dependent unscheduled downtime × 100) / (supplier-dependent operations time)	8.3.4.3

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8.6.3 *Maintainability Metrics*

8.6.3.1 For IPSs and MPCTs, input to the following maintainability metrics shall be~~is~~ based on aggregate equipment module performance in the numerator and aggregate equipment module performance in the denominator.

Table 5 Maintainability Metrics, Aggregate Denominator

Metric	*Formula*	*Paragraph Reference*
MTTPM — Mean time to [perform] preventive maintenance (PM)	(SDT preventive maintenance) / (# of PM events)	8.4.1.1
MTTR — Mean time to repair	(UDT repair, equipment-related + UDT repair, nonequipment-related) / (# of equipment-related repair events + # of nonequipment-related repair events)	8.4.1.2
E-MTTR — Mean time to repair during equipment-related failures	(UDT repair, equipment-related) / (# of equipment-related repair events)	8.4.1.3
MTOL — Mean time off-line	(scheduled downtime + unscheduled downtime) / (# of continuous downtime events)	8.4.1.4

8.6.3.2 For IPSs and MPCTs, input to the following maintainability metrics shall be~~is~~ based on aggregate equipment module performance in the numerator and nonaggregate equipment system performance in the denominator.

Table 6 Maintainability Metrics, Nonaggregate Denominator

Metric	*Formula*	*Paragraph Reference*
TFR — Total failure rate	(# of equipment module-level failures) / (equipment system total time)	8.4.2.1
impairment time (%)	(time when at least one equipment module is in UDT × 100) / (equipment system total time)	8.4.2.2

8.6.4 *Utilization Metrics* — For all IPSs and MPCTs, input to metrics shall be~~is~~ based on temporal mapped equipment ~~SEMI E10~~ states per § 7.

Table 7 Utilization Metrics

Metric	*Formula*	*Paragraph Reference*
total utilization (%)	(productive time × 100) / (total time)	8.5.1
operational utilization (%)	(productive time × 100) / (operations time)	8.5.2

9 Uncertainty Measurements for Some Equipment Reliability Metrics

~~NOTE 31:~~NOTE 33: For purposes of simplicity, this section refers to MTBF; however, substitutions can be made for many of the equipment reliability metrics listed in Table 3 providing they are exponentially distributed (e.g., MFD_u and MFD_p ~~may~~ can often not be exponentially distributed).

9.1 The measures of equipment reliability, availability, and maintainability defined in § 8 are single-value point estimates. They do not indicate the uncertainty or precision of the point estimate. Precision varies depending upon the number of failures observed and the amount of time contained within the observation period.

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9.2 Precision is described by calculating a lower confidence bound (LCB) and upper confidence bound (UCB) for the MTBF, MCBF, and MWBF calculations and presenting this confidence interval along with the MTBF point estimate.

9.3 These procedures assume that the failure rate is constant and the times between failures are independently distributed according to the exponential distribution. Therefore, there are no improvement or degradation trends and it is meaningful to calculate MTBF. § 10 applies when the failure times indicate that a nonconstant failure rate is present (e.g., when there is reliability growth or degradation). § 10 would typically apply during prototype reliability improvement testing.

9.4 Since MTTR distributions may not follow an exponential distribution assumption, applying these procedures to put confidence bounds on MTTR and other equipment maintainability metrics listed in Table 5 and Table 6 may be inappropriate.

9.5 Note that all procedures and tables referred to in this section apply equally well to measuring the precision of point estimates for similar equipment reliability metrics, where hours are replaced by cycles or ~~units~~work, for example. These procedures apply to E-MTBF, ~~or~~ E-MCBF, or E-MWBF in the same way. It is also appropriate to combine data from identical equipment being used in the same way, in order to improve the precision of MTBF point estimates.

9.6 *Calculation of LCBs and UCBs* — To obtain MTBF LCBs and UCBs, multiply the MTBF point estimate by factors obtained by table look-up (Tables A0and A0 in Appendix 1). For the case when there are zero failures during the observation period, LCB factors for the MTBF are given in the first row of Table A0 (e.g., they multiply the amount of productive time that had no failures to obtain the desired MTBF LCB). There is no UCB estimate for performance when there are zero failures.

9.6.1 *Calculation of the MTBF LCB* — Use 0in Appendix 1 to obtain a $k_{r;conf}$ factor, where *r* is the number of failures observed during the observation period and *conf* is the confidence level desired. The rows of 0in Appendix 1 correspond to different values of *r* and the columns correspond to different values of *conf*. Confidence levels ranging from 80% to 95% are typical choices.

9.6.1.1 Since the equipment being measured has demonstrated (at a given confidence level) that it is at least as good as the MTBF LCB, this LCB is an important and useful performance statistic, and is often used contractually.

9.6.1.2 Note that the factors in 0in Appendix 1 for a 90% confidence level are less than 0.5 until the number of failures equals or exceeds 4. This means that when the number of failures is under 4, the MTBF LCB will be less than half the MTBF point estimate, and confidence intervals will be wide. From the point of view of precision, it is advantageous to have had 4 or more failures.

9.6.1.3 *Example* — During a given calendar quarter, an equipment was productive for 1200 hours and had 6 failures. The $MTBF_p$ point estimate is 1200 / 6 = 200 hours. A 90% LCB factor from 0in Appendix 1 (corresponding to $r = 6$ failures) is 0.570. That means that 200 × 0.570 = 114.0 hours is a 90% LCB for the true equipment $MTBF_p$.

9.6.2 *Calculation of the MTBF UCB* — Use 0in Appendix 1 to obtain a $k_{r;conf}$ factor, where *r* is the number of failures observed during the observation period and *conf* is the confidence level desired. The rows of 0in Appendix 1 correspond to different values of *r* and the columns correspond to different values of *conf*. Confidence levels ranging from 80% to 95% are typical choices.

9.6.2.1 *Example* — During a given calendar quarter, an equipment was productive for 1200 hours and had 6 failures. The $MTBF_p$ point estimate is 1200 / 6 = 200 hours. A 90% UCB factor from 0in Appendix 1 (corresponding to $r = 6$ failures) is 1.904. That means that 200 × 1.904 = 380.8 hours is a 90% UCB for the true equipment $MTBF_p$.

9.6.3 *Calculation of a Confidence Interval for the MTBF* — LCB and UCB (i.e., $100 \times [1 - \alpha/2]$) for the MTBF can be combined to give a $100 \times (1 - \alpha)$ confidence interval. Here $\alpha/2$ is the chance of missing on either end of the interval. A 90% LCB has an $\alpha/2 = 0.1$ chance of not being low enough to capture the true MTBF, and the same is true for a 90% UCB. Therefore, a 90% LCB and a 90% UCB combine to give an 80% confidence interval. Similarly, a 95% LCB and a 95% UCB would combine to give a 90% confidence interval.

9.6.3.1 *Example* — During a calendar quarter, an equipment was productive for 1200 hours and had 6 failures. The $MTBF_p$ point estimate is 1200 / 6 = 200 hours. The 90% LCB and UCB are 114 and 380.8 respectively (see §§ A1-

2.6 and A1-2.7 in Appendix 1). The interval (114, 380.8) is then an 80% confidence interval for the true equipment $MTBF_p$.

9.6.4 *Calculation of the MTBF LCB when There Are Zero Failures* — Use the first row of 0in Appendix 1 (corresponding to $r = 0$) to obtain a $k_{0;conf}$ factor corresponding to the desired confidence level. Multiply the length of the observation period by this factor to obtain the LCB estimate.

9.6.4.1 *Example* — During a calendar quarter, an equipment was productive for 1200 hours and had zero failures. From 0in Appendix 1, the 90% confidence level LCB factor is 0.434. That means that 1200 × 0.434 = 520.8 hours, is a 90% LCB estimate for the true equipment $MTBF_p$.

9.6.5 Choosing an observation period length in order to be able to demonstrate a required MTBF at a given confidence, we first ~~must~~ shall pick a maximum number of failures, *r*, that can occur during the observation period and still allow us to confirm a required MTBF objective at a given confidence level. Next, the length of an observation period needed can be calculated using the factors in 0in Appendix 1. The required MTBF is multiplied by a factor based on *r* and the desired confidence level to obtain the total length of an observation period needed.

9.6.5.1 Note that minimum observation period lengths are obtained by allowing no failures. The cost, however, of using a minimum observation period length is to increase the possibility of an acceptable equipment failing the test by chance. As mentioned in the discussion in § 9.6.1.2, it is advantageous to design a test that allows at least four failures, whenever possible.

9.6.5.2 *Example* — We would like to confirm an equipment MTBF of 400 hours at an 80% confidence level. We want to be able to pass a qualification test with four or less failures. We look up the appropriate factor from 0in Appendix 1 and find 6.72. That means the length of the observation period required is 400 × 6.72 = 2688 hours. We can do this on one equipment or split the observation period across multiple equipment systems. When we have accumulated 2688 hours and if no more than 4 failures have occurred, then we will have demonstrated an MTBF of at least 400 hours at an 80% confidence level.

10 Reliability Growth or Degradation Measurement

~~NOTE 32:~~NOTE 34: For purposes of simplicity, this section refers to MTBF; however, substitutions can be made for the defined variations of MTBF/E-MTBF, MCBF/E-MCBF, and MWBF/E-MWBF) defined in Table 3.

10.1 The previous calculations are meaningful only when the MTBF (or MCBF or MWBF) and E-MTBF (or E-MCBF or E-MWBF) are constant over the observation period. If reliability is improving (typical during design verification and debug and also early life run-in) or if reliability is degrading (typical near the end of life for the equipment, or if certain subassemblies have been over-stressed and are wearing out), then an overall MTBF calculation is inappropriate and misleading and other methods ~~must~~ shall be used. Exact time of failure recording is required in order to detect reliability improvement or reliability degradation trends, and to fit appropriate models.

10.2 *Exact Time of Failure Recording* — Clock times of failure ~~must~~ shall be converted to durations of cumulative time as measured from the initial productive use of the equipment (often set as time 0) or from other starting points if appropriate. This is easily accomplished if total time is continuously monitored by duration within each of the six basic equipment states.

10.2.1 *Example* — An equipment system is intended for use during first shift operation five days a week. For simplicity, assume 100% productive utilization. After the first three weeks of use, it fails half-way through the day, and is not repaired until the start of the next day's operation. No more failures occur before the end of the first four weeks of operation. The exact time of failure is 124 hours (3 weeks of 5 × 8 = 40 hours per week plus half of an 8 hour day). If a second failure occurred 2 hours into the third day of the fifth week, then the exact time of failure would be 174 hours.

10.3 *Reliability Growth (Degradation) Models* — A useful family of reliability growth (degradation) models was developed by the U.S. Army Materials Systems Analysis Activity (AMSAA). These AMSAA models are described in Appendix 2, along with a general test for reliability growth (degradation) trends. Exact time of failure data is needed to test for trends, fit an AMSAA model, and test the fit for adequacy. The failures used to fit the model ~~must~~ shall occur during productive time (other failures can occur, but these are not used to fit reliability models).

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APPENDIX 1
CONFIDENCE BOUND FACTORS

NOTICE: The material in this Appendix is an official part of SEMI E10 and was approved by full letter ballot procedures on May 12, 2014.

~~NOTE 33:~~NOTE 35: This Appendix offers detailed information related to § 9.

A1-1 Introduction

A1-1.1 Tables A0 and A0 contain factors that multiply an MTBF, MCBF, or MWBF point estimate to obtain LCBs and UCBs. 0applies in the common case of time-censored, ~~or~~ cycle-censored, or work-censored data, where the equipment is observed for a fixed period of time or for a predetermined number of cycles or work and the number of failures that will occur is unknown in advance. The alternative is failure-censored data, where the number of failures is specified in advance and the equipment is observed until that many failures occur. 0contains LCB factors for failure-censored data. Since failure-censored data rarely occurs in equipment reliability measurement, 0is only included for completeness. The UCB factors given in 0apply to both kinds of censored data.

A1-1.2 Table A0 can be used to plan equipment assessment or qualification tests in order to be able to demonstrate a desired MTBF, MCBF, or MWBF at a given confidence level. In order to use Table A0, ~~you must~~ first choose a maximum number of failures, *r*, ~~you might~~that could be observed during the observation period and still be able to meet the required MTBF, MCBF, or MWBF objective.

A1-2 Calculating Confidence Bound Factors

A1-2.1 For reference, here are the formulas for the LCB and UCB factors for time-censored data found in Tables A0 and A0 for MTBF metrics:

$$MTBF_{LOWER} = \frac{2r}{X^2_{2r+2;1-\alpha}} \times MTBF_p \tag{A1-1}$$

$$where\ r = \#\ of\ failures$$

$$MTBF_{UPPER} = \frac{2r}{X^2_{2r;\alpha}} \times MTBF_p \tag{A1-2}$$

A1-2.2 In both cases, the confidence level is 100 × (1 − α) that the true MTBF is above $MTBF_{LOWER}$ and below $MTBF_{UPPER}$ and chi square distribution tables are used.

