Background Statement for SEMI Draft Document 6579

Revision to SEMI E79-0814[E]
SPECIFICATION FOR DEFINITION AND MEASUREMENT OF EQUIPMENT PRODUCTIVITY

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 E79 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:** Some 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 SEMI E10 basic equipment states. Added "of manufacturing equipment in the semiconductor and related industries" in ¶ 1.1 to clarify the additional industry segments covered by SEMI and for consistency with E10 applies. Added some new terms/definitions from SEMI E10 and harmonized definitions with planned changes in SEMI E10. Various other, mostly editorial, changes were made to address grammar and consistency, but with no actual intended changes from the original technical meaning.

Review Information for Information Ballot

Please submit your feedback to:

Equipment RAMP Metrics Task Force Leader(s):	Steve Meyer: steven.j.meyer@intel.com Russell Fitzpatrick: russell_fitzpatrick@amat.com David Busing: david.busing@sbcglobal.net
Co-Chair of Metrics TC	David Bouldin: david.bouldin@sbcglobal.net

SEMI
673 S. Milpitas Blvd.
Milpitas, CA 95035-5446
Phone: 408.943.6900

DRAFT
Document Number: 6579
Date: 10/25/2019

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SEMI Draft Document 6579

Revision to SEMI E79-0814[E]
SPECIFICATION FOR DEFINITION AND MEASUREMENT OF EQUIPMENT PRODUCTIVITY

~~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 February 1999; previously published November 2006.~~

~~[E] This Standard was editorially modified in October 2014 to correct a typographical error. Changes were made to the title of Related Information 3.~~

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

1 Purpose

1.1 ~~The purpose of t~~This Document ~~is to~~ provides metrics for measuring equipment productivity of manufacturing equipment in the semiconductor and related industries.

2 Scope

2.1 This Document defines metrics and calculations for measurement of equipment productivity, including overall equipment efficiency (OEE).

2.2 It is important to note that equipment productivity is impacted greatly by factors far beyond the equipment system itself, including user actions, recipe settings, facility issues, material availability, scheduling requirements, etc.

2.3 Effective application of this Document requires that equipment performance is tracked using the metrics for equipment reliability, availability, and maintainability (RAM) and utilization ~~established~~ specified in SEMI E10.

2.3.1 Productivity metrics for intended process sets (IPSs) and multi-path cluster tools (MPCTs) require tracking of SEMI E10 equipment states and recipes at the level of individual processing equipment modules.

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

3 Limitations

3.1 This Document is currently limited to measuring equipment productivity using time-based OEE as the primary metric. This Document does not address any RAM issues over and above those defined in SEMI E10.

NOTE 1: See ¶ 6.1.3 for more information contrasting the time-based overall equipment 'efficiency' (OEE) metrics in this Document with the traditional total productive maintenance (TPM) overall equipment 'effectiveness' (also using the same acronym OEE) metric, which is based on units of production.

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

NOTE 2: 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 SEMI E10 Related Information 4 regarding ~~T~~the specific relationship between the SEMI E116 states and those needed by this Document ~~is not provided~~.

3.3 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 and equipment system type.

3.4 This Document does not address the impact of productivity changes on cost or other performance metrics. The equipment cost of ownership (COO) Standard SEMI E35 provides the methodology for determining the impact of productivity changes on cost.

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4 Referenced Standards and Documents

4.1 *SEMI Standards and Safety Guidelines*

SEMI E10 — Specification for Definition and Measurement of Equipment Reliability, Availability, and Maintainability (RAM) and Utilization

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

5.1.2 *CD-SEM* — critical-dimension scanning electron microscope

5.1.3 *CMP* — chemical mechanical planarization

5.1.4 *COO* — cost of ownership

5.1.5 *CVD* — chemical vapor deposition

5.1.6 *DEE* — demand equipment efficiency

~~5.1.7 *DT* — downtime~~

~~5.1.8~~ 5.1.7 *ENG* — engineering state

~~5.1.9~~ 5.1.8 *EPT* — equipment performance tracking

~~5.1.10~~ 5.1.9 *IEE* — intrinsic equipment efficiency

~~5.1.11~~ 5.1.10 *IPS* — intended process set

~~5.1.12~~ 5.1.11 *IPS/MPCT* — intended process set or multi-path cluster tool

~~5.1.13~~ 5.1.12 *LPCVD* — low-pressure chemical vapor deposition

~~5.1.14~~ 5.1.13 *MPCT* — multi-path cluster tool

~~5.1.15~~ 5.1.14 *NST* — nonscheduled state

~~5.1.16~~ 5.1.15 *OEE* — overall equipment efficiency

~~5.1.17~~ 5.1.16 *OROEE* — optimized-recipe overall equipment efficiency

~~5.1.18~~ 5.1.17 *ORTHT* — optimized-recipe theoretical production time per unit

