SEMI E10-0304
SPECIFICATION FOR DEFINITION AND MEASUREMENT OF EQUIPMENT RELIABILITY, AVAILABILITY, AND MAINTAINABILITY (RAM)

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1 Purpose

1.1 This Document establishes a common basis for communication between users and suppliers of semiconductor manufacturing equipment by providing standards for measuring RAM performance of that equipment in a manufacturing environment.

2 Scope

2.1 The Document defines six basic equipment states into which all equipment conditions and periods of time must fall. The equipment states are determined by functional issues, independent of who performs the function. The measurement of equipment reliability in this specification concentrates on the relationship of equipment failures to equipment usage, rather than the relationship of failures to total elapsed time.

2.2 § 5 (Equipment States) defines how equipment time is categorized. § 6 (RAM Measurement) defines formulas for measurement of equipment performance. § 7 (Uncertainty Measurement) gives additional methods for evaluating the statistical significance of calculated performance metrics.

2.3 Effective application of this Specification requires that equipment performance (RAM) be tracked with regard to time and/or equipment cycles. Automated tracking of equipment states is not within the scope of this Specification, but is covered by SEMI E58. Clear and effective communication among users and suppliers promotes continuous improvement in equipment performance.

2.4 The RAM indices in this Specification may be applied directly to non-cluster tools at the whole equipment and subsystem levels. The RAM indices may be applied at the subsystem level (e.g., process module) for multi-path cluster tools.

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

3 Referenced Standards and Documents

3.1 *SEMI Standards and Safety Guidelines*

SEMI E58 — Automated Reliability, Availability, and Maintainability Standard (ARAMS)

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

4 Terminology

4.1 *Definitions*

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

4.1.2 *cluster tool* — a manufacturing system made up of integrated processing modules mechanically linked together (the modules may or may not come from the same supplier).

4.1.2.1 *single path cluster tool* — a cluster tool with only one process flow path (as used).

4.1.2.2 *multi-path cluster tool* — a cluster tool with more than one independent process flow path (e.g., multiple load ports/load-locks, multiple process chambers of the same type) and used as such.

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

4.1.4 *downtime (DT)* — the time when the equipment is not in a condition, or is not available, to perform its intended function. It does not include any portion of non-scheduled time.

4.1.5 *downtime event* — a detectable occurrence significant to the equipment that causes the equipment to go from an uptime state to either a scheduled or an unscheduled downtime state.

4.1.6 *failure* — any unscheduled downtime event that changes the equipment to a condition where it cannot perform its intended function. Any part failure, software or process recipe problem, facility or utility supply malfunction, or human error could cause the failure.

NOTE 1: It is important to categorize and qualify failures in ways that facilitate the resolution of problems and improve overall equipment performance. Use of this Specification requires agreement between supplier and user on categorizing failures.

4.1.7 *equipment-related failure* — any unplanned event that changes the equipment to a condition where it cannot perform its intended function solely caused by the equipment.

4.1.8 *host* — the intelligent system that communicates with the equipment, acts as a supervisory agent, and represents the factory and the user to the equipment.

4.1.9 *intended function* — a manufacturing function that the equipment was built to perform. This includes transport functions for transport equipment and measurement functions for metrology equipment, as well as process functions such as physical vapor deposition and wire bonding. Complex equipment may have more than one intended function.

4.1.10 *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.

4.1.11 *maintenance* — the act of sustaining equipment in or restoring it to a condition to perform its intended function. In this Document, maintenance refers to function, not organization; it includes adjustments, change of consumables, software upgrades, repair, preventive maintenance, etc., no matter who performs the task.

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

4.1.13 *non-scheduled time* — the time when the equipment is not scheduled to be utilized in production.

4.1.14 *operations time (oper-time)* — total time minus non-scheduled time.

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

4.1.16 *product* — units produced during productive time (see unit).

4.1.17 *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 and unscheduled downtime.