A1-2.3 For 0 fails, use:

$$MTBF_{LOWER} = \frac{productive\ time}{-\log_e \alpha} \tag{A1-3}$$

A1-2.4 Factors to use when there are 0 failures based on this formula are given in the first row of Table A0.

A1-2.5 For failure-censored data, $MTBF_{UPPER}$ is the same, but the LCB factor in Table A0 is:

$$MTBF_{LOWER} = \frac{2r}{X^2_{2r;1-\alpha}} \times MTBF_p \tag{A1-4}$$

A1-2.6 Use Table A0 for time-, or cycle-, or work-censored data. Multiply the MTBF, ~~or~~ MCBF, or MWBF point estimate by the appropriate factor to obtain a lower bound at the given confidence level. For 0 failures, multiply the operating hours, ~~or~~ cycles, or work by the factor corresponding to the desired confidence level.

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1-Sided Lower Confidence Bound Factors for the MTBF, MCBF, or MWBF (Time-~~Censored or~~, Cycle-, or Work-Censored Data)

	Confidence Level						
Number of Failures, r	*60%*	*70%*	*80%*	*85%*	*90%*	*95%*	*97.5%*
0	1.091	0.831	0.621	0.527	0.434	0.334	0.271
1	0.494	0.410	0.334	0.297	0.257	0.211	0.179
2	0.644	0.553	0.467	0.423	0.376	0.318	0.277
3	0.718	0.630	0.544	0.499	0.449	0.387	0.342
4	0.763	0.679	0.595	0.550	0.500	0.437	0.391
5	0.795	0.714	0.632	0.589	0.539	0.476	0.429
6	0.817	0.740	0.661	0.618	0.570	0.507	0.459
7	0.834	0.760	0.684	0.642	0.595	0.532	0.485
8	0.848	0.777	0.703	0.662	0.616	0.554	0.508
9	0.859	0.790	0.719	0.679	0.634	0.573	0.527
10	0.868	0.802	0.733	0.694	0.649	0.590	0.544
12	0.883	0.821	0.755	0.718	0.675	0.617	0.572
15	0.899	0.841	0.780	0.745	0.704	0.649	0.606
20	0.916	0.864	0.809	0.777	0.739	0.688	0.647
30	0.935	0.892	0.844	0.816	0.783	0.737	0.700
50	0.953	0.918	0.879	0.856	0.829	0.790	0.759
100	0.969	0.943	0.915	0.897	0.877	0.847	0.822
500	0.987	0.976	0.962	0.954	0.944	0.929	0.916

A1-2.7 Use Table A0 for time-, cycle-, work-, or failure-censored data. Multiply the MTBF, MCBF, or MWBF point estimate to obtain an upper bound at the given confidence level.

1-Sided Upper Confidence Bound Factors for the MTBF, MCBF, or MWBF

	Confidence Level						
Number of Failures, r	*60%*	*70%*	*80%*	*85%*	*90%*	*95%*	*97.5%*
1	1.958	2.804	4.481	6.153	9.491	19.496	39.498
2	1.453	1.823	2.426	2.927	3.761	5.628	8.257
3	1.313	1.568	1.954	2.255	2.722	3.669	4.849
4	1.246	1.447	1.742	1.962	2.293	2.928	3.670
5	1.205	1.376	1.618	1.795	2.055	2.538	3.080
6	1.179	1.328	1.537	1.687	1.904	2.296	2.725
7	1.159	1.294	1.479	1.610	1.797	2.131	2.487
8	1.144	1.267	1.435	1.552	1.718	2.010	2.316
9	1.133	1.247	1.400	1.507	1.657	1.917	2.187
10	1.123	1.230	1.372	1.470	1.607	1.843	2.085
12	1.108	1.203	1.329	1.414	1.533	1.733	1.935
15	1.093	1.176	1.284	1.357	1.456	1.622	1.787
20	1.077	1.147	1.237	1.296	1.377	1.509	1.637

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	Confidence Level						
Number of Failures, r	*60%*	*70%*	*80%*	*85%*	*90%*	*95%*	*97.5%*
30	1.060	1.115	1.185	1.231	1.291	1.389	1.482
50	1.044	1.085	1.137	1.170	1.214	1.283	1.347
100	1.029	1.058	1.093	1.115	1.144	1.189	1.229
500	1.012	1.025	1.039	1.049	1.060	1.078	1.094

A1-2.8 Use Table A0 for failure-censored data. Multiply the MTBF, MCBF, or MWBF point estimate to obtain a lower bound at the given confidence level. Failure-censored data means the test or observation period lasts as long as needed to obtain a preset number of failures.

1-Sided Lower Confidence Bound Factors for the MTBF, MCBF, or MWBF (Failure-Censored Data)

	Confidence Level						
Number of Failures, r	*60%*	*70%*	*80%*	*85%*	*90%*	*95%*	*97.5%*
1	1.091	0.831	0.621	0.527	0.434	0.334	0.271
2	0.989	0.820	0.668	0.593	0.514	0.422	0.359
3	0.966	0.830	0.701	0.635	0.564	0.477	0.415
4	0.958	0.840	0.725	0.665	0.599	0.516	0.456
5	0.955	0.849	0.744	0.688	0.626	0.546	0.488
6	0.954	0.856	0.759	0.706	0.647	0.571	0.514
7	0.953	0.863	0.771	0.721	0.665	0.591	0.536
8	0.954	0.869	0.782	0.734	0.680	0.608	0.555
9	0.954	0.874	0.791	0.745	0.693	0.623	0.571
10	0.955	0.878	0.799	0.755	0.704	0.637	0.585
12	0.956	0.886	0.812	0.771	0.723	0.659	0.610
15	0.958	0.895	0.828	0.790	0.745	0.685	0.639
20	0.961	0.906	0.846	0.812	0.772	0.717	0.674
30	0.966	0.920	0.870	0.841	0.806	0.759	0.720
50	0.971	0.935	0.896	0.872	0.844	0.804	0.772
100	0.978	0.952	0.923	0.906	0.885	0.855	0.830
500	0.989	0.978	0.964	0.956	0.945	0.930	0.918

A1-2.9 Use Table A0 to determine the observation period length needed to demonstrate a desired MTBF, MCBF, or MWBF at a given confidence level if *r* failures occur. Multiply the desired MTBF, MCBF, or MWBF by the *k* factor corresponding to *r* and the confidence level.

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Observation Period Length Guide

k Factor For Given Confidence Levels						
Number of Failures, r	*50%*	*60%*	*75%*	*80%*	*90%*	*95%*
0	0.693	0.916	1.39	1.61	2.30	3.00
1	1.68	2.02	2.69	2.99	3.89	4.74
2	2.67	3.11	3.92	4.28	5.32	6.30
3	3.67	4.18	5.11	5.52	6.68	7.75
4	4.67	5.24	6.27	6.72	7.99	9.15
5	5.67	6.29	7.42	7.90	9.28	10.51
6	6.67	7.35	8.56	9.07	10.53	11.84
7	7.67	8.38	9.68	10.23	11.77	13.15
8	8.67	9.43	10.80	11.38	13.00	14.43
9	9.67	10.48	11.91	12.52	14.21	15.70
10	10.67	11.52	13.02	13.65	15.40	16.96
15	15.67	16.69	18.48	19.23	21.29	23.10
20	20.68	21.84	23.88	24.73	29.06	30.89

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APPENDIX 2
RELIABILITY GROWTH OR DEGRADATION MODELS

NOTICE: The material in this Appendix is an official part of SEMI E10 and was approved by full letter ballot procedures on May 12, 2014.

~~NOTE 34:~~NOTE 36: This Appendix offers detailed information related to § 10.

A2-1 Introduction

A2-1.1 If the times between failures (known as 'interarrival times') of a repairable equipment system are independent random times sampled from the same exponential distribution, then the (theoretical) rate of occurrence of failures is a constant λ and the MTBF is just 1/λ. This situation is known in the reliability literature as a homogeneous Poisson process (HPP). An HPP assumption underlies the definition of MTBF given in § 8, and the confidence bound factors described in § 9 and Appendix 1. These concepts are described in detail in Ascher and Feingold [1] and Tobias and Trindade [2].

A2-1.1.1 This test can also be applied to test for trends for the MCBF and MWBF metrics using either cycles or work in place of times to define cycles between failures (known as 'interarrival cycles') or work between failures (known as 'interarrival work').

A2-1.2 If reliability is either improving or degrading with time, then the rate of occurrence of failures is no longer a constant and an MTBF calculation will be misleading.

A2-1.3 This Appendix contains a simple test for trend that may be applied if a time-varying rate of occurrence of failures is suspected, as well as a description of a well-known and powerful model that may be used when reliability improvement trends are evident in the equipment failure time data.

A2-2 Testing for Trends

A2-2.1 A nonparametric 'reverse arrangement test' devised by Kendall [3] and further developed into a table by Mann [4] will be described. Begin by writing the interarrival times in the order they occurred. For a period with r failures, these might be $X_1, X_2, \ldots, X_r$. Starting from left to right, define a reversal as any instance in which a lesser value occurs before any subsequent greater value in the sequence. In other words, any time we have $X_i < X_j$ and $i < j$, we count it as a reversal.

A2-2.1.1 For example, suppose an equipment has $r = 4$ failures at 30, 160, 220, and 360 hours of productive time. The interarrival times are 30, 130, 60, and 140. The total number of reversals is 3 + 1 + 1 = 5.

A2-2.2 A larger than expected number of reversals indicates an improving trend; a smaller number of reversals than expected indicates a degradation trend.

A2-2.3 For r up to 12, use Table A0 below (adapted from [2]) to determine whether a given number of reversals, R, is statistically significant at the $100 \times (1 - \alpha)$ confidence level.

Critical Values $R_{r;1-\alpha}$ the Number of Reversals for the Reverse Arrangement Test at a Given Confidence Level

Sample Size	*Single-Sided Lower Critical Value (Too Few Reversals Provide Evidence of Degradation)*			*Single-Sided Upper Critical Value (Too Many Reversals Provide Evidence of Improvement)*		
r	*99%*	*95%*	*90%*	*90%*	*95%*	*99%*
4		0	0	6	6	
5	0	1	1	9	9	10
6	1	2	3	12	13	14
7	2	4	5	16	17	19
8	4	6	8	20	22	24
9	6	9	11	25	27	30
10	9	12	14	31	33	36

Sample Size	*Single-Sided Lower Critical Value (Too Few Reversals Provide Evidence of Degradation)*			*Single-Sided Upper Critical Value (Too Many Reversals Provide Evidence of Improvement)*		
r	*99%*	*95%*	*90%*	*90%*	*95%*	*99%*
11	12	16	18	37	39	43
12	16	20	23	43	46	50

A2-2.4 For r greater than 12, approximate critical values for the number of reversals (based on Kendall's normal approximation) can be calculated from:

$$R_{(r;\,1\text{-}\alpha)} = z_{critical}\sqrt{\frac{(2r+5)(r-1)r}{72}} + \frac{r(r-1)}{4} - \frac{1}{2} \qquad \text{(A2-1)}$$

A2-2.5 In this equation z_{critical} comes from the critical values of the standard normal distribution (for 90% significance, $z_{\text{critical}} = 1.282$, for 95% significance, $z_{\text{critical}} = 1.645$, and for 99% significance, $z_{\text{critical}} = 2.33$). The formula calculates the critical value for detecting an improvement trend. For degradation trends (a small number of reversals) use $(r)(r - 1) / 2$ minus $R_{r;1\text{-}\alpha}$ as the critical value. Note that $(r)(r - 1) / 2$ is just the total possible number of reversals when there are r failures.

A2-2.5.1 For example, with 17 failures, the formula for $R_{r;1\text{-}\alpha}$, using 95% significance, gives a critical number of reversals of $R_{17,95} = 88$. The maximum number of reversals is $17 \times 16 / 2 = 136$. That means that observing 88 or more reversals signals a likely improvement trend, while observing $136 - 88 = 48$ or less reversals signals a likely degradation trend.

A2-2.6 The example given in the next section shows an application for the reverse arrangement test using Table A0.

A2-2.7 *AMSAA Reliability Growth Model* — Assume the sequence of interarrival times indicates an improvement trend. This will typically be the case during reliability improvement testing, where failures are analyzed down to root causes and actions are taken to improve the equipment's reliability. Duane [5] observed that a plot of t_k/k versus t_k, where t_k is the equipment system age at the time of kth failure, typically appears linear on log versus log graph paper. The slope β of this line measures the rate of reliability growth. Typical empirical values of β lie between 0.3 and 0.6. Crow [6] developed this empirical observation into the power relationship model used by the AMSAA reliability growth model. This model has proved successful in a wide range of applications.