~~5.1.19~~ 5.1.18 *PEE* — production equipment efficiency

~~5.1.20~~ 5.1.19 *PRD* — productive state

~~5.1.21~~ 5.1.20 *PVD* — physical vapor deposition

~~5.1.22~~ 5.1.21 *ROEE* — reference overall equipment efficiency

~~5.1.23~~ 5.1.22 *RAM* — reliability, availability, and maintainability

~~5.1.24~~ 5.1.23 *RTHT* — reference theoretical production time per unit

~~5.1.25~~ 5.1.24 *RTP* — rapid thermal process

~~5.1.26~~ 5.1.25 *SBY* — standby state

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~~5.1.27~~ 5.1.26 *SDT* — scheduled downtime state

~~5.1.28~~ 5.1.27 *SPCT* — single-path cluster tool

~~5.1.29~~ 5.1.28 *TEU* — total effective units

~~5.1.30~~ 5.1.29 *TEUOEE* — total effective units OEE

~~5.1.31~~ 5.1.30 *THT* — theoretical production time per unit

~~5.1.32~~ 5.1.31 *THTP* — theoretical unit throughput by recipe

~~5.1.33~~ 5.1.32 *TPM* — total productive maintenance

~~5.1.34~~ 5.1.33 *UDT* — unscheduled downtime state

~~5.1.35~~ 5.1.34 *VAOEE* — value-added in-process overall equipment efficiency

~~5.1.36~~ 5.1.35 *VTHT* — value-added in-process theoretical production time per unit

5.2 *Terminology Applicable to Calculation of the OEE Metric*

5.2.1 *actual unit output* — the number of units processed by the equipment system during production time.

5.2.2 *availability efficiency* — the fraction of total time that an equipment system is in a condition to perform its intended function when required.

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. [SEMI E10]

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]

5.2.5 *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). [SEMI E10]

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.

5.2.6 *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. [SEMI E10]

NOTE 4: Life expectancy concept comes from SEMI E35.

5.2.7 *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. [SEMI E10]

5.2.8 *effective unit output* — the number of units processed by the equipment system during production time that were of acceptable quality. In general, effective unit output is actual unit output less equipment-assignable rework and equipment-assignable scrap.

~~5.2.9 *engineering time* — during an observation period, the accumulated time when the equipment system is in the engineering state. [SEMI E10]~~

~~5.2.10~~ 5.2.9 *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. [SEMI E10]

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5.2.10 *engineering time* — during an observation period, the accumulated time when the equipment system is in the engineering state (ENG). [SEMI E10]

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

5.2.12 *equipment-assignable rework units* — any units being reworked due to a fault or defect assignable to the subject equipment system. The units may be reworked at the equipment system where the fault or defect occurred, or at other equipment systems.

5.2.13 *equipment-assignable scrap units* — any units that are permanently removed from production due to a fault or defect assignable to the subject equipment system. The units may be removed from production at the operation where the fault or defect occurred, or at a subsequent operation.

5.2.14 *equipment module* — an indivisible entity within an equipment system. An equipment module may be either a nonprocessing equipment module or a processing equipment module. [SEMI E10]

5.2.15 *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. [SEMI E10]

5.2.16 *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]

5.2.17 *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. [SEMI E10]

5.2.18 *intended process set (IPS)* — a predetermined set of equipment modules that is used to achieve a process and is specified by the user for equipment operation. A multi~~-~~path cluster tool (MPCT) may have one or more such intended process sets (IPSs). An IPS may include alternative equipment modules at one or more steps of the process. An IPS may therefore contain one or many process paths. [SEMI E10]

5.2.19 *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. [SEMI E10]

5.2.20 *noncluster tool* — an equipment system made up of only one processing equipment module. [SEMI E10]

5.2.21 *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. [SEMI E10]

~~5.2.22 *nonscheduled time* — during an observation period, the accumulated time when the equipment system is in the nonscheduled state. [SEMI E10]~~

~~5.2.23~~ 5.2.22 *nonscheduled state (NST)* — the equipment state when the equipment system is not scheduled to be utilized in production. [SEMI E10]

5.2.23 *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). [SEMI E10]

5.2.24 *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. [SEMI E10]

5.2.25 *operational efficiency* — the fraction of uptime that an equipment system is performing its intended function.

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5.2.26 *operations time* — total time minus nonscheduled time. [SEMI E10]

5.2.27 *operator* — any person who communicates locally with the equipment through the equipment's control panel. [SEMI E10]

5.2.28 *overall equipment efficiency (OEE)* — a metric of equipment system performance, expressed as the fraction of total time the equipment system is processing effective units -assuming theoretically efficient time standards.

NOTE 5: The OEE metric accounts for all losses that reduce equipment system performance from its maximum potential performance, assuming no alterations to the existing equipment system design or recipe specifications.