4.1.18 *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 and unscheduled downtime.

4.1.19 *reliability* — the probability that the equipment will perform its intended function, within stated conditions, for a specified period of time.

4.1.20 *shutdown* — the time required to put the equipment in a safe condition when entering a non-scheduled state. It includes any procedures necessary to reach a safe condition. Shutdown is only included in non-scheduled time.

4.1.21 *specification (equipment operation)* — the documented set of intended functions within stated conditions for equipment operation as agreed upon between user and supplier.

4.1.22 *start-up* — the time required for equipment to achieve a condition where it can perform its intended function, when leaving a non-scheduled state. It includes pump down, warm-up, cool-down, stabilization periods, initialization

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routines, software load, restoring dynamic values (e.g., parameters, recipes), control system reboot, etc. Start-up is only included in non-scheduled time.

4.1.23 *support tool* — a tool that, although not part of a piece of equipment, is required by and becomes integral with it during the course of normal operation (e.g., cassettes, wafer carriers, probe cards, computerized controllers/monitors).

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

4.1.25 *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 non-scheduled time.

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

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

4.1.28 *uptime* — the time when the equipment is in a condition to perform its intended function. It includes productive, standby, and engineering time, and does not include any portion of non-scheduled time.

4.1.29 *user* — any entity interacting with the equipment, either locally as an operator or remotely via the host. From the equipment's view point, both the operator and the host represent the user.

4.1.30 *utilization* — the percent of time the equipment is performing its intended function during a specified time period.

4.1.31 *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 Equipment States

5.1 To clearly measure equipment performance (RAM), this Document defines six basic equipment states into which all equipment conditions and periods of time must fall.

5.2 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, an operator, a production technician, a maintenance technician, or a process engineer.

5.3 Figure 1 is a stack chart of the six basic equipment states. These basic equipment states can be divided into as many sub-states as are required to achieve the equipment tracking resolution that a manufacturing operation desires. SEMI E10 makes no attempt to list all possible substates, but does give some examples for guidance.

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

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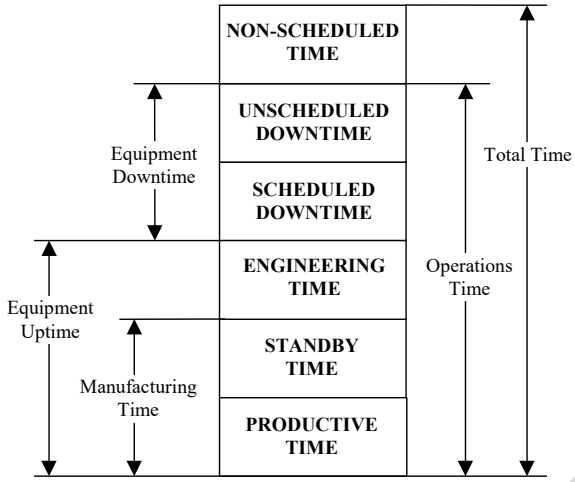

Figure 1
Equipment States Stack Chart

5.5 *PRODUCTIVE STATE* — The time (productive time) when the equipment is performing its intended function. The productive state includes:

- Regular production (including loading and unloading of units),
- Work for third parties,
- Rework, and
- Engineering runs done in conjunction with production units (e.g., split lots and new applications).

5.6 *STANDBY STATE* — The time (standby time), other than non-scheduled time, when the equipment is in a condition to perform its intended function, chemicals and facilities are available, but it is not operated. The standby state includes:

- No operator available (including breaks, lunches, and meetings),
- No units available (including no units due to lack of available support equipment, such as metrology tools),
- No support tools (e.g., cassettes, wafer carriers, probe cards), and
- No input from external automation systems (i.e., host).