A2-2.8 The AMSAA model assumes that during reliability improvement testing the MTBF is improving with time and has an instantaneous value denoted by $\text{MTBF}_I(t)$. When the test ends at time T, the MTBF becomes a constant with the value $\text{MTBF}_I(T)$. A point estimate of the MTBF after a test of T hours with r failures is given by:

$$MTBF_I(T) = \frac{T}{r \times (1 - \beta)} \qquad \text{(A2-2)}$$

A2-2.8.1 This model can also be applied to test reliability growth for the MCBF and MWBF metrics.

A2-2.9 In this equation, β is the reliability improvement (Duane) slope and is estimated by:

$$\beta = 1 - \frac{r-1}{\sum_{i=1}^{r} \ln \frac{T}{t_i}} \qquad \text{(A2-3)}$$

using the 'modified maximum likelihood estimates' given by Crow [6]. Crow developed confidence bounds for $\text{MTBF}_I(T)$ that are described in [2] and [6].

A2-2.9.1 *Example* — MTBF_p is used for this example. During a calendar quarter an equipment system has 550 hours of productive time. Eleven failures were recorded at the following points of productive time: 18, 20, 35, 41, 67, 180, 252, 287, 390, 410, and 511 hours. Determine whether there appears to be an improvement trend and use the AMSAA model to estimate the achieved MTBF_I at the end of the quarter.

A2-2.9.2 *Solution* — The interarrival times are: 18, 2, 15, 6, 26, 113, 72, 35, 103, 20, and 101. The number of reversals is 7 + 9 + 7 + 7 + 5 + 0 + 2 + 2 + 0 + 1 = 40. Using Table A0, this is significant at greater than the 95% confidence

level, indicating an improvement trend is likely. Figure A2-1 shows the Duane plot, which appears to show a linear improvement trend on log-log paper. The AMSAA model equations give an improvement slope estimate of 0.43 and an instantaneous $MTBF_P$ point estimate at 550 hours of 87.2. Note that a standard calculation ignoring the improvement trend would yield an $MTBF_P$ point estimate of 550 / 11 = 50, which is a 43% underestimate.

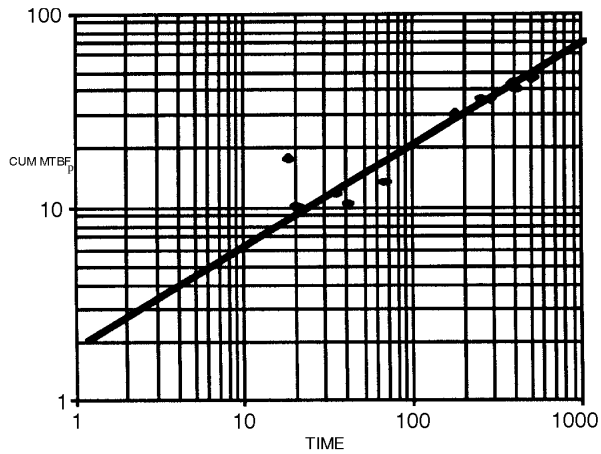

Figure A2-1
Duane Plot of Cumulative $MTBF_P$ vs. Time

A2-2.10 Figure A2-2 summarizes the recommended procedure to follow when analyzing equipment system reliability data, with appropriate references to SEMI E10 sections or Appendices.

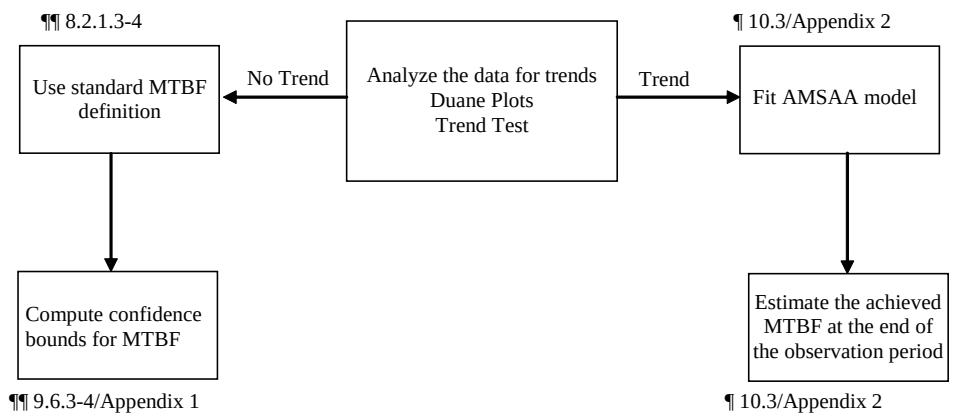

Figure A2-2
Flow Chart for Reliability Data Analysis

A2-3 References

A2-3.1 Ascher, H. and H. Feingold, *Repairable Systems Reliability*, Marcel Dekkar, Inc., New York, 1984.

A2-3.2 Tobias, P.A. and D.C. Trindade, *Applied Reliability, Second Edition*, Van Nostrand Reinhold, Inc., New York, 1995.

A2-3.3 Kendall, M.G., "A New Measure of Rank Correlation." *Biometrika*, 1938, volume 30, pp. 81–93.

A2-3.4 Mann, H.B., "Nonparametric Test Against Trend." *Econometrica*, 1945, volume 13, pp. 245–225.

A2-3.5 Duane, J.T., "Learning Curve Approach to Reliability Monitoring." *IEEE Transactions on Aerospace*, volume 2 (1964): pp. 563–566.

A2-3.6 Crow, L.H., "Reliability Analysis for Complex Repairable Systems." *Reliability and Biometry*, F. Proschan and R.J., Serfling, eds., SIAM, Philadelphia (1974): pp. 126–134.

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RELATED INFORMATION 1
MTBF, RENEWAL PROCESSES, AND THE EXPONENTIAL DISTRIBUTION

NOTICE: This Related Information is not an official part of SEMI E10 and was derived from the work of the Metrics Global Technical Committee. This Related Information was approved for publication by full letter ballot procedures on May 12, 2014.

R1-1 MTBF Metrics

R1-1.1 The concept of MTBF arises from a branch of probability study called renewal theory. Each particular definition of MTBF is based on a model of equipment time that is a renewal process. Reliability processes in general have 'up' and 'down' segments in each time cycle (hereinafter in this Related Information section called cycle) that together represent all equipment time of interest. Refer to Figure R1-1. A time cycle in this process begins in an 'up' segment with equipment in a presumably 'good-as-new' state. The equipment continues in the 'up' segment until it fails and transitions into the 'down' segment. When repair is complete or the failure is rectified and equipment is effectively 'renewed', the equipment transitions into the 'up' segment of a new cycle in the renewal process. The renewal process is defined such that cycles in the process ~~may~~ can be assumed to be statistically comparable to one another. In simple reliability models, the time for the 'up' segment is the time between failures, and the time for 'down' segment is the time to repair.

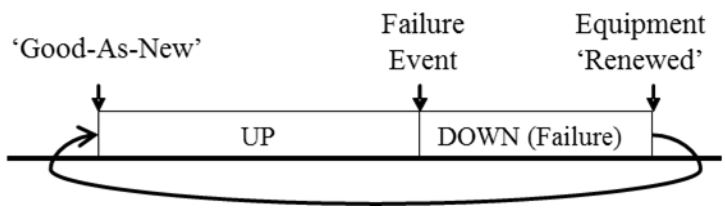

Figure R1-1
Reliability Renewal Cycle

R1-1.2 A renewal cycle model provides significant analytic structure. In the case of a reliability renewal process with exponentially distributed 'up' and 'down' segments, the number of failures as a function of the cumulative time in 'up' segments has the Poisson distribution. A system following the distribution is said to have time-average behavior such that the average of the system behavior over time is the same as the behavior of the 'average cycle'. In terms of SEMI E10, MTBF and its related function, MFD, are intended to describe the system at large, and not just a moment in time. Approaching such a system at random, the observer should expect to find the system 'up' with probability equal to the ratio of 'up' time (MTBF) to the average renewal cycle time (MTBF + MFD). The genuine MTBF and MFD values are assumed by the model to be inherent constants of the system rather than dynamic values, and measurement of these constants is an ongoing process that improves as more and more data is collected. MTBF point estimates are generally considered invalid or misleading when observed over small time intervals.

$$\Pr(\text{Equipment Available}) = (\text{average time in 'up' segment of cycle}) / (\text{average time for whole cycle}) \quad \text{(R1-1)}$$

$$= \text{MTBF} / (\text{MTBF} + \text{MFD}) \quad \text{(R1-2)}$$

R1-1.3 Historically, renewal cycle models used MTTR rather than MFD as a companion metric to MTBF. However, due to the metrics' definitions in SEMI E10, MTTR and E-MTTR are not necessarily suitable companion metrics to any variations of MTBF in SEMI E10. Companion metrics in a reliability process ~~must~~ should have the same definition of failure events and mutually exclusive time in the 'up' and 'down' segments of the cycle. In this Document, $MTBF_u$ and MFD_u are suitable companion metrics, as are $MTBF_p$ and MFD_p.

R1-1.4 The collection of 'up' and 'down' segments of a particular renewal process need not represent 24 hours by 7 days per week. With $MTBF_p$, the 'up' segment of the renewal cycle is productive time only and the 'down' segment is the failure time, repair time, and subsequent requalification time related to only PRD. For $MTBF_p$, the 'up' segment

specifically excludes engineering time and failures from engineering time, implicitly expecting the likelihood of failures to be different when equipment engineers are 'pushing the envelope' of that equipment. Also, the 'down' segment specifically excludes PM and other general maintenance issues covered under SDT. NST is neither 'up' nor 'down' and is entirely excluded from consideration.

R1-1.5 The meaning of the metric $MTBF_p$, then, is literally the productive time of the average renewal cycle as defined above. Because the exponential distribution is assumed (implicitly) in SEMI E10, this value may be estimated as the cumulative productive time divided by the cumulative failures from productive time. The reciprocal of $MTBF_p$ expresses how often similar equipment systems should fail as a result of usage strictly in productive time.

R1-2 Exponential Distribution and MTBF

R1-2.1 MTBF in SEMI E10 implicitly assumes an exponential distribution of the time between failures. MTBF is not only the expected value of this distribution. It is also the solitary parameter of this distribution.

$$\text{PDF } f(x, \text{MTBF}) = (1 / \text{MTBF}) \times \exp(-x / \text{MTBF}),\ x \geq 0 \quad \text{(R1-3)}$$

$$\text{CDF } f(x, \text{MTBF}) = 1 - \exp(-x / \text{MTBF}),\ x \geq 0 \quad \text{(R1-4)}$$

$$E(f(x, \text{MTBF})) = \text{MTBF} \quad \text{(R1-5)}$$

$$\text{StDev}(f(x, \text{MTBF})) = \text{MTBF} \quad \text{(R1-6)}$$

R1-2.2 The probability that a system will remain 'up' for a period longer than *t* is given by:

$$\Pr(X > t) = \exp(-t / \text{MTBF}) \quad \text{(R1-7)}$$

R1-2.3 The probability that a system will remain 'up' an additional time *s*, having already been 'up' *t*, demonstrates the memoryless property that is exclusive to the exponential distribution.

$$\Pr(X > t + s \mid X > t) = \Pr(X > t + s) / \Pr(X > t) \quad \text{(R1-8)}$$

$$= \exp(-(t + s) / \text{MTBF}) / \exp(-t / \text{MTBF}) \quad \text{(R1-9)}$$

$$= \exp(-(t + s - t) / \text{MTBF}) \quad \text{(R1-10)}$$

$$= \exp(-s / \text{MTBF}) \quad \text{(R1-11)}$$

$$= \Pr(X > s) \quad \text{(R1-12)}$$

R1-2.3.1 In this case, the distribution of the additional time *s* is the same as for a new unit and is independent of the previous time *t*. This defies the expectation that an equipment system is more likely to fail the longer it has been up. Qualitatively, the memoryless property says that a system's resistance to failure is not a function of its age or wear.

R1-2.4 To the extent that the analysts believe the exponential distribution to be representative of times between failures and that the MTBF is the accurate parameter of that distribution, measures of risk for specific scenarios can~~may~~ be estimated. Table R1-1 below shows the probability of survival time as a percentage of the MTBF.

R1-2.4.1 For example, if MTBF = 500 hours, then the probability of survival for 1000 hours (200% of MTBF) is 13.5%.

Table R1-1 Exponential Distribution Probability of Survival Time as a Percentage of MTBF

Survival Time (% of MTBF)	*25%*	*50%*	*75%*	*100%*	*150%*	*200%*	*300%*	*400%*	*500%*
Probability	77.9%	60.7%	47.2%	36.8%	22.3%	13.5%	5.0%	1.8%	0.7%

R1-3 Analyzing Failure Duration and Times Between Failures for Nonexponential Distributions

R1-3.1 For a number of useful analyses, a 'best practice' would be to maintain individual data records for each reliability renewal cycle with attributes and statistics regarding the cycle's failure, including the following:

- The start time, end time, and duration

- The type of SEMI E10 downtime event: equipment-related repair event, nonequipment-related repair event, or nonrepair failure
- Cumulative SEMI E10 statistics within the failure (e.g., equipment-related repair time, nonequipment-related repair time, supplier maintenance delay, nonsupplier maintenance delay)
- Additional non-SEMI E10 classifications (e.g., failing equipment subsystem, failure mode, product or process family at time of failure)

R1-3.2 Given such a list, MFD can be calculated as the mean of the individual failure durations. With individual data points, though, other statistical parameters ~~may~~ can be calculated, such as standard deviation, and specific appropriate treatment can be given to censored failure data.