5.2.29 *performance efficiency* — the fraction of uptime that an equipment system is processing actual units assuming theoretically efficient time standards. This metric is the same as the product of operational efficiency and rate efficiency.

5.2.30 *processing equipment module* — an indivisible production entity within an equipment system. Examples of processing equipment modules include processing chambers and processing stations. [SEMI E10]

5.2.31 *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. [SEMI E10]

5.2.32 *product* — units produced during productive time (see unit). [SEMI E10]

5.2.33 *production time* — the sum of all periods of time in which a processing equipment module is performing its intended function. For a noncluster tool, a single-path cluster tool (SPCT), or an individual processing equipment module within a multi-path cluster tool (MPCT), production time is equivalent to the SEMI E10 productive time for that entity. For an intended process set (IPS) or an MPCT, production time is the sum of the SEMI E10 productive times of all processing equipment modules.

~~5.2.34 *productive time* — during an observation period, the accumulated time the equipment system is in the productive state. [SEMI E10]~~

~~5.2.35~~ 5.2.34 *productive state (PRD)* — the equipment state in which the equipment system is performing its intended function. [SEMI E10]

5.2.35 *productive time* — during an observation period, the accumulated time when the equipment system is in the productive state (PRD). [SEMI E10]

5.2.36 *quality efficiency* — the fraction of theoretical production time for actual units that an equipment system is processing effective units assuming theoretically efficient time standards.

5.2.37 *rate efficiency* — the fraction of production time that an equipment system is processing actual units -assuming theoretically efficient time standards.

5.2.38 *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. [SEMI E10]

5.2.39 *scheduled downtime* — during an observation period, the accumulated time when the equipment system is in the scheduled downtime state (SDT). [SEMI E10]

5.2.40 *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~~. SDT includes any activities required to restore the equipment system to a condition where it can perform its intended function. [SEMI E10]

5.2.41 *single-path cluster tool (SPCT)* — a cluster tool in which all units follow only one process path. [SEMI E10]

~~5.2.42 *standby time* — during an observation period, the accumulated time the equipment system is in the standby state. [SEMI E10]~~

~~5.2.43~~ 5.2.42 *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. [SEMI E10]

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5.2.43 *standby time* — during an observation period, the accumulated time when the equipment system is in the standby state (SBY). [SEMI E10]

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

NOTE 6: Within the scope of this Document, the term 'state' generally refers to one of the following six basic equipment states defined in SEMI E10: productive (PRD), standby (SBY), engineering (ENG), scheduled downtime (SDT), unscheduled downtime (UDT), and nonscheduled (NST).

5.2.45 *supplier* — provider of equipment and related services to the user (e.g., unit manufacturer). Also called equipment vendor or original equipment manufacturer (OEM). [SEMI E10]

~~5.2.45~~ 5.2.46 *theoretical production time* — the production time during a period that is theoretically required to complete the unit quantities of the production recipes undertaken during the period. Theoretical production time is computed as the aggregation over all recipes of the theoretical production time per unit for the recipe applied to the unit quantity of that recipe. For multi-path cluster tools (MPCTs), theoretical production time is the sum of the theoretical production times for all processing equipment modules.

~~5.2.46~~ 5.2.47 *theoretical production time per unit (THT)* — the minimum rate of time per unit to complete processing, given the specified recipe, equipment system design, continuous operation, and no efficiency losses.

~~5.2.47~~ 5.2.48 *theoretical unit throughput by recipe (THTP)* — for a given production recipe, the number of units per period of time that theoretically could be processed by the equipment system. For each recipe, theoretical unit throughput is equal to the reciprocal of theoretical production time per unit.

~~5.2.48~~ 5.2.49 *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. [SEMI E10]

NOTE 7: For a multi-path cluster tool (MPCT), total time is defined in SEMI E79 as the aggregate total time of all processing equipment modules.

5.2.50 *unit* — any wafer, substrate, die, packaged die, or piece part thereof. [SEMI E10]

~~5.2.49~~ 5.2.51 *unscheduled downtime* — during an observation period, the accumulated time when the equipment system is in the unscheduled downtime state. [SEMI E10]

~~5.2.50~~ 5.2.52 *unscheduled downtime state (UDT)* — ~~any unplanned or unscheduled~~ the equipment 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~~nscheduled downtime~~ includes any activities required to restore~~starts when~~ the equipment system ~~has experienced a failure event and lasts until it is restored~~ to a condition where it can~~may~~ perform its intended function. [SEMI E10]

~~5.2.51 *unit* — any wafer, substrate, die, packaged die, or piece part thereof. [SEMI E10]~~

~~5.2.52~~ 5.2.53 *uptime* — during an observation period, the accumulated~~the~~ time when the equipment 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. [SEMI E10]

NOTE 8: For a multi-path cluster tool (MPCT) in SEMI E79, uptime is the aggregate uptime of all processing equipment modules.