5.7 *ENGINEERING STATE* — The time (engineering time) when the equipment is in a condition to perform its intended function (no equipment or process problems exist), but is operated to conduct engineering experiments. The engineering state includes:

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

5.8 *SCHEDULED DOWNTIME STATE* — The time (scheduled downtime) when the equipment is not available to perform its intended function due to planned downtime events. The scheduled downtime state includes:

- Maintenance delay (maint-delay),
- Production test,
- Preventive maintenance,
- Change of consumables/chemicals,

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- Setup, and
- Facilities related (fac-rel).

5.8.1 *Maintenance Delay* — The time (maint-delay downtime) during which the equipment cannot perform its intended function because it is waiting for either user or supplier personnel or parts (including consumables/chemicals) associated with maintenance. Maintenance delay may also be due to an administrative decision to leave the equipment down and postpone maintenance.

5.8.1.1 Maintenance delays may occur at any point in the maintenance process. These maintenance delay downtimes must be tracked separately from maintenance time. Delay downtime is included in time off-line, but not in time to repair (see §§ 6.3 and 6.4 Equipment Availability and Maintainability).

5.8.2 *Production Test* — The time (production test downtime) for the planned interruption of equipment availability for evaluation of units, as defined in the specifications of 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, nor does it include any testing done following a preventive maintenance, setup, or repair procedure.

5.8.3 *Preventive Maintenance* — The sum of the times (preventive maintenance downtimes) for:

- Preventive action: A predefined maintenance procedure (including equipment ramp-down and ramp-up), at scheduled intervals, designed to reduce the likelihood of equipment failure during operation. Scheduled intervals may be based upon time, equipment cycles, or equipment conditions.
- Equipment test: The operation of equipment to demonstrate equipment functionality; (e.g., system reaches base pressure, wafers 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 2: Equipment suppliers are responsible for specifying a preventive maintenance 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.

5.8.4 *Change of Consumables/Chemicals* — The time (change of consumables/chemicals downtime) for the scheduled interruption of operation to replenish the raw materials of semiconductor processing. It includes changes of gas bottles, acids, targets, sources, etc., and any purging, cleaning, or flushing normally associated with those changes. It does not include delays in obtaining those consumables/chemicals.

5.8.5 *Setup* — The sum of the times (setup downtimes) for:

- Conversion: The time required to complete an equipment alteration necessary to accommodate a change in process, unit, package configuration, etc. (excluding modifications, rebuilds, and upgrades).
- Equipment test: The operation of equipment to demonstrate equipment functionality; (e.g., system reaches base pressure, wafers 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 3: Equipment suppliers are responsible for providing procedures which achieve setup conversion and testing within predetermined specifications. Users are obligated to identify any deviation from the procedures if they expect the supplier to make setups fall within those specifications.

5.8.6 *Facilities Related* — The time (facilities-related downtime) when the equipment cannot perform its intended function solely as a result of out of specification facilities. Those facilities include:

- Environmental (e.g., temperature, humidity, vibration, particle count),
- House hookups (e.g., power, cooling water, house gases, exhaust, LN2), and
- Communications links with other equipment or host computers.

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5.8.6.1 Any downtime created by the items listed above shall be included in facilities-related downtime. For example, if, as a result of a scheduled 15-minute power outage an otherwise unnecessary cryo pump regeneration is needed, all time required to return the equipment to a condition where it can perform its intended function is included in facilities-related downtime.

5.9 *UNSCHEDULED DOWNTIME STATE* — The time (unscheduled downtime) when the equipment is not in a condition to perform its intended function due to unplanned downtime events:

- Maintenance delay (maint-delay)
- Repair
- Change of consumables/chemicals
- Out-of-spec input
- Facilities related (fac-rel)

5.9.1 *Maintenance Delay* — The time (maint-delay downtime) during which the equipment cannot perform its intended function because it is waiting for either user or supplier personnel or parts (including consumables/chemicals) associated with maintenance. Maintenance delay may also be due to an administrative decision to leave the equipment down and postpone maintenance.