R1-3.3 Having the SEMI E10 and non-SEMI E10 attributes allows the separation of data for Pareto analyses by both count and cumulative downtime. The attributes ~~may~~ can be used to filter failures for analyses, such as testing for dependence between failure types.

R1-3.4 Having just the individual time-ordered list of failures allows an analysis to graphically see if failures are clustered together and possibly part of a more significant equipment system issue.

R1-3.5 Having the individual failure start and end times allows the correlation of other equipment system data and even nonequipment system data with failures. So in addition to supporting metrics to measure the impact of failures, individual data records provide a pathway to understanding and eliminating those failures.

EXAMPLE CALCULATIONS

NOTICE: This Related Information is not an official part of SEMI E10 and was derived from the work of the Metrics Global Technical Committee. This Related Information was approved for publication by full letter ballot procedures on May 12, 2014.

R1-4 Overview

R1-4.1 This section presents an example scenario that demonstrates equipment~~SEMI E10~~ state/substate tracking and metrics for equipment modules, intended process sets (IPSs), and multi-path cluster tools (MPCTs). Note that this example does not include the reliability metrics for work as they would be done basically the same as for cycles, which is a specific type of work that is often used across many types of equipment systems.

R1-4.2 This example uses a simplified MPCT, a short timescale, and a scenario with highly compressed activity that demonstrates many features of equipment~~SEMI E10~~ state/substate tracking and metrics.

R1-5 Example Scenario

R1-5.1 This example uses a hypothetical MPCT with a mainframe equipment module, a handler nonprocessing equipment module, and three processing equipment modules: Modules A, B, and C. See Table R2-1. These three processing equipment modules are used in two intended process sets (i.e., IPS1 and IPS2) each with two process steps.

Table R1-2 Hypothetical MPCT Description

Equipment Modules	*Description*
Mainframe (abstract)	MPCT platform
Handler	Nonprocessing equipment module
Module A	Processing equipment module
Module B	Processing equipment module
Module C	Processing equipment module

R1-5.2 An abstract mainframe equipment module is used to track failures for the MPCT 'at large' including physical facilities resources, information to and from the host, and common computing resources. For this hypothetical MPCT, there are no 'active' tasks to track for the mainframe equipment module; hence, no productive time is ever tracked and this equipment module is more likely to be in SBY. It is therefore also true for this equipment module that metrics dependent on productive time (e.g., utilization [%]) do not yield meaningful values.

R1-5.3 For this hypothetical MPCT, all normal operations performed by the handler nonprocessing equipment module are treated as productive time regardless of the purpose of the units being handled. Hence, there is no tracking of certain equipment~~SEMI E10~~ states (e.g., ENG, SDT) for this equipment module.

R1-5.4 The mainframe equipment module, the handler nonprocessing equipment module, and Module A are required for both IPSs. If any of these equipment modules go down, then IPS1, IPS2, and the MPCT (in the absence of processing equipment modules in PRD) would go down. Hence, they are candidates for a key group, *K*, when determining the reliability functions for *IPS1* and *IPS2*. For the module states defined as (1 = Up, 0 = Down), *Mm* (Mainframe module), *Mh* (Handler module), *Ma* (Module A), *Mb* (Module B), *Mc* (Module C), the reliability functions for *K*, *IPS1*, and *IPS2* are as follows:

$$K = Mm \times Mh \times Ma \quad \text{(R2-1)}$$

$$IPS1 = K \times Mb \quad \text{(R2-2)}$$

$$IPS2 = K \times (1 - [(1-Mb) \times (1-Mc)]) \quad \text{(R2-3)}$$

R1-5.5 For IPS1, process step 1 requires Module A and process step 2 requires Module B. For IPS2, process step 1 requires Module A and process step 2 uses either Module B or Module C. See Table R2-2.

Table R1-3 Process Step Description

	Process Step 1	*Process Step 2*
IPS1	Module A	Module B
IPS2	Module A	Module B or Module C

R1-5.6 In this scenario, the MPCT processes five units, where three units are product, one is a scheduled monitor unit, and one is for engineering purposes. Two of these units require IPS1 and three require IPS2. See Table R2-3.

Table R1-4 Individual Unit Descriptions by IPS and Purpose

	IPS Required	*Unit Purpose*	*Event References in Scenario (see Table R2-6)*	*Unit Status*
Unit 1	IPS1	Monitor unit	Event #3 through Event #8	Completed successfully
Unit 2	IPS2	Product	Event #10 through Event #19	Completed successfully
Unit 3	IPS2	Product	Event #14 through Event #24	Completed successfully
Unit 4	IPS2	Product	Event #25 through Event #34	Completed successfully
Unit 5	IPS1	Engineering	Event #30 through Event #35	Failed

R1-5.7 An overview of this scenario demonstrates how SEMI E10 tracking applies to individual equipment modules, IPSs, and an MPCT. Refer to Table R2-5 for the details of each event.

R1-5.7.1 The scenario demonstrated the use of NST to isolate active IPSs. The scenario begins with all equipment modules and both IPSs in NST, which is the only way in which an MPCT can also be in NST. From event #2 through event #8, IPS2 is in NST and IPS2 is in operations time. From event #9 through event #28, IPS1 is in NST and IPS2 is in operations time. From event #39 through the end of the scenario, both IPSs are simultaneously in operations time.

R1-5.7.2 The scenario demonstrates several equipment modules failures with different effects on the IPSs and MPCT.

R1-5.7.2.1 The Handler module is in UDT from events #20 until event #23. Because IPS2 and the MPCT are still in PRD until event #21, they each delay going into UDT.

R1-5.7.2.2 Module A goes into UDT from ENG at event #30 and remains in UDT until event #40. IPS1 has a failure event from ENG. IPS2 and the MPCT continue in PRD until event #34, then they both experience failure events from PRD.

R1-5.7.2.3 Module C is in UDT at event #41 through event #44, but does not put either IPS or the MPCT in UDT. This is because Module B, the alternative to Module C in IPS2, remains in SBY.

R1-5.7.2.4 The Mainframe module has a facilities-related failure from event #43 through event #45 that also puts both IPSs and the MPCT in UDT. Even though the failure of Module C is remedied at event #44, the IPSs and MPCT remain down because of the Mainframe module in UDT.

R1-5.7.3 The scenario demonstrates how different equipment modules in ENG affect the IPSs and MPCT differently.

R1-5.7.3.1 Module A is in ENG from event #30 until event #32. IPS1 is in ENG because it has no other processing equipment modules in PRD, UDT, or SDT. IPS2 is in PRD during this same time because Module C, which is exclusive to IPS2, is in PRD.

R1-5.7.3.2 The Mainframe module is in ENG from event #47 through event #48. With all other equipment modules in SBY, both IPSs and the MPCT are in ENG.

R1-5.7.4 The scenario demonstrates different effects of SDT equipment modules.

R1-5.7.4.1 From event #3 through event #8, the scenario demonstrates the substate SDT production test due to a monitor unit. As the monitor unit passes from Module A to Module B, IPS1 and MPCT are in SDT production test.

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R1-5.7.4.2 While Module A is in UDT, at event #37, preventive maintenance is performed on Module B. Then at event #38, preventive maintenance is performed on Module C. Both IPSs and the MPCT remain in UDT regardless of the preventive maintenance.

R1-5.7.4.3 Preventive maintenance is performed on Module A from event #42 through event #46. Both IPSs and the MPCT are in the substate SDT preventive maintenance. However, when the Mainframe module fails at event #43 through event #45, both IPSs and the MPCT are in UDT because of that failure. When the Mainframe module is tracked into SBY at event #45, both IPSs and the MPCT revert to the substate SDT preventive maintenance, while the preventive maintenance on Module A continues until event #46. This has the odd event of having the one preventive maintenance operation on Module A look like two separate operations on each of the IPSs and the MPCT. But since the MTTPM metric is based on equipment module-level aggregates, only one PM event and the complete correct time seen at Module A will be considered.

R1-6 Example MPCT Usage Scenario

R1-6.1 Table R2-4 provides the legend for the abbreviations of the SEMI E10 states and substates used in Table R2-5.

Table R1-5 Legend of Equipment~~SEMI E10~~ Time, States, and Substates

Abbreviation	*Equipment~~SEMI E10~~ Time, State, and Substate*
OPT	Operations Time
NST	Nonscheduled ~~Time~~
UDT-r/e	Unscheduled Downtime repair, equipment-related
UDT-fac	Unscheduled Downtime facilities-related
UDT-d/n	Unscheduled Downtime maintenance delay, nonsupplier
UDT-d/s	Unscheduled Downtime maintenance delay, supplier
UDT-us	Unscheduled Downtime unspecified
SDT-pm	Scheduled Downtime preventive maintenance
SDT-pt	Scheduled Downtime production test
ENG	Engineering
SBY	Standby
PRD	Productive

R1-6.2 Table R2-6 presents the example MPCT usage scenario with event times, descriptions for each event, and explanations of equipment~~SEMI E10~~ states and substates for each equipment module, IPS, and the MPCT.

Table R1-6 Equipment Module, IPS, and MPCT ~~SEMI E10~~Equipment States by Event[1]

Event #, Event Time hh:mm:ss, (State Time) hh:mm:ss	*Event Description*	*Mainframe*	*Handler*	*Module A*	*Module B*	*Module C*	*IPS1*	*IPS2*	*MPCT*	*Explanation of Equipment~~SEMI E10~~ States and Events*
#1 00:00:00 (01:00:00)	End of an unworked shift occurs.	NST	NST	NST	NST	NST	NST	NST	NST	*Modules:* All are tracked in NST. *IPSs:* Both are tracked in NST. *MPCT:* It is in NST because all IPSs are in NST.
#2 01:00:00 (00:14:55)	IPS1 is tracked in OPT in preparation for Unit 1.	SBY	SBY	SBY	SBY	NST	SBY	NST	SBY	*Modules:* All, except Module C, are tracked in SBY. *IPSs:* IPS1 is in SBY because all equipment modules in SBY. *MPCT:* It is in SBY because all IPSs tracked in OPT are in SBY.

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Event #, Event Time hh:mm:ss, (State Time) hh:mm:ss	*Event Description*	*Mainframe*	*Handler*	*Module A*	*Module B*	*Module C*	*IPS1*	*IPS2*	*MPCT*	*Explanation of Equipment~~SEMI E10~~ States and Events*
#3 01:14:55 (00:00:05)	Handler moves Unit 1 from carrier to Module A.	SBY	PRD	SDT-pt	SBY	NST	SDT-pt	NST	SDT-pt	*Modules:* Handler is tracked in PRD. For loading a monitor unit, Module A is tracked in SDT-pt. This is a continuous downtime event for Module A. *IPSs:* IPS1 is in SDT-pt because IPS1is down due to SDT-pt equipment modules with no substate ambiguity. *MPCT:* It is in SDT-pt because all IPSs tracked in OPT are in SDT-pt with no substate ambiguity.
#4 01:15:00 (00:14:55)	Module A begins processing Unit 1.	SBY	SBY	SDT-pt	SBY	NST	SDT-pt	NST	SDT-pt	*Modules:* Handler is tracked in SBY. Module A continues in SDT-pt. *IPSs:* Same eq. state and reason as event #3 *MPCT:* Same eq. state and reason as event #3
#5 01:29:55 (00:00:05)	Handler moves Unit 1 from Module A to Module B.	SBY	PRD	SDT-pt	SDT-pt	NST	SDT-pt	NST	SDT-pt	*Modules:* Handler is tracked in PRD. For handling a monitor unit, Module A and Module B are tracked in SDT-pt. This is a continuous downtime event for Module B. *IPSs:* Same eq. state and reason as event #3 *MPCT:* Same eq. state and reason as event #3
#6 01:30:00 (00:14:55)	Module B begins processing Unit 1.	SBY	SBY	SBY	SDT-pt	NST	SDT-pt	NST	SDT-pt	*Modules:* Handler and Module A are tracked in SBY. Module B continues in SDT-pt. *IPSs:* Same eq. state and reason as event #3 *MPCT:* Same eq. state and reason as event #3
#7 01:44:55 (00:00:05)	Handler moves Unit 1 from Module B to carrier.	SBY	PRD	SBY	SDT-pt	NST	SDT-pt	NST	SDT-pt	*Modules:* Handler is tracked in PRD. For unloading a monitor unit, Module B is tracked in SDT-pt. *IPSs:* Same eq. state and reason as event #3 *MPCT:* Same eq. state and reason as event #3
#8 01:45:00 (00:05:00)	Unit 1 is complete.	SBY	SBY	SBY	SBY	NST	SBY	NST	SBY	*Modules:* Handler and Module B are tracked in SBY. *IPSs:* IPS1 is in SBY because all equipment modules are in SBY. *MPCT:* It is in SBY because all IPSs tracked in OPT are in SBY.
#9 01:50:00 (00:09:55)	IPS1 is tracked in NST. IPS2 is tracked in OPT.	SBY	SBY	SBY	SBY	SBY	NST	SBY	SBY	*Modules:* Module C is tracked in SBY. *IPSs:* IPS1 is tracked in NST. IPS2 is in SBY because all equipment modules are in SBY. *MPCT:* Same eq. state and reason as event #8
#10 01:59:55 (00:00:05)	Handler moves Unit 2 from carrier to Module A.	SBY	PRD	PRD	SBY	SBY	NST	PRD	PRD	*Modules:* Handler is tracked in PRD. For loading product, Module A is tracked in PRD. *IPSs:* IPS2 is in PRD because at least one processing equipment module is in PRD. *MPCT:* It is in PRD because at least one IPS is in PRD.
#11 02:00:00 (00:10:00)	Module A begins processing Unit 2.	SBY	SBY	PRD	SBY	SBY	NST	PRD	PRD	*Modules:* Handler is tracked in SBY. Module A continues in PRD. *IPSs:* Same eq. state reason as event #10 *MPCT:* Same eq. state reason as event #10
#12 02:10:00 (00:00:05)	Handler moves Unit 2 from Module A to Module C.	SBY	PRD	PRD	SBY	PRD	NST	PRD	PRD	*Modules*: Handler is tracked in PRD. For handling product, Modules A and C are tracked in PRD. *IPSs:* Same eq. state and reason as event #10 *MPCT:* Same eq. state and reason as event #10