~~5.2.53~~ 5.2.54 *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]

5.3 *Terminology Applicable to Calculation of Additional Productivity Metrics Defined in Appendix 1*

5.3.1 *demand equipment efficiency (DEE)* — a measure of equipment productivity during the time that products are planned to be available to process at the equipment system.

5.3.2 *equipment down no product time* — the period of equipment system downtime during which there are no units available at the equipment system to process.

5.3.3 *intrinsic equipment efficiency (IEE)* — a measure of equipment system productivity that measures the combined productivity losses due to rate efficiency, recipe design, and equipment system design.

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5.3.4 *IPS/MPCT ~~P~~parallel ~~P~~productivity ~~E~~efficiency (IPS/MPCT PPE)* — a measure of equipment system efficiency during productive time where idling in parallel processing equipment modules is discounted as an efficiency loss.

5.3.5 *no product time* — the period of standby time that the equipment system is idle because there are no units available at the equipment system to process.

5.3.6 *optimized-recipe overall equipment efficiency (OROEE)* — a measure of equipment system productivity assuming recipes are optimized for minimum theoretical production time.

~~NOTE 9: In the previous version of SEMI E79, optimized-recipe OEE was referred to as engineering OEE.~~

5.3.7 *optimized-recipe theoretical production time per unit (ORTHT)* — the theoretical production time per unit required to process a given recipe assuming the recipe specification is optimized for minimum theoretical production time. ORTHT is based on minimum durations for the objective processing steps (e.g., implant time for ion implanters) plus minimum allowances for any additional supporting process steps (e.g., heating, cooling, gas stabilization) that are deemed absolutely necessary. ORTHT shall be defined to be less than or equal to the corresponding theoretical production time per unit (THT) used in calculating OEE.

~~NOTE 10: In the previous version of SEMI E79, optimized-recipe THT was referred to as engineering THT.~~

5.3.8 *planned no product time* — the period of operations time that the factory model or production schedule expects the equipment system to be idle because there are no units available to process at the equipment system.

5.3.9 *production equipment efficiency (PEE)* — a measure of equipment system productivity during the time that products are available to process at the equipment system.

~~NOTE 11:~~NOTE 9: One application of PEE is to measure the productivity of nonconstraint equipment systems, which are expected to have periods of idle time due to lack of available work.

5.3.10 *reference overall equipment efficiency (ROEE)* — a measure of equipment system productivity relative to a benchmark theoretical production time.

5.3.11 *reference theoretical production time per unit (RTHT)* — the theoretical production time per unit required to process a given recipe on benchmark equipment (i.e., the fastest equipment system design of similar type) for a benchmark product and process design. RTHT shall be defined to be less than or equal to the corresponding theoretical production time per unit (THT) used in calculating OEE.

5.3.12 *total effective units (TEU)* — a subset of effective units used in OEE that additionally discounts nonequipment-assignable scrap units and nonequipment-assignable rework units. The count of total effective units is always less than or equal to the count of effective units.

5.3.13 *total effective units OEE (TEUOEE)* — a measure of equipment system productivity assuming total effective units. This metric reflects the effect on a subject equipment system of quality losses external to the subject equipment system.

5.3.14 *value-added in-process overall equipment efficiency (VAOEE)* — a measure of equipment system productivity assuming that only the value-added portion of processing cycles for effective units is efficient.

5.3.15 *value-added in-process theoretical production time per unit (VTHT)* — the theoretical production time per unit that credits only the objective processing steps that add value to products. VTHT shall be defined to be less than or equal to the optimized-recipe theoretical production time per unit (ORTHT) used in calculating optimized-recipe overall equipment efficiency (OROEE*)*.

6 Overview

6.1 *Efficiency Measurement and OEE*

6.1.1 All efficiency metrics in this Document are time-based efficiencies, where one accounting of accumulated equipment system time is compared to another. Some of these accounts of equipment system time are based on direct monitoring of the equipment system, such as total time, uptime, and productive time defined in SEMI E10. Other accounts are based on theoretical models of equipment system time.

6.1.2 All efficiency and loss metrics in this Document are bounded from zero to one (i.e., decimal fractions) for ease of calculation, but may also be expressed in percentages if the user prefers. Metrics values outside these boundaries represent errors in tracking, modeling, and/or calculation.

6.1.3 Efficiency metrics in this Document are variations or components of a popular, traditional measurement from total productive maintenance (TPM) literature called overall equipment 'effectiveness' (also using the same acronym 'OEE' used in this Document for overall equipment 'efficiency'). Some literature examples are given in § 9. This alternate effectiveness metric is based on units of production and traditionally expressed in terms of units. In this Document, the efficiency metrics are expressed in terms of equipment system time. Overall equipment efficiency (OEE) is the more correct term for the time-based calculations defined in this Document. Traditional unit-based 'effectiveness' calculations and the time-based OEE calculations within this Document yield essentially the same results.