5.9.1.1 Maintenance delays may occur at any point in the maintenance process. These maintenance delay downtimes should be tracked separately from maintenance time. Delay downtime is included in time off-line, but not in maintenance time (see §§ 6.3 and 6.4 Equipment Availability and Maintainability).

5.9.2 *Repair* — The sum of the times (repair downtimes) for:

- Diagnosis: The procedure of identifying the source of an equipment problem or failure.
- Corrective action: The maintenance procedure (including equipment ramp-down and ramp-up, re-booting, resetting, recycling, restarting, reverting to a previous software version, etc.) employed to address an equipment failure and return the equipment to a condition where it can perform its intended function.
- Equipment test: The operation of equipment to demonstrate equipment functionality (e.g., system reaches base pressure, wafers 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.

5.9.3 *Change of Consumables/Chemicals* — The time (change of consumables/chemicals downtime) for the unscheduled interruption of operation to replenish the raw materials of semiconductor processing. It includes changes of gas bottles, acids, targets, sources, etc., and any purging, cleaning, or flushing normally associated with those changes. It does not include delays in obtaining these consumables/chemicals.

5.9.4 *Out-of-Spec Input* — The time (out-of-spec input downtime) when the equipment cannot perform its intended function solely as a result of problems created by out-of-specification or faulty inputs. Those inputs include:

- Support tools (e.g., warped cassettes or wafer carriers, faulty probe cards, reticles),
- Unit (e.g., upstream process problems, warped wafers, contaminated wafers, warped lead frames),
- Test data (e.g., metrology tool out of calibration, misread charts, erroneous data interpretation/entry), and
- Consumables/chemicals (e.g., contaminated acid, leaky target bond, degraded photo resist, degraded mold compound).

5.9.4.1 Any downtime created by the items listed above shall be included in out-of-specification input downtime. For example, if, as a result of an intermittent probe card short, a prober/tester system is put down for repair, all downtime incurred prior to identifying the problem is re-categorized as out-of-specification input downtime.

5.9.5 *Facilities Related* — The time (facilities-related downtime) when the equipment cannot perform its intended function solely as a result of out-of-specification facilities. Those facilities include:

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- Environmental (e.g., temperature, humidity, vibration, particle count),
- House hookups (e.g., power, cooling water, house gases, exhaust, LN2), and
- Communications links with other equipment or host computers.

5.9.5.1 Any downtime created by the items listed above shall be included in facilities-related downtime. For example, if, as a result of an unscheduled 15-minute power outage, an otherwise unnecessary cryo pump regeneration is needed, all time required to return the equipment to a condition where it can perform its intended function is included in facilities-related downtime.

5.10 *NON-SCHEDULED STATE* — The time (non-scheduled time) when the equipment is not scheduled to be utilized in production, such as unworked shifts, weekends, and holidays (including shutdown and start-up).

5.10.1 If equipment is out of the production plan due to off-line training or an installation, modification, rebuild, or upgrade (hardware or software) that cannot be accommodated by the regular preventive maintenance schedule, its status is the non-scheduled state. This includes any qualification time required to bring the equipment to a condition where it can perform its intended function from one of these states.

5.10.2 Any maintenance done to equipment during these periods cannot be counted in the non-scheduled state, since all maintenance must fall into either scheduled or unscheduled downtime (this includes automatic maintenance routines such as a programmed cryo pump regeneration).

5.10.3 By the same convention, any production or engineering work done during these periods must fall into either productive or engineering time (this includes an unattended operation that may shut itself off "after hours").

6 RAM Measurement

6.1 Reliability, availability, and maintainability are measures of equipment performance which have been used widely in industry for decades. This section defines them for the semiconductor industry in a manner that is consistent with existing industrial standards. Along with the definitions for RAM are given indicators by which these measures can be quantified.

6.2 *EQUIPMENT RELIABILITY* — The probability that the equipment will perform its intended function, within stated conditions, for a specified period of time.