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Event #, Event Time hh:mm:ss, (State Time) hh:mm:ss	*Event Description*	*Mainframe*	*Handler*	*Module A*	*Module B*	*Module C*	*IPS1*	*IPS2*	*MPCT*	*Explanation of Equipment~~SEMI E10~~ States and Events*
#13 02:10:05 (00:04:50)	Module C begins processing Unit 2.	SBY	SBY	SBY	SBY	PRD	NST	PRD	PRD	*Modules:* Handler and Module A are tracked in SBY. Module C continues in PRD. *IPSs:* Same eq. state and reason as event #10 *MPCT:* Same eq. state and reason as event #10
#14 02:14:55 (00:00:05)	Handler moves Unit 3 from carrier to Module A.	SBY	PRD	PRD	SBY	PRD	NST	PRD	PRD	*Modules:* Handler is tracked in PRD. For loading product, Module A is tracked in PRD. *IPSs:* Same eq. state and reason as event #10 *MPCT:* Same eq. state and reason as event #10
#15 02:15:00 (00:10:55)	Module A begins processing Unit 3.	SBY	SBY	PRD	SBY	PRD	NST	PRD	PRD	*Modules:* Handler is tracked in SBY. Module A continues in PRD. *IPSs:* Same eq. state and reason as event #10 *MPCT:* Same eq. state and reason as event #10
#16 02:25:55 (00:04:05)	Handler moves Unit 3 from Module A to Module B.	SBY	PRD	PRD	PRD	PRD	NST	PRD	PRD	*Modules:* Handler is tracked in PRD. For handling product, Modules A and B are tracked in PRD. *IPSs:* Same eq. state and reason as event #10 *MPCT:* Same eq. state and reason as event #10
#17 02:30:00 (00:14:55)	Module B begins processing Unit 3.	SBY	SBY	SBY	PRD	PRD	NST	PRD	PRD	*Modules:* Handler and Module A are tracked in SBY. Module B continues in PRD. *IPSs:* Same eq. state and reason as event #10 *MPCT:* Same eq. state and reason as event #10
#18 02:44:55 (00:00:05)	Handler moves Unit 2 from Module C to carrier.	SBY	PRD	SBY	PRD	PRD	NST	PRD	PRD	*Modules:* Handler is tracked in PRD. For unloading product, Module C is tracked in PRD. *IPSs:* Same eq. state and reason as event #10 *MPCT:* Same eq. state and reason as event #10
#19 02:45:00 (00:15:00)	Unit 2 is complete.	SBY	SBY	SBY	PRD	SBY	NST	PRD	PRD	*Modules:* Handler and Module C are tracked in SBY. *IPSs:* Same eq. state and reason as event #10 *MPCT:* Same eq. state and reason as event #10
#20 03:00:00 (00:05:00)	Handler calibration routine fails for reasons unknown. Module B processing continues.	SBY	UDT-us	SBY	PRD	SBY	NST	PRD	PRD	*Modules:* Handler is tracked in UDT-us. This is a failure from uptime for the Handler. As of event # 22, this will become an equipment-related failure. *IPSs:* IPS2 is in PRD, regardless of the Handler failure, because it has a processing equipment module in PRD. This is not a failure for IPS2. *MPCT:* It is in PRD because IPS2 is in PRD, regardless of the Handler failure. This is not a failure for the MPCT.
#21 03:05:00 (00:05:00)	Module B completes processing. Handler is awaiting a nonsupplier technician to examine it.	SBY	UDT-d/n	SBY	SBY	SBY	NST	UDT-d/n	UDT-d/n	*Modules:* Handler is tracked in substate UDT-d/n. Module B is tracked in SBY. *IPSs:* IPS2 is in UDT-d/n due to UDT-d/n equipment modules with no substate ambiguity. This is a failure from PRD for IPS2. As of event #22, this will become an equipment-related failure. *MPCT:* It is in UDT-d/n because all IPSs in OPT are in UDT-d/n with no substate ambiguity. This is a failure from PRD for the MPCT. As of event #22, this will become an equipment-related failure.

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Event #, Event Time hh:mm:ss, (State Time) hh:mm:ss	*Event Description*	*Mainframe*	*Handler*	*Module A*	*Module B*	*Module C*	*IPS1*	*IPS2*	*MPCT*	*Explanation of Equipment~~SEMI E10~~ States and Events*
#22 03:10:00 (00:20:00)	Handler equipment-related repair begins.	SBY	UDT-r/e	SBY	SBY	SBY	NST	UDT-r/e	UDT-r/e	*Modules:* Handler is tracked in substate UDT-r/e. *IPSs:* IPS2 is in UDT-r/e due to UDT-r/e equipment modules with no substate ambiguity. *MPCT:* It is in UDT-r/e because all IPSs in OPT are in UDT-r/e with no substate ambiguity.
#23 03:30:00 (00:00:10)	Handler repair is complete and moves Unit 3 from Module B to carrier.	SBY	PRD	SBY	PRD	SBY	NST	PRD	PRD	*Modules:* Handler is tracked in PRD. For unloading product, Module B is tracked in PRD. *IPSs:* IPS2 is in PRD because at least one processing equipment module is in PRD. *MPCT:* It is in PRD because at least one IPS is in PRD.
#24 03:30:10 (00:29:45)	Unit 3 is complete.	SBY	SBY	SBY	SBY	SBY	NST	SBY	SBY	*Modules:* Handler and Module B are tracked in SBY. *IPSs:* IPS2 is in SBY because all equipment modules are in SBY. *MPCT:* It is in SBY because all IPSs tracked in OPT are in SBY.
#25 03:59:55 (00:00:05)	Handler moves Unit 4 from carrier to Module A.	SBY	PRD	PRD	SBY	SBY	NST	PRD	PRD	*Modules:* Handler is tracked in PRD. For loading product, Module A is tracked in PRD. *IPSs:* IPS2 is in PRD because at least one processing equipment module is in PRD. *MPCT:* It is in PRD because at least one IPS is in PRD.
#26 04:00:00 (00:14:55)	Module A begins processing Unit 4.	SBY	SBY	PRD	SBY	SBY	NST	PRD	PRD	*Modules:* Handler is tracked in SBY. Module A continues in PRD. *IPSs:* Same eq. state and reason as event #25 *MPCT:* Same eq. state and reason as event #25
#27 04:14:55 (00:00:05)	Handler moves Unit 4 from Module A to Module C.	SBY	PRD	PRD	SBY	PRD	NST	PRD	PRD	*Modules:* Handler is tracked in PRD. For handling product, Modules A and C are tracked in PRD. *IPSs:* Same eq. state and reason as event #25 *MPCT:* Same eq. state and reason as event #25
#28 04:15:00 (00:40:00)	Module C begins processing Unit 4.	SBY	SBY	SBY	SBY	PRD	NST	PRD	PRD	*Modules:* Handler is tracked in SBY. Module C is tracked in PRD. *IPSs:* Same eq. state and reason as event #25 *MPCT:* Same eq. state and reason as event #25
#29 04:55:00 (00:04:55)	IPS1 is tracked in OPT.	SBY	SBY	SBY	SBY	PRD	SBY	PRD	PRD	*Modules:* Handler continues in SBY. Module C continues in PRD. *IPSs:* IPS1 is in SBY because all equipment modules are in SBY. IPS2 continues in PRD. *MPCT:* Same eq. state and reason as event #25
#30 04:59:55 (00:00:05)	Handler moves Unit 5 from carrier to Module A.	SBY	PRD	ENG	SBY	PRD	ENG	PRD	PRD	*Modules:* Handler is tracked in PRD. For loading an engineering unit, Module A is tracked in ENG. *IPS:* IPS1 is in ENG because it has no processing equipment modules in PRD, it is not down, and it has at least one equipment module in ENG. IPS2 continues in PRD. *MPCT:* Same reason as event #25

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Event #, Event Time hh:mm:ss, (State Time) hh:mm:ss	*Event Description*	*Mainframe*	*Handler*	*Module A*	*Module B*	*Module C*	*IPS1*	*IPS2*	*MPCT*	*Explanation of Equipment~~SEMI E10~~ States and Events*
#31 05:00:00 (00:15:00)	Module A begins processing Unit 5.	SBY	SBY	ENG	SBY	PRD	ENG	PRD	PRD	*Modules:* Handler is tracked in SBY. Module A continues in ENG. *IPSs:* Same reason as event #30 *MPCT:* Same reason as event #25
#32 05:15:00 (00:05:00)	An unspecified failure at Module A occurs.	SBY	SBY	UDT-us	SBY	PRD	UDT-us	PRD	PRD	*Modules:* Module A is tracked in UDT-us. This is a failure from uptime for Module A. As of event #36, it will become an equipment-related failure. *IPSs:* IPS1 is in UDT-us because it is down due to UDT-us equipment modules with no substate ambiguity. This is a failure from uptime for IPS1. As of event #36, it will become an equipment-related failure. IPS2 continues in PRD. *MPCT:* It is in PRD because IPS2 continues in PRD. This is not a failure for the MPCT.
#33 05:20:00 (00:05:05)	Handler moves Unit 4 from Module C to carrier.	SBY	PRD	UDT-us	SBY	PRD	UDT-us	PRD	PRD	*Modules:* Handler is tracked in PRD. For unloading product, Module C continues in PRD. *IPSs:* Same eq. state and reason as event #32 *MPCT:* Same eq. state and reason as event #32
#34 05:25:05 (00:04:50)	Unit 4 is complete. Module A is awaiting a nonsupplier technician to examine it.	SBY	SBY	UDT-d/n	SBY	SBY	UDT-d/n	UDT-d/n	UDT-d/n	*Modules:* Handler and Module C are tracked in SBY. Module A is tracked in substate UDT-d/n. *IPSs:* Both are in UDT-d/n because both are down due to UDT-d/n equipment modules with no substate ambiguity. This is a failure from PRD for IPS2. It will become an equipment-related failure as of event #36. *MPCT:* It is in UDT-d/n because all IPSs are in UDT-d/n with no substate ambiguity. This is a failure from PRD for the MPCT. It will become an equipment-related failure as of event #36.
#35 05:29:55 (00:00:05)	Handler moves Unit 5 from Module A to carrier.	SBY	PRD	UDT-d/n	SBY	SBY	UDT-d/n	UDT-d/n	UDT-d/n	*Modules:* Handler is tracked in PRD. Module A continues in UDT-d/n regardless of the Handler. *IPSs:* Both IPSs continue in UDT-d/n. *MPCT:* It continues in UDT-d/n.
#36 05:30:00 (00:15:00)	Equipment-related repair begins on Module A.	SBY	SBY	UDT-r/e	SBY	SBY	UDT-r/e	UDT-r/e	UDT-r/e	*Modules:* Handler is tracked in SBY. Module A is tracked in UDT-r/e. *IPSs:* Both are in UDT-r/e because they are down due to UDT-r/e equipment modules with no substate ambiguity. *MPCT:* It is in UDT-r/e because all IPSs are in UDT-r/e with no substate ambiguity.
#37 05:45:00 (01:15:00)	Module A requires part from supplier. PM routine begins on Module B.	SBY	SBY	UDT-d/s	SDT-pm	SBY	UDT-d/s	UDT-d/s	UDT-d/s	*Modules:* Module A substate is tracked in UDT-d/s. Module B is tracked in SDT-pm. This is a PM event for Module B. *IPSs:* Both are in UDT-d/s, regardless of the SDT-pm on Module B. *MPCT:* It is in UDT-d/s because all IPSs are in UDT-d/s with no substate ambiguity.