6.1.4 Component metrics of OEE are defined as follows:

- availability efficiency
- operational efficiency
- rate efficiency
- quality efficiency

6.1.4.1 These components are defined in this Document in terms that are consistent with SEMI E10, as shown in Figure 1.

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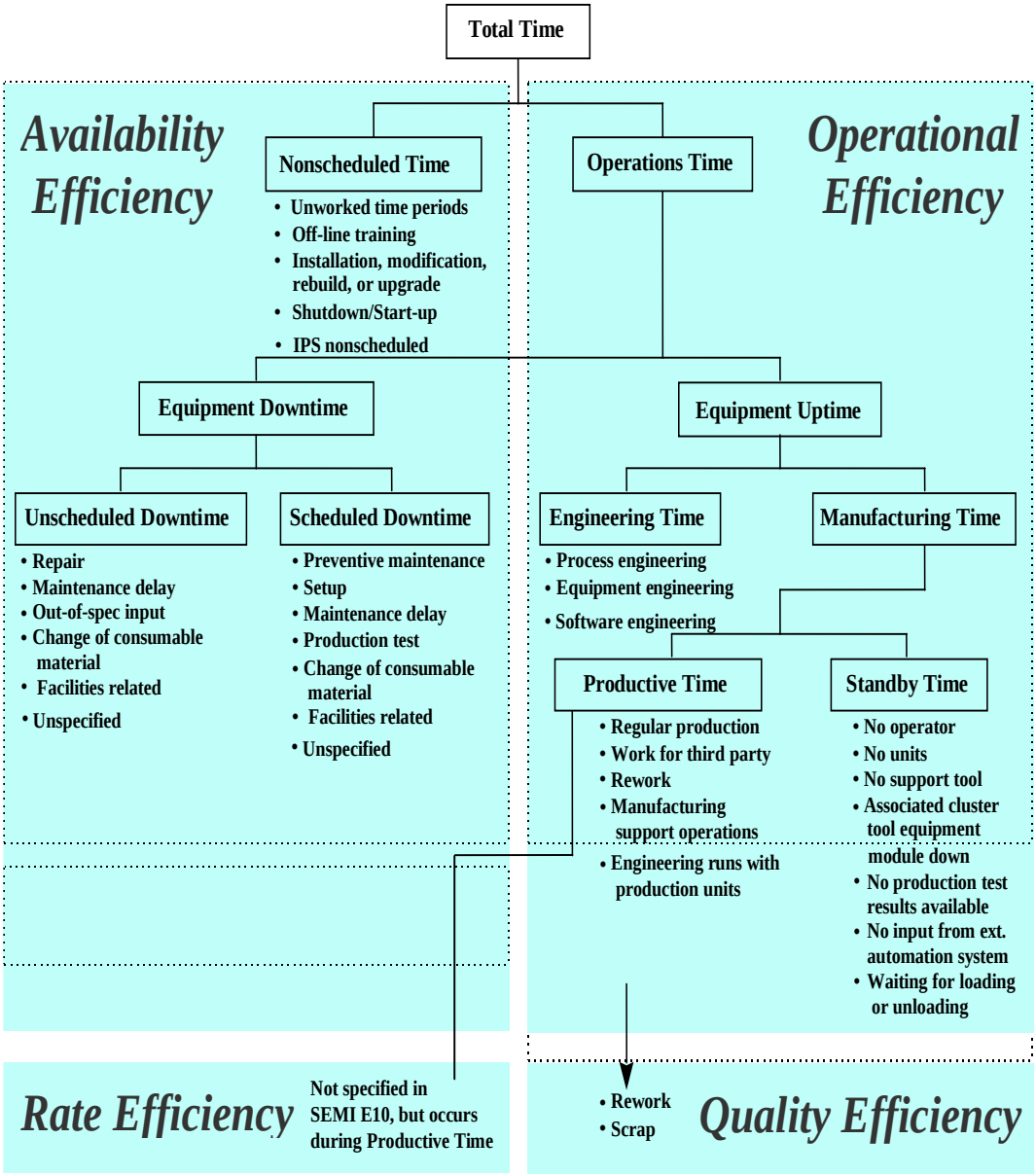

Figure 1
Relationship Between SEMI E10 and OEE

6.2 *Theoretical Production Time Standards by Recipe*

6.2.1 This Document requires the development and application of a set of theoretical production time standards by recipe, where each time standard is referred to as the theoretical production time per unit of recipe i (THT_i):

$$THT_i = \text{theoretical production time per unit of recipe } i \quad (1)$$

~~NOTE 12:~~NOTE 10: Theoretical production time per unit of recipe i may also be calculated as the reciprocal of theoretical unit throughput of recipe i.

6.2.2 THT_i is applied to the count of the units output during the observation period to obtain a theoretically 'earned' time for the equipment system that is considered efficient.