NOTE 4: Two different methods of measuring this are presented, productive time (§§ 6.2.1 and 6.2.2) and equipment cycles (§§ 6.2.3 and 6.2.4):

- Productive time only considers what happens while making units (useful for manufacturing operation purposes).
- Equipment cycles take into account the wear and tear created by every machine cycle during all equipment states (useful for equipment reliability purposes).

6.2.1 $MTBF_p$ — 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 state to a productive state are included in this calculation. Using $MTBF_p$, therefore, requires that the user not only have the capability of capturing failure information, but also tracking and categorizing total time accurately.

$$MTBF_p = \frac{productive\ time}{\#\ of\ failures\ that\ occur\ during\ productive\ time}$$

6.2.2 $E\text{-}MTBF_p$ — Mean (productive) time between equipment-related failures; the average time the equipment performed its intended function between these 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 state to a productive state are included in this calculation. Using $E\text{-}MTBF_p$, therefore, requires that the user not only have the capability of capturing failure information, but also tracking and categorizing total time and the root causes of failures accurately.

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$$E\text{–}MTBF_p = \frac{\textit{productive time}}{\textit{\# of equipment-related failures that occur during productive time}}$$

6.2.3 *MCBF* — Mean cycles between failures; the average number of equipment cycles between failures; total equipment cycles divided by the number of failures during those cycles. This calculation transcends equipment states to include all cycles that the system, or subsystem, being considered experiences. It does not require tracking equipment states, only equipment cycles and equipment failures.

$$MCBF = \frac{\textit{total equipment cycles}}{\textit{\# of failures}}$$

6.2.4 *E-MCBF* — Mean cycles between equipment-related failures; the average number of equipment cycles between these equipment-related failures; total equipment cycles divided by the number of equipment-related failures during those cycles. This calculation transcends equipment states to include all cycles that the system, or subsystem, being considered experiences. It does not require tracking equipment states, only equipment cycles and equipment-related failures and their root causes.

$$E\text{–}MCBF = \frac{\textit{total equipment cycles}}{\textit{\# of equipment-related failures}}$$