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Event #, Event Time hh:mm:ss, (State Time) hh:mm:ss	*Event Description*	*Mainframe*	*Handler*	*Module A*	*Module B*	*Module C*	*IPS1*	*IPS2*	*MPCT*	*Explanation of Equipment~~SEMI E10~~ States and Events*
#38 07:00:00 (01:00:00)	PM routine on Module B completed. PM routine begins on Module C.	SBY	SBY	UDT-d/s	SBY	SDT-pm	UDT-d/s	UDT-d/s	UDT-d/s	*Modules:* Module A continues in UDT-d/s. Module B is tracked in SBY. Module C is tracked in SDT-pm. This is a PM event for Module C. *IPSs:* Both continue in UDT-d/s, regardless of the SDT-pm on Module C. *MPCT:* Same eq. state and reason as event #37
#39 08:00:00 (00:30:00)	Module A repair resumes. PM routine on Module C is completed.	SBY	SBY	UDT-r/e	SBY	SBY	UDT-r/e	UDT-r/e	UDT-r/e	*Modules:* Module A substate is tracked in UDT-r/e. Module C is tracked in SBY. *IPSs:* Both are in UDT-r/e because both are down due to UDT-r/e equipment modules with no substate ambiguity. *MPCT:* It is in UDT-r/e because all IPSs in OPT are in UDT-r/e with no substate ambiguity.
#40 08:30:00 (00:30:00)	Module A repair is completed.	SBY	SBY	SBY	SBY	SBY	SBY	SBY	SBY	*Modules:* Module A is tracked in SBY. *IPSs:* Both are in SBY because all of their equipment modules are in SBY. *MPCT:* It is in SBY because all IPSs tracked in OPT are in SBY.
#41 09:00:00 (00:30:00)	Module C repair begins.	SBY	SBY	SBY	SBY	UDT-r/e	SBY	SBY	SBY	*Modules:* Module C is tracked in UDT-r/e. This is an equipment-related failure event from uptime for Module C. *IPSs:* IPS1 is in SBY because all of its equipment modules are in SBY. IPS2 is in SBY, despite the failure of Module C, because Module B, the alternative, is in SBY. This is not a failure for either IPS. *MPCT:* It is in SBY because all IPSs in OPT are in SBY. This is not a failure for the MPCT.
#42 09:30:00 (00:30:00)	Module A PM routine begins. Module C repair continues.	SBY	SBY	SDT-pm	SBY	UDT-r/e	SDT-pm	SDT-pm	SDT-pm	*Modules:* Module A is tracked in SDT-pm. This is a PM event for Module A. *IPSs:* Both are in SDT-pm because they are not down due to Module C, but they are down due to Module A with no substate ambiguity. *MPCT:* It is in SDT-pm because all IPSs in OPT are in SDT-pm with no substate ambiguity.
#43 10:00:00 (00:30:00)	Mainframe failure occurs due to a facilities issue.	UDT-fac	SBY	SDT-pm	SBY	UDT-r/e	UDT-fac	UDT-fac	UDT-fac	*Modules:* Mainframe is tracked in UDT-fac. This is a nonequipment-related failure from uptime for the Mainframe. *IPSs:* Both are in UDT-fac because they are both down due to UDT-fac equipment modules. IPS2 is not down due to Module C UDT-r/e. These are nonequipment-related failures for both IPSs. *MPCT:* It is in UDT-fac because all IPS in OPT are in UDT-fac. This is a nonequipment-related failure for the MPCT.
#44 10:30:00 (00:30:00)	Module C repair completes.	UDT-fac	SBY	SDT-pm	SBY	SBY	UDT-fac	UDT-fac	UDT-fac	*Modules:* Module C is tracked in SBY. *IPSs:* Both continue in UDT-fac for the same reason as event #43, and IPS2 no longer has UDT substate ambiguity. *MPCT:* Same state and reason as event #43

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Event #, Event Time hh:mm:ss, (State Time) hh:mm:ss	*Event Description*	*Mainframe*	*Handler*	*Module A*	*Module B*	*Module C*	*IPS1*	*IPS2*	*MPCT*	*Explanation of Equipment~~SEMI E10~~ States and Events*
#45 11:00:00 (00:15:00)	Mainframe repair completes.	SBY	SBY	SDT-pm	SBY	SBY	SDT-pm	SDT-pm	SDT-pm	*Modules:* Mainframe is tracked in SBY. *IPSs:* Both are in SDT-pm because both are down due to SDT-pm equipment modules with no substate ambiguity. *MPCT:* It is in SDT-pm because all IPSs in OPT are in SDT-pm with no substate ambiguity.
#46 11:15:00 (00:15:00)	Module A PM completes.	SBY	SBY	SBY	SBY	SBY	SBY	SBY	SBY	*Modules:* Module A is tracked in SBY. *IPSs:* Both are in SBY because all their equipment modules are in SBY. *MPCT:* It is in SBY because all IPSs tracked in OPT are in SBY.
#47 11:30:00 (00:30:00)	Mainframe begins qualification of new software.	ENG	SBY	SBY	SBY	SBY	ENG	ENG	ENG	*Modules:* Mainframe is tracked in ENG. *IPSs:* Both are in ENG because they have no processing equipment modules in PRD, they are not down, and they each have at least one equipment module in ENG. *MPCT:* It is in ENG because all IPSs tracked in OPT are in ENG.
#48 12:00:00 (00:00:00)	Mainframe completes qualification of new software.	SBY	SBY	SBY	SBY	SBY	SBY	SBY	SBY	*Modules:* Mainframe is tracked in SBY. *IPSs:* Both are in SBY because all their equipment modules are in SBY. *MPCT:* It is in SBY because all IPSs tracked in OPT are in SBY.

#1 The use of color in this table follows the color code convention for the basic equipment states as given in § R1-11.2 and is only provided as a convenience for the user.

R1-7 Fundamental Quantities

R1-7.1 This section presents the fundamental quantities derived from the scenario that need to be generated as inputs to ~~SEMI E10~~ the metrics defined in this Document.

R1-7.2 Table R2-6 shows the times, expressed in hours, for each of the equipment modules, IPSs, and the MPCT in each of the six basic equipment~~SEMI E10~~ states and the operations time, uptime, and total time.

R1-7.2.1 In this scenario, neither the Mainframe nor IPS1 has any productive time.

Table R1-7 Times in Basic Equipment~~SEMI E10~~ States, Operations Time, Uptime, and Total Time

Fundamental Quantity	*Mainframe*	*Handler*	*Module A*	*Module B*	*Module C*	*IPS1*	*IPS2*	*MPCT*
Nonscheduled Time (hours)	1.0000	1.0000	1.0000	1.0000	1.8333	4.0833	1.8333	1.0000
Unscheduled Downtime (hours)	1.0000	0.5000	3.2500	0.0000	1.5000	4.2500	4.4986	4.4986
Scheduled Downtime (hours)	0.0000	0.0000	2.0014	1.5014	1.0000	1.2514	0.7500	1.2514
Engineering Time (hours)	0.5000	0.0000	0.2514	0.0000	0.0000	0.7514	0.5000	0.5000
Standby Time (hours)	9.5000	10.329	4.8250	8.8444	5.9139	1.6639	1.9111	2.2431
Productive Time (hours)	0.0000	0.1708	0.6722	0.6542	1.7528	0.0000	2.5069	2.5069
Operations Time (hours)	11.000	11.000	11.000	11.000	10.167	7.9167	10.167	11.000

Fundamental Quantity	*Mainframe*	*Handler*	*Module A*	*Module B*	*Module C*	*IPS1*	*IPS2*	*MPCT*
Uptime (hours)	10.000	10.500	5.7486	9.4986	7.6667	2.4153	4.9181	5.2500
Total Time (hours)	12.000	12.000	12.000	12.000	12.000	12.000	12.000	12.000

R1-7.3 Table R2-7 shows the times, expressed in hours, for each of the equipment modules, IPSs, and the MPCT in each of the conditional UDT equipment states.

R1-7.3.1 In this scenario, none of the equipment modules have any unscheduled downtime from PRD. Even so, both IPS2 and MPCT have unscheduled downtime from PRD.

R1-7.3.2 Module A is the only equipment module with UDT maintenance delay, supplier. But this delay in this scenario translated directly into UDT maintenance delay, supplier for both IPSs and the MPCT.

Table R1-8 Times in Conditional UDT Substates

Fundamental Quantity	*Mainframe*	*Handler*	*Module A*	*Module B*	*Module C*	*IPS1*	*IPS2*	*MPCT*
UDT maintenance delay, supplier (hours)	0.0000	0.0000	2.2500	0.0000	0.0000	2.2500	2.2500	2.2500
UDT for failures during uptime (hours)	1.0000	0.5000	3.2500	0.0000	1.5000	3.2500	3.4986	3.4986
UDT for failures during productive time (hours)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	3.4986	3.4986

R1-7.4 Table R2-8 shows the failure counts, expressed in integer values, for each of the equipment modules, IPSs, and the MPCT in each of the fundamental time categories.

R1-7.4.1 In this scenario, none of the equipment modules had any failures from PRD. Even so, IPS2 and the MPCT each have two failures from PRD.

R1-7.4.2 Both IPSs and the MPCT had an additional failure from SDT that counts towards total failures, but not failures during uptime.

Table R1-9 Failure Counts in Each of the Fundamental Time Categories

Fundamental Quantity	*Mainframe*	*Handler*	*Module A*	*Module B*	*Module C*	*IPS1*	*IPS2*	*MPCT*
# of failures during total time (count of events)	1	1	1	0	1	2	3	3
# of failures during uptime (count of events)	1	1	1	0	1	1	2	2
# of equipment-related failures during uptime (count of events)	0	1	1	0	1	1	2	2
# of failures during productive time (count of events)	0	0	0	0	0	0	2	2
# of equipment-related failures during productive time (count of events)	0	0	0	0	0	0	2	2

R1-7.5 Table R2-9 shows the cycle counts, expressed in integer values, for each of the equipment modules, IPSs, and the MPCT in each of the fundamental time categories.

R1-7.5.1 For the Handler equipment module, a cycle is counted for each transport of a unit, and is much higher than the number of units visiting the MPCT in the scenario.

R1-7.5.2 One of the five units visiting the MPCT is an SDT production test unit, and is not counted in cycles during uptime or productive time. Transport of this unit is counted under the cycles for the handler, however.

Table R1-10 Equipment Cycles in Each of the Fundamental Time Categories

Fundamental Quantity	*Mainframe*	*Handler*	*Module A*	*Module B*	*Module C*	*IPS1*	*IPS2*	*MPCT*
Equipment Cycles during Uptime (count of cycles)	Not Applicable	14	4	1	2	1	3	4
Equipment Cycles during Productive Time (count of cycles)	Not Applicable	14	3	1	2	0	3	3

R1-7.6 Table R2-10 shows the times, expressed in hours, for each of the equipment modules, IPSs, and the MPCT in each of the equipment-dependent and supplier-dependent time categories.

Table R1-11 Equipment-Dependent and Supplier Dependent Quantities

Fundamental Quantity	*Mainframe*	*Handler*	*Module A*	*Module B*	*Module C*	*IPS1*	*IPS2*	*MPCT*
Equipment-Dependent Scheduled Downtime (hours)	0.0000	0.0000	1.7500	1.2500	1.0000	0.7500	0.7500	0.7500
Equipment-Dependent Unscheduled Downtime (hours)	0.0000	0.3333	0.7500	0.0000	1.5000	0.7500	1.0833	1.0833
Equipment-Dependent Operations Time (hours)	10.0000	10.8333	8.2486	10.7486	10.1667	3.9153	6.7514	7.0833
Supplier-Dependent Scheduled Downtime (hours)	0.0000	0.0000	1.7500	1.2500	1.0000	0.7500	0.7500	0.7500
Supplier-Dependent Unscheduled Downtime (hours)	0.0000	0.3333	3.0000	0.0000	1.5000	3.0000	3.3333	3.3333
Supplier-Dependent Operations Time (hours)	10.0000	10.8333	10.4986	10.7486	10.1667	6.1653	9.0014	9.3333

R1-7.7 Table R2-11 shows the repair- and maintenance-related quantities, for each of the equipment modules, IPSs, and the MPCT in each of the equipment-dependent and supplier-dependent time categories. Times are expressed in hours. Counts are expressed in integer values. All quantities for IPSs and the MPCT are equipment module-level aggregates.

R1-7.7.1 In this scenario there are no nonequipment-related repair events for any equipment system. There is a facilities-related failure that is resolved without any repair time.