6.2.3 THT_i is the strictly theoretically efficient time assuming the specified recipe, the specified equipment system design, and continuous operation.

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6.2.3.1 Recipe specifications and settings for THT_i are the ones actually used in production and are not idealized.

6.2.3.2 To accurately represent the specified equipment system design, optimal times for material handling and other support tasks shall~~must~~ be included where those tasks cannot occur in parallel with processing tasks.

6.2.3.3 Equipment systems of the same design (e.g., same make, model, configuration) are expected to have the same THT_i values, whereas equipment systems of a different design may have different THT_i values even if they perform the same intended function.

6.2.3.4 Continuous operation requires that equipment system loading is optimized for throughput and there are no internal or external interruptions or delays to processing.

6.2.3.5 Given the constraints of a specified recipe, an equipment system design, and continuous operation, THT_i shall not include allowances for any other efficiency losses (e.g., slower-than-ideal changes in temperature or pressure, longer-than-ideal reaction times for valves or moving parts, different moments within a maintenance cycle, different moments in the life-cycle of a consumable material or consumable part).

6.2.4 For accurate measurement of the metrics rate efficiency and OEE (e.g., to guarantee that they are always correctly bounded between zero and one), THT_i shall~~must~~ be defined so that it is less than or equal to the actual productive time for any unit of recipe i.

$$THT_i \leq \textit{actual production time for any unit of recipe } i \quad (2)$$

6.2.5 For noncluster tool, single-path cluster tools, or individual processing equipment modules, the set of THT_i standards is based on the equipment system as a whole. For intended process sets (IPSs) or multi-path cluster tools (MPCTs), the set of THT_i standards is based on each of the individual processing equipment modules of the IPS or MPCT (IPS/MPCT).

~~NOTE 13:~~NOTE 11: Additional guidance for establishing THT_i standards is provided in Related Information 3.

7 Fundamental Quantities of Equipment System Productivity Measurement

7.1 The metrics in this Document require the following fundamental quantities as inputs:

- Total time
- Uptime
- Production time
- Theoretical production time for actual units
- Theoretical production time for effective units

7.1.1 Figure 2 indicates how these SEMI E79 fundamental quantities are related to time in SEMI E10 equipment states and how they delineate various sources of efficiency loss. The domain for improvement of all losses, except operational loss, is shared between the equipment system supplier and equipment system user. Improvement of operational loss is the exclusive domain of the equipment system user.

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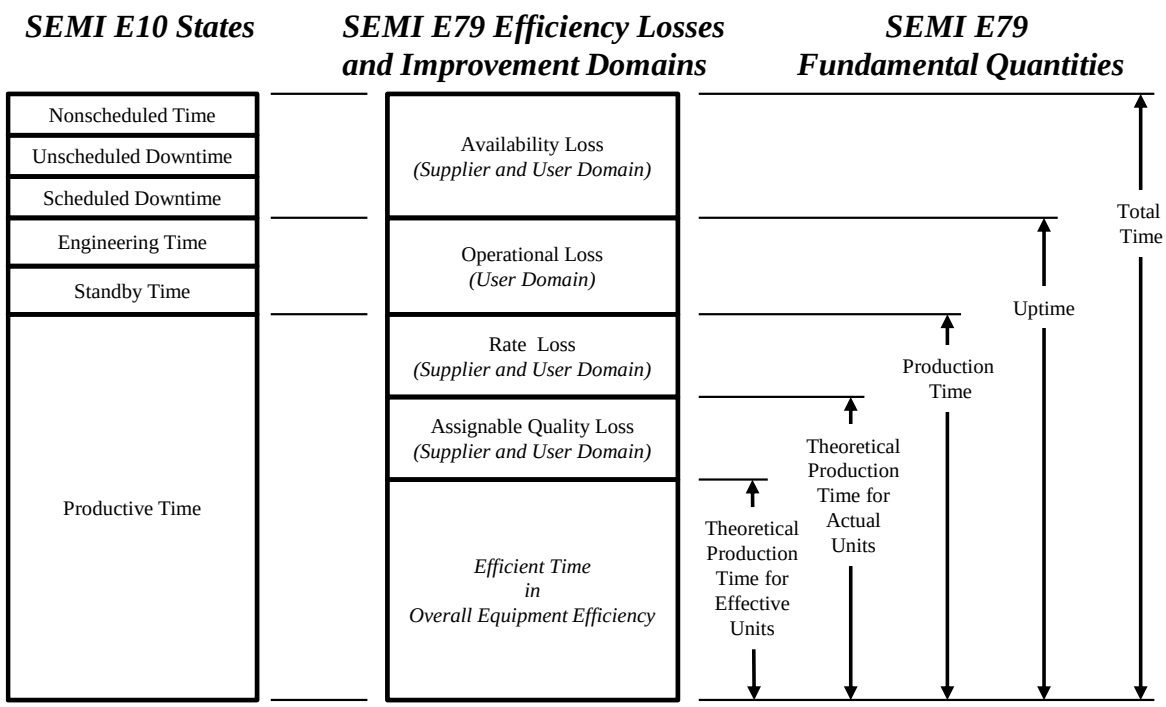

Figure 2
Stack Chart of Productivity Losses and Improvement Domains

7.1.2 Total time, uptime, and production time are based on SEMI E10 equipment state tracking. Theoretical production time for actual units and theoretical production time for effective units are based on unit output of each recipe and processing time standards per unit for each recipe.