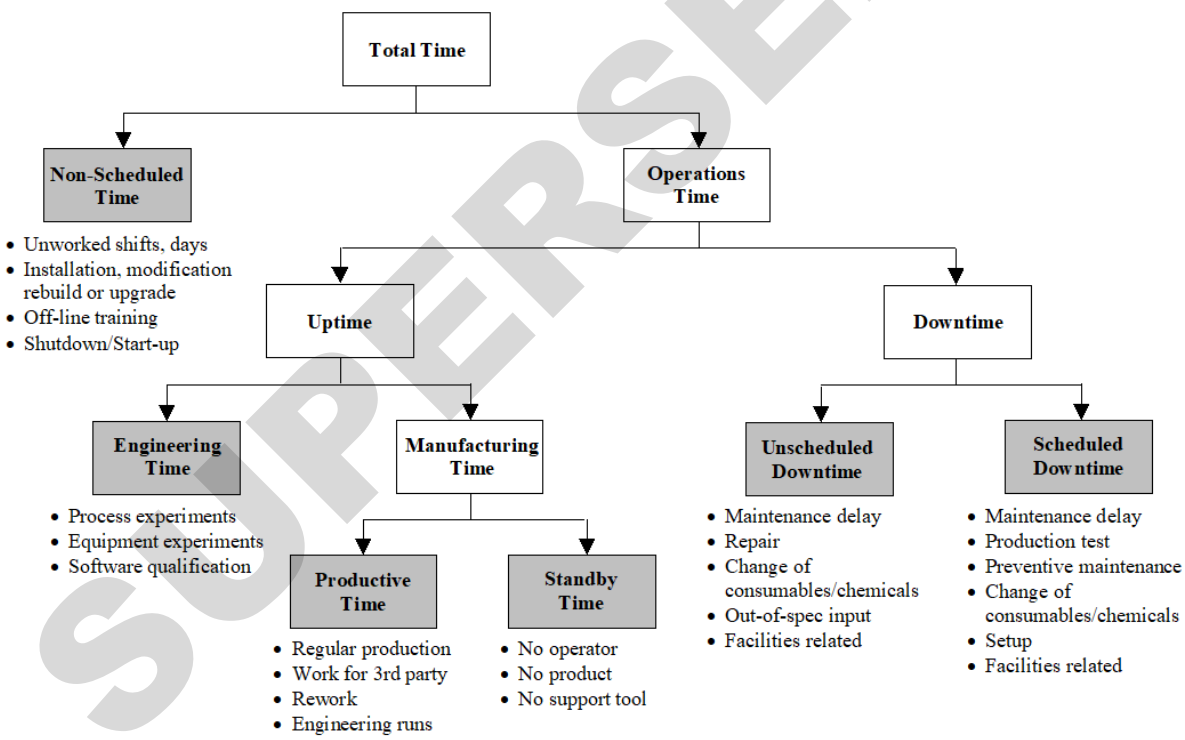

Figure 2
SEMI E10 Summary of Time

6.3 *EQUIPMENT AVAILABILITY* — The probability that the equipment will be in a condition to perform its intended function when required.

6.3.1 *Equipment Dependent Uptime* — The percent of time the equipment is in a condition to perform its intended function during the period of operations time minus the sum of all maintenance delay downtime, out-of-spec input

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downtime, and facilities-related downtime. This calculation is intended to reflect equipment reliability and maintainability based solely on equipment merit.

$$\textit{equipment dependent uptime (\%)} = \frac{\textit{equipment uptime} \times 100}{\textit{(oper-time – (all maint-delay DT + out-of-spec input DT + fac-rel DT))}}$$

6.3.2 *Supplier Dependent Uptime* — The percent of time the equipment is in a condition to perform its intended function during the period of operations time minus the sum of user maintenance delay downtime, out-of-spec input downtime, and facilities-related downtime. This calculation subtracts only user maintenance delay downtime from the period, thereby taking into account supplier delays for parts and service. The intention is to provide an effective performance measurement for use in supplier service contracts.

$$\textit{supplier dependent uptime (\%)} = \frac{\textit{equipment uptime} \times 100}{\textit{(oper-time – (user maint-delay DT + out-of-spec input DT + fac-rel DT))}}$$

6.3.3 *Operational Uptime* — The percent of time the equipment is in a condition to perform its intended function during the period of operations time. This calculation is intended to reflect overall operational performance for a piece of equipment.

$$\textit{operational uptime } (\%) = \frac{\textit{equipment uptime} \times 100}{\textit{operations time}}$$

6.4 *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.

6.4.1 *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 failures during that period.

$$MTTR = \frac{\textit{total repair time}}{\textit{\# of failures}}$$

6.4.2 *E-MTTR* — Mean time to repair 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 failures during that period.

$$E\text{–}MTTR = \frac{\textit{total repair time for equipment-related failures}}{\textit{\# of equipment-related failures}}$$

6.4.3 *MTOL* — Mean time off-line; the average time to maintain the equipment in or return the equipment to a condition where it can perform its intended function when downtime is incurred; the sum of all downtime (scheduled and unscheduled) during a specified time period, divided by the number of downtime events during that period.

$$MTOL = \frac{\textit{total equipment downtime}}{\textit{\# of DT events}}$$

6.4.4 *Equipment Dependent Scheduled Downtime* — The percent of time the equipment is not available to perform its intended function due to scheduled downtime events such as preventive maintenance. This time period does not include any maintenance delay downtime caused either by supplier or user. This calculation is intended to reflect the need for preventive maintenance based solely on equipment design.

$$\textit{equipment dependent scheduled downtime (\%)} = \frac{\textit{equipment scheduled downtime} \times 100}{\textit{(oper-time – (all maint-delay DT + out-of-spec input DT + fac-rel DT))}}$$

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