Table R1-12 Repair- and Maintenance-Related Quantities

Fundamental Quantity	*Mainframe*	*Handler*	*Module A*	*Module B*	*Module C*	*IPS1*	*IPS2*	*MPCT*
SDT – Preventive Maintenance (PM) (hours)	0.0000	0.0000	1.7500	1.2500	1.0000	3.0000	4.0000	4.0000
# of PM Events (count of events)	0	0	1	1	1	2	3	3

UDT Repair, Equipment-Related (hours)	0.0000	0.3333	0.7500	0.0000	1.5000	1.0833	2.5833	2.5833
UDT Repair, Nonequipment-Related (hours)	0.0000	0.0000	0.0000	0.0000	0.0000no	0.0000	0.0000	0.0000
# of Equipment-Related Repair Events (count of events)	0	1	1	0	1	2	3	3
# of Nonequipment-Related Repair Events (hours)	0	0	0	0	0	0	0	0
SDT + UDT (hours)	1.0000	0.5000	5.2514	1.5014	2.5000	8.2528	10.7528	10.7528
# of Continuous Downtime Events (count of events)	1	1	3	2	2	7	9	9
# of Module-Level Failures (count of events)	1	1	1	0	1	3	4	4

R1-7.8 Table R2-12 shows the repair- and maintenance-related quantities of impairment time for each of the equipment modules, IPSs, and the MPCT. Times are expressed in hours. Impairment time represents a special temporal mapping of all time during which at least one equipment module is in ~~a~~ UDT ~~state~~.

R1-7.8.1 In this scenario, the impairment time for each IPS and the MPCT is greater than that of any equipment module.

Table R1-13 Repair and Maintenance Quantities of Impairment Time

Fundamental Quantity	*Mainframe*	*Handler*	*Module A*	*Module B*	*Module C*	*IPS1*	*IPS2*	*MPCT*
Impairment Time (when at least one equipment module is in UDT) (hours)	1	0.5	3.25	0	1.5	4.75	5.75	5.75

R1-8 EMI E10 Metrics

R1-8.1 *Reliability Metrics*

R1-8.1.1 Table R2-13 shows the mean time between failure and mean failure duration metrics, expressed in hours, for each of the modules, IPSs, and the MPCT.

R1-8.1.1.1 For equipment systems with no failures during the observation period (designated 'NF'), MTBF metrics do not have defined values. It is still possible to calculate a lower confidence bound in these cases.

Table R1-14 Mean Time Between Failures and Mean Failure Duration Metrics

Metric	*Mainframe*	*Handler*	*Module A*	*Module B*	*Module C*	*IPS1*	*IPS2*	*MPCT*
$MTBF_u$ — Mean Uptime Time Between Failures	10.0000	10.5000	5.7486	NF[1]	7.6667	2.4153	2.4590	2.6250
MFD_u — Mean Failure Duration for Failures during Uptime	1.0000	0.5000	3.2500	NF	1.5000	3.2500	1.7493	1.7493
E-$MTBF_u$ — Mean Uptime Time Between Equipment-Related Failures	NF	10.5000	5.7486	NF	7.6667	2.4153	2.4590	2.6250

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Metric	*Mainframe*	*Handler*	*Module A*	*Module B*	*Module C*	*IPS1*	*IPS2*	*MPCT*
$MTBF_p$ — Mean Productive Time Between Failures	NF	NF	NF	NF	NF	NF	1.2535	1.2535
MFD_p — Mean Failure Duration For Failures During Productive Time	NF	NF	NF	NF	NF	NF	1.7493	1.7493
E-$MTBF_p$ — Mean Productive Time Between Equipment-Related Failures	NF	NF	NF	NF	NF	NF	1.2535	1.2535

#1 NF means no failures.

R1-8.1.2 Table R2-14 shows the mean cycles between failures, expressed in decimal values, for each of the equipment modules, IPSs, and the MPCT.

R1-8.1.2.1 For equipment systems with no failures during the observation period (designated 'NF'), MTBF metrics do not have defined values. It is still possible to calculate a lower confidence bound in these cases.

Table R1-15 Mean Cycles Between Failures Metrics

Metric	*Mainframe*	*Handler*	*Module A*	*Module B*	*Module C*	*IPS1*	*IPS2*	*MPCT*
$MCBF_u$ — Mean Cycles Between Failures during Uptime	0.0000	14.0000	4.0000	NF[1]	2.0000	1.0000	1.5000	2.0000
E-$MCBF_u$ — Mean Cycles Between Equipment-Related Failures during Uptime	NF	14.0000	4.0000	NF	2.0000	1.0000	1.5000	2.0000
$MCBF_p$ — Mean Cycles Between Failures during Productive Time	NF	NF	NF	NF	NF	NF	1.5000	1.5000
E-$MCBF_p$ — Mean Cycles Between Equipment-Related Failures during Productive Time	NF	NF	NF	NF	NF	NF	1.5000	1.5000

#1 NF means no failures.

R1-8.2 *Availability Metrics*

R1-8.2.1 Table R2-15 shows the availability metrics, expressed as percentages of time between 0% and 100%, for each of the equipment modules, IPSs, and the MPCT.

R1-8.2.1.1 In this scenario, although the IPSs and MPCT have low values for Total Uptime and Operational Uptime metrics, a significant amount of the downtime is neither equipment dependent nor supplier dependent. This is reflected in higher values for Equipment-Dependent Uptime and Supplier-Dependent Uptime.

Table R1-16 Availability Metrics

Metric	*Mainframe*	*Handler*	*Module A*	*Module B*	*Module C*	*IPS1*	*IPS2*	*MPCT*
Total Uptime (%)	83.33%	87.50%	47.91%	79.16%	63.89%	20.13%	40.98%	43.75%
Operational Uptime (%)	90.91%	95.45%	52.26%	86.35%	75.41%	30.51%	48.37%	47.73%
Equipment-Dependent Uptime (%)	100.0%	96.92%	69.69%	88.37%	75.41%	61.69%	72.85%	74.12%

Metric	*Mainframe*	*Handler*	*Module A*	*Module B*	*Module C*	*IPS1*	*IPS2*	*MPCT*
Equipment-Dependent Scheduled Downtime (%)	0.00%	0.00%	21.22%	11.63%	9.84%	19.16%	11.11%	10.59%
Equipment-Dependent Unscheduled Downtime (%)	0.00%	3.08%	9.09%	0.00%	14.75%	19.16%	16.05%	15.29%
Supplier-Dependent Uptime (%)	100.0%	96.92%	54.76%	88.37%	75.41%	39.18%	54.64%	56.25%
Supplier-Dependent Scheduled Downtime (%)	0.00%	0.00%	16.67%	11.63%	9.84%	12.16%	8.33%	8.04%
Supplier-Dependent Unscheduled Downtime (%)	0.00%	3.08%	28.58%	0.00%	14.75%	48.66%	37.03%	35.71%

R1-8.3 *Maintainability Metrics*

R1-8.3.1 *Mean Time Between Events Metrics*

R1-8.3.1.1 Table R2-16 shows the mean time between event metrics, expressed in hours, for each of the equipment modules, IPSs, and the MPCT.

R1-8.3.1.2 In this scenario, some of the equipment systems did not have any of the related events (designated NE) for these metrics, such as PM events. In these cases, values for the metrics are not defined.

Table R1-17 Mean Time Between Events Metrics

Metric	*Mainframe*	*Handler*	*Module A*	*Module B*	*Module C*	*IPS1*	*IPS2*	*MPCT*
MTTPM — Mean Time to [Perform] Preventive Maintenance (PM)	NE[1]	NE	1.7500	1.2500	1.0000	1.5000	1.3333	1.3333
MTTR — Mean Time To Repair	NE	0.3333	0.7500	NE	1.5000	0.5417	0.8611	0.8611
E-MTTR — Mean Time to Repair during Equipment-Related Failures	NE	0.3333	0.7500	NE	1.5000	0.5417	0.8611	0.8611
MTOL — Mean Time Off-Line	1.0000	0.5000	1.7505	0.7507	1.2500	1.1790	1.1948	1.1948

#1 NE means no events, such as PM events.

R1-8.3.2 *Other Maintainability Metrics*

R1-8.3.2.1 TFR is expressed as the rate of equipment module-level failure counts versus total time. Impairment Rate (%) is expressed as the percentage rate of impairment time (versus total time) between 0% and 100%. Table R2-17 shows these other maintainability metrics for each of the equipment modules, IPSs, and the MPCT.

R1-8.3.2.1.1 In this scenario, IPS2 and MPCT have down equipment modules almost 48% of total time.

Table R1-18 Other Maintainability Metrics

Metric	*Mainframe*	*Handler*	*Module A*	*Module B*	*Module C*	*IPS1*	*IPS2*	*MPCT*
TFR — Total Failure Rate (failures per hour)	0.0833	0.0833	0.0833	0.0000	0.0833	0.2500	0.3333	0.3333
Impairment Time (%)	8.33%	4.17%	27.08%	0.00%	12.50%	39.58%	47.92%	47.92%

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R1-8.4 *Utilization Metrics*

R1-8.4.1 Table R2-18 shows the utilization metrics, expressed as percentage of time between 0% and 100%, for each of the equipment modules, IPSs, and the MPCT.

R1-8.4.1.1 In this scenario, utilization values for the equipment modules are lower than the values for IPS2 and MPCT.

Table R1-19 Utilization Metrics

Metric	*Mainframe*	*Handler*	*Module A*	*Module B*	*Module C*	*IPS1*	*IPS2*	*MPCT*
Total Utilization (%)	0.00%	1.42%	5.60%	5.45%	14.61%	0.00%	20.89%	20.89%
Operational Utilization (%)	0.00%	1.55%	6.11%	5.95%	17.24%	0.00%	24.66%	22.79%

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RESERVED ARAMS COLOR CODES AND NUMERICAL/TEXT FOR EQUIPMENT STATES AND SUBSTATES

NOTICE: This Related Information is not an official part of SEMI E10 and was derived from the work of the Metrics Global Technical Committee. This Related Information was approved for publication by full letter ballot procedures on May 12, 2014.

R1-9 Introduction

R1-9.1 SEMI E10 has been revised multiple times since the currently Inactive SEMI E58 (ARAMS) Standard has been revised. Some of these changes have resulted in some revisions being needed to the content currently provided in SEMI E58 in order to be fully consistent with the content in SEMI E10. The content with the recommended changes is provided in this section. However, please note that this section does not contain all of the changes needed to bring the entire SEMI E58 into complete consistency with SEMI E10. It includes the content changes related to the reserved numerical and text codes.

R1-9.2 For user convenience, this section also reproduces the color codes defined in SEMI E58 for the six basic equipment states defined in SEMI E10.

R1-10 Reserved Color Codes for Equipment States

NOTE 34: This section reproduces the content contained in § 18.4 of SEMI E58-0703 with the recommended technical changes only, if any (i.e., no changes to comply with the latest versions of the *Regulations*, *Procedure Manual*, and *Style Manual*).

R1-10.1 *Color Codes* — The use of color associated with the display of ARAMS (i.e., SEMI E10) equipment state information is optional. To ensure consistency for the user, the following color schemes shall be applied for all cases where color is associated with an ARAMS equipment state.

R1-10.1.1 *Uptime Equipment States*

- PRD: green
- SBY: yellow
- ENG: blue

R1-10.1.2 *Downtime Equipment States*

- SDT: light red
- UDT: red

R1-10.1.3 *Other Equipment States*

- NST: grey

R1-10.2 This scheme provides a visual grouping.

NOTE 35: The colors used for the two downtime states should be both clearly related and readily distinguishable, such as pink and bright red.

R1-11 Reserved ARAMS Numerical/Text Codes for Equipment Substates

NOTE 36: This section reproduces the content contained in § 9 of SEMI E58-0703 with the recommended technical changes only, if any (i.e., no changes to comply with the latest versions of the *Regulations*, *Procedure Manual*, and *Style Manual*).

R1-11.1 This section defines the format for ARAMS Substate Codes and a set of reserved values for generic substates based on the descriptions in SEMI E10. The format is defined specifically to allow further resolution of the six basic SEMI E10 equipment states by both the factory and equipment supplier.

R1-11.2 An ARAMS Substate Code consists of four ordered alphanumeric text characters, where the first two characters are reserved digits. The first character indicates the primary ARAMS state as follows:

1. PRD

2. SBY
3. ENG
4. SDT
5. UDT
6. NST

R1-11.3 The second character of the code, if nonzero, indicates a substate of the primary state. A zero in the second position indicates no substate has been selected. This may also be referred to as a substate of 'default.'

R1-11.4 Codes of the form 'n000' indicate no substates of a basic state have been selected. This is the 'default code' for that basic state. For example, a code of '1000' indicates PRD with no substates.

R1-11.5 Descriptive formatted text is defined to correspond to each ARAMS code. The first three characters of this text represent the basic state. If the next character is a forward slash '/', then subsequent text represents a substate of the basic state.