7.1.3 For noncluster tools, SPCTs, or individual processing equipment modules, these fundamental quantities may be determined in a straightforward manner considering the equipment system as a whole.

7.1.4 For IPSs/MPCTs, each fundamental quantity is calculated as the aggregate sum of that fundamental quantity over all processing equipment modules in the equipment system. For example, MPCT production time is the sum of production time for all of the processing equipment modules in the MPCT.

7.1.5 Unlike certain MPCT metrics in SEMI E10, all MPCT metrics in this Document may be calculated directly and do not depend on calculating IPS metrics first.

~~NOTE 14:~~NOTE 12: Because for any MPCT, multiple IPSs may operate simultaneously, it may not be practical or insightful to measure IPS efficiency over just any observation period. Better measurements may result when observation periods are selected such that only one IPS is operating. Selecting an observation period when multiple IPSs are operating is likely to result in a distorted measurement of each IPS.

7.1.6 It is recognized that interactions between modules within IPSs/MPCTs may impose varying amounts of standby time on the individual processing equipment modules. The approach to IPS/MPCT measurement in this Document treats these interactions as standby losses for the IPS/MPCT. No allowances are made for these interactions in theoretical production time for effective units, in theoretical production time for actual units, or in production time.

7.2 *Total Time*

7.2.1 Total time is defined in SEMI E10 as all time observed for an equipment system at the rate of 24 hours/day, 7 days/week.

7.2.2 For a noncluster tool, an SPCT, or an individual processing equipment module, total time is the duration of the observation period.

$$\textit{total time} = \textit{duration of observation period} \quad (3)$$

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7.2.3 For an IPS/MPCT, total time is the aggregate total time for all the processing equipment modules in the IPS/MPCT.

$$\textit{IPS/MPCT total time} = \Sigma_j \textit{ total time for processing equipment module } j \quad (4)$$

$$= (\textit{duration of observation period}) \times (\textit{number of processing equipment modules in the IPS/MPCT}) \quad (5)$$

7.3 *Uptime*

7.3.1 Uptime is defined in SEMI E10 as the time when the equipment system is in a condition to perform its intended function. It includes productive, standby, and engineering times, and does not include any portion of downtime or nonscheduled time.

7.3.2 For a noncluster tool, an SPCT, or an individual processing equipment module, uptime is the sum of productive time, standby time, and engineering time during the observation period.

$$\textit{uptime} = \textit{productive time} + \textit{standby time} + \textit{engineering time} \quad (6)$$

7.3.3 For an IPS/MPCT, uptime is the aggregate uptime for all the processing equipment modules in the IPS/MPCT.

$$\textit{IPS/MPCT uptime} = \Sigma_{\text{all } j} \textit{ uptime for processing equipment module } j \quad (7)$$

$$\begin{aligned} = \Sigma_{\text{all } j} (&\textit{productive time for processing equipment module } j \\ &+ \textit{standby time for processing equipment module } j \\ &+ \textit{engineering time for processing equipment module } j) \end{aligned} \quad (8)$$

7.4 *Production Time*

7.4.1 Production time in this Document is very closely related to SEMI E10 productive time, which is the time when an equipment system is performing its intended function. Production time always includes time for loading and unloading units for all equipment systems.

7.4.1.1 For a noncluster tool, an SPCT, or an individual processing equipment module, production time is the same as SEMI E10 productive time.

$$\textit{production time} = \textit{productive time} \quad (9)$$

7.4.1.2 For an IPS/MPCT, production time is the aggregate sum of SEMI E10 productive time, including time for loading and unloading units, for all processing equipment modules in the IPS/MPCT. This quantity is not the same as the temporal-mapped productive time used in SEMI E10 metrics.

$$\textit{IPS/MPCT production time} = \Sigma_{\text{all } j} (\textit{production time for processing equipment module } j) \quad (10)$$

~~NOTE 15:~~NOTE 13: For an IPS/MPCT, time for a transport operation that repositions a unit from one processing equipment module to another is intentionally credited to both processing equipment modules, as this shared operation consumes time from both equipment modules.

7.5 *Theoretical Production Time for Actual Units*

7.5.1 Theoretical production time for actual units is defined as the subset of production time that is earned by actual units during the observation period at strictly theoretically efficient rates assuming the specified recipes, the specified equipment system design, and continuous operation. This quantity requires a set of time standards for theoretical production time per unit of recipe i, THT_i, as presented in § 6.2.