R1-11.6 *Reserved Codes* — States and substates referenced by the reserved text in this section are based on SEMI E10 specifications. For further definition of terminology, see main body of SEMI E10.

R1-11.6.1 The following ARAMS Substate Codes, and the corresponding descriptive text strings for the English language (delimited by single quotes), are reserved. Descriptive text with a substate of 'Reserved' indicates the corresponding code is reserved for future expansion by SEMI E58 and/or this Document.

R1-11.6.2 In the future, text strings in other languages may also be reserved. Equipment supporting other languages shall provide a method for the user to define alternative text strings. This provides the consistency, across different equipment systems, which is important to the user.

R1-11.6.2.1 *PRD*

- 1000 'PRD' (default PRD code)
- 1100 'PRD/Regular production (including loading and unloading of units internal to the equipment and recipe download)'
- 1200 'PRD/Work for a third party'
- 1300 'PRD/Rework'
- 1400 'PRD/Engineering runs done in conjunction with production units (e.g., split lots, new applications)'
- 1500 'PRD/Manufacturing support operations (e.g., processing test units to support other processes or equipment)'
- 1600 'PRD/Reserved'
- 1700 'PRD/Reserved'
- 1800 'PRD/Reserved'
- 1900 'PRD/Reserved'

R1-11.6.2.2 *SBY*

- 2000 'SBY' (default SBY code)
- 2100 'SBY/No operator available (e.g., breaks, lunches, meetings)'
- 2200 'SBY/No units available (e.g., no units due to lack of available support equipment, such as metrology equipment)'
- 2300 'SBY/No support tool (e.g., wafer carrier, probe card)'
- 2400 'SBY/Associated cluster tool equipment module down'
- 2500 'SBY/No production test results available for review'

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- 2600 ‘SBY/No input from external automation systems (e.g., host)’
- 2700 ‘SBY/Waiting times or inactive times, including waiting for load and waiting for unload’
- 2800 ‘SBY/Reserved’
- 2900 ‘SBY/Reserved’

R1-11.6.2.3 *ENG*

- 3000 ‘ENG’ (default Engineering code)
- 3100 ‘ENG/Process engineering (e.g., process characterization)’
- 3200 ‘ENG/Equipment engineering (e.g., equipment evaluation)’
- 3300 ‘ENG/ Software engineering (e.g., software qualification)’
- 3400 ‘ENG/Reserved’
- 3500 ‘ENG/Reserved’
- 3600 ‘ENG/Reserved’
- 3700 ‘ENG/Reserved’
- 3800 ‘ENG/Reserved’
- 3900 ‘ENG/Reserved’

R1-11.6.2.4 *SDT*

- 4000 ‘SDT’ (unspecified default SDT code)
- 4100 ‘SDT/Maintenance delay, nonsupplier’
- 4200 ‘SDT/ Maintenance delay, supplier’
- 4300 ‘SDT/Preventive maintenance’
- 4400 ‘SDT/Change of consumable material’
- 4500 ‘SDT/Setup’
- 4600 ‘SDT/Production test’
- 4700 ‘SDT/Facilities related’
- 4800 ‘SDT/Unspecified’
- 4900 ‘SDT/Reserved’

R1-11.6.2.5 *UDT*

- 5000 ‘UDT’ (unspecified default UDT code)
- 5100 ‘UDT/Maintenance delay, nonsupplier’
- 5200 ‘UDT/Maintenance delay, supplier’
- 5300 ‘UDT/Repair, equipment-related’
- 5400 ‘UDT/Out-of-specification input’
- 5500 ‘UDT/Change of consumable material’
- 5600 ‘UDT/Facilities-related’
- 5700 ‘UDT/Repair, nonequipment-related’
- 5800 ‘UDT/Unspecified’

- 5900 'UDT/Reserved'

R1-11.6.2.6 *NST*

- 6000 'NST' (default NST code)
- 6100 'NST/Unworked time periods'
- 6200 'NST/Equipment installation'
- 6300 'NST/Equipment modification'
- 6400 'NST/Off-line training'
- 6500 'NST/Shutdown/startup'
- 6600 'NST/IPS (IPS equipment systems only)'
- 6700 'NST/Reserved'
- 6800 'NST/Reserved'
- 6900 'NST/Reserved'

R1-11.7 *Additional Codes* — Additional codes may be defined by both the user and supplier, subject to the following constraints:

- The new code defines a refinement of a primary ARAMS state, as defined in § 9 of SEMI E58, through use of the characters in the third and fourth positions.
- Alphabetic characters are permitted in the third and fourth positions. For purposes of sorting, these characters are assumed to be case-sensitive. All characters other than alphanumeric are prohibited.
- The third character is used to differentiate between codes defined by the user (factory) and those defined by the equipment supplier. If the third character is a digit, then the code is user defined. Otherwise, the code is supplier-defined. The user is free to assign values between '01' and '9z' as the third and fourth characters, while the supplier may assign values between 'A0' and 'zz'.

NOTE 37: Additional reserved codes may be added to § 9.2 of SEMI E58 or in § R1-2.6.2.1 in this Document in the future.

R1-11.8 Code definitions are exchanged as ARAMS Substate Tables, described in SEMI E58 § 10.3.

R1-11.9 *Valid ARAMS Substate Code* — A valid ARAMS Substate Code is defined as any code with four alphanumeric characters where the first character is a digit between 1 and 6 and the second character is a digit between 0 and 9.

R1-11.10 *Manufacturing Code* — A user request for the equipment to go to manufacturing specifies a special code of '0000'. The code '0000' is not itself an ARAMS Substate Code and shall not be used as a code representing the current ARAMS state/substate in the variable ARAMSState.

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GUIDANCE FOR DETERMINING PRODUCTIVE TIME BOUNDARIES

NOTICE: This Related Information is not an official part of SEMI E10 and was derived from the work of the Metrics Global Technical Committee. This Related Information was approved for publication by full letter ballot procedures on May 12, 2014.

R1-12 Introduction

R1-12.1 This Related Information section has been created in an effort to provide practical guidance to the industry on where to draw SEMI E10 productive time boundaries. This is accomplished by referencing SEMI Equipment Automation Standards equipment state models and identifying states in those Standards where SEMI E10 productive time is active.

R1-13 SEMI E30 (GEM) Generic Equipment Model

R1-13.1 When comparing the SEMI E10 productive time equipment state (i.e., PRD) with the SEMI E30 processing state model, SEMI E10 productive time can be said to contain all of the time from the SEMI E30 executing state. In addition, the SEMI E10 productive time definition states that loading and unloading time is included, which also implies a mapping to a portion of the SEMI E30 setup state time. Figure R4-1 illustrates the SEMI E30 processing state model and the associated states that participate in time contribution to ~~the~~ SEMI E10 ~~productive time state~~PRD.

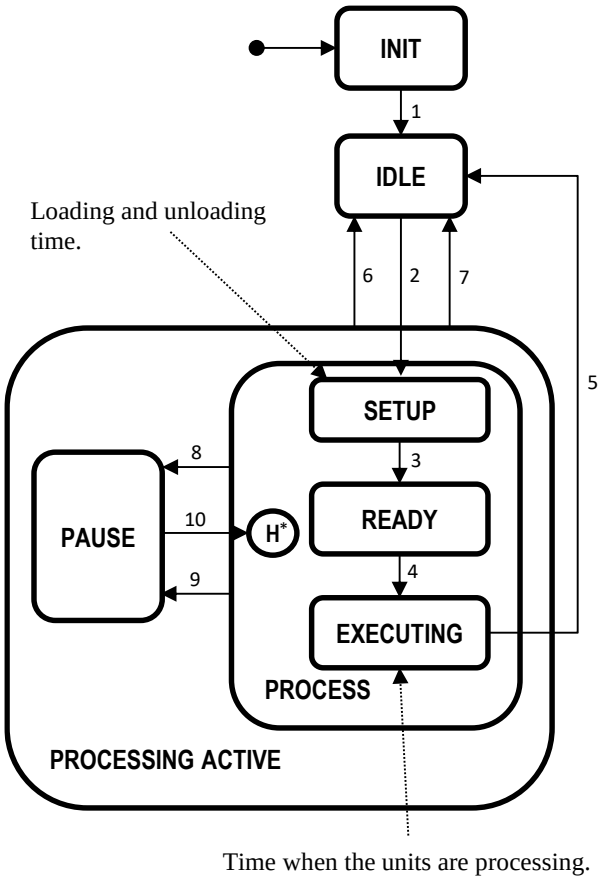

Figure R1-2
Annotated GEM Processing State Model

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R1-14 SEMI E116 (EPT) Equipment Performance Tracking

R1-14.1 Relative to the SEMI E116 (EPT) 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.' Figure R4-2 and Table R4-1 from SEMI E116 illustrate the 'busy' state and the associated task types from the event variable definitions table.

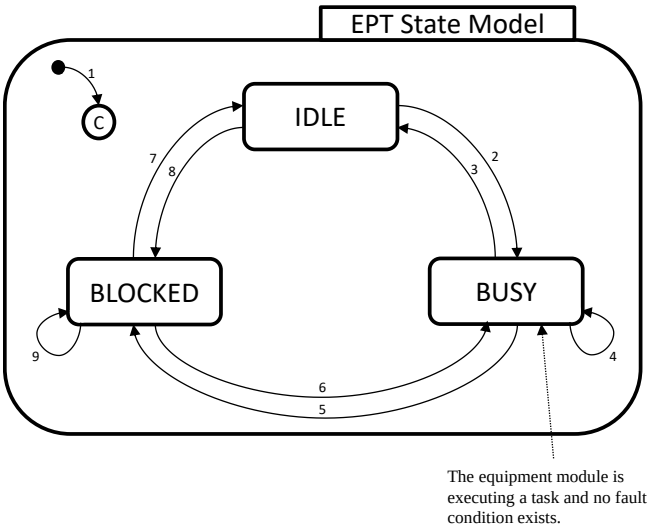

Figure R1-3
EPT State Model

Table R1-20 EPT Task Type for Busy State Association

VARIABLE NAME	*DESCRIPTION*	*TYPE*	*ACCESS*	*COMMENT*
Task Type	The type of EPT Task currently running on this EPT module.	Enumerated	RO	0 = No Task 1 = Unspecified 2 = Process - adding value (e.g., exposing) 3 = Support - incapable of adding value (e.g., Handling/Transport) 4 = Equipment Maintenance (e.g., equipment initiated clean cycle) 5 = Equipment Diagnostics (e.g., equipment-initiated health check) 6 = Waiting (e.g., chamber waiting for a robot to remove a substrate)

R1-15 SEMI E58 (ARAMS) Automated Reliability Availability Maintainability

R1-15.1 Since the SEMI E58 (ARAMS) Standard provided automated data collections support for an earlier version of SEMI E10, the correlation for productive time is straightforward. Relative to SEMI E58, ~~the~~ SEMI E10 ~~productive time state~~PRD is intended to be synonymous with the ARAMS ~~productive state~~PRD. Figure R4-3 is the SEMI E58 ARAMS state model depicting its version of ~~the productive state~~PRD.

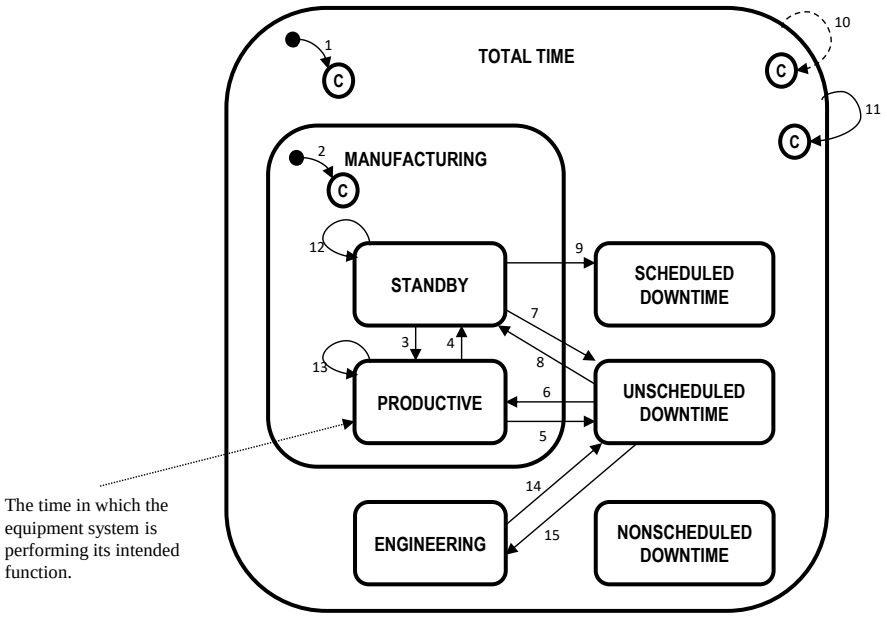

Figure R1-4
ARAMS Equipment State Model

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