7.5.2 For a noncluster tool, an SPCT, or an individual processing equipment module, the set of THT_i standards is based on the equipment system as a whole. Theoretical production time for actual units is then calculated for the equipment system as a whole.

$$\textit{theoretical production time for actual units} = \sum_i (\textit{actual unit output of recipe } i \times THT_i) \quad (11)$$

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7.5.3 For an IPS/MPCT, the set of THT_i standards is based on the individual processing equipment modules. Theoretical production time for actual units is calculated for each individual processing equipment module, then summed over all the processing equipment modules in the IPS/MPCT.

$$\textit{IPS/MPCT theoretical production time for actual units}$$

$$= \Sigma_{\text{all j}} (\textit{theoretical production time for actual units for processing equipment module j}) \quad (12)$$

$$= \Sigma_{\text{all j}} \Sigma_{\text{all i}} (\textit{actual unit output of recipe i on processing equipment module j} \times THT_i) \quad (13)$$

7.6 *Theoretical Production Time for Effective Units*

7.6.1 Theoretical production time for effective units is defined as the subset of theoretical production time for actual units that is earned by effective units during the observation period at strictly theoretically efficient rates assuming the specified recipes, the specified equipment system design, and continuous operation. This quantity is calculated using the same set of processing time standards as used in theoretical production time for actual units (see § 7.5), but uses a subset of actual unit output called effective unit output.

7.6.2 Effective unit output is actual unit output less equipment-assignable rework units and equipment-assignable scrap units of the subject equipment system. For any equipment system and observation period, the count of effective units shall~~must~~ always be less than or equal to actual units.

$$\begin{aligned} \textit{effective unit output} &= \textit{actual unit output} \\ &\quad - \textit{equipment-assignable scrap units} \\ &\quad - \textit{equipment-assignable rework units} \end{aligned} \quad (14)$$

~~NOTE 16:~~NOTE 14: Effective unit output still includes unit quality losses that are not assignable to the subject equipment system (e.g., losses due to misprocessing on other equipment systems). Appendix 1 presents a metric called Total Effective Units OEE (TEUOEE) that considers nonequipment-assignable sources of unit quality loss in addition to equipment-assignable sources.

7.6.3 For a noncluster tool, an SPCT, or an individual processing equipment module, the set of THT_i standards is based on the equipment system as a whole. Theoretical production time for effective units is then calculated for the equipment system as a whole.

$$\textit{theoretical production time for effective units} = \Sigma_{\text{all i}} (\textit{effective unit output of recipe i} \times THT_i) \quad (15)$$

7.6.4 For an IPS/MPCT, the set of THT_i standards is based on the individual processing equipment modules. Theoretical production time for effective units is calculated for each processing equipment module, then summed over all processing equipment modules in the IPS/MPCT.

$$\textit{IPS/MPCT theoretical production time for effective units}$$

$$= \Sigma_{\text{all j}} (\textit{theoretical production time for effective units for processing equipment module j}) \quad (16)$$

$$= \Sigma_{\text{all j}} \Sigma_{\text{all i}} (\textit{effective unit output of recipe i on processing equipment module j} \times THT_i) \quad (17)$$

8 Productivity Metrics

~~NOTE 17:~~NOTE 15: Example calculations for each of these equations are provided in Related Information 1.

8.1 *Efficiency Metrics*

8.1.1 *Overall Equipment Efficiency (OEE)* — The fraction of total time that an equipment system is processing effective units -assuming theoretically efficient time standards.

$$\textit{OEE} = (\textit{theoretical production time for effective units}) / (\textit{total time}) \quad (18)$$

8.1.2 OEE may be calculated directly, as above, or as the product of the four following component efficiency metrics: availability efficiency, operational efficiency, rate efficiency, and quality efficiency. Each of these metrics can be used to measure the relative value of distinct equipment system efficiency losses.

$$\textit{OEE} = (\textit{availability efficiency}) \times (\textit{operational efficiency}) \times (\textit{rate efficiency}) \times (\textit{quality efficiency}) \quad (19)$$

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8.1.3 *Availability Efficiency* — The fraction of total time that an equipment system is in a condition to perform its intended function when required.

$$\textit{availability efficiency} = (\textit{uptime}) / (\textit{total time}) \quad (20)$$

~~NOTE 18:~~NOTE 16: For a noncluster tool, an SPCT, or an individual processing equipment module, availability efficiency is the same as the SEMI E10 metric total uptime, but expressed as a decimal fraction. However, for an IPS/MPCT, availability efficiency is based on aggregated sums in the numerator and denominator, and the SEMI E10 metric total uptime is based on temporal-mapped SEMI E10 equipment states.

8.1.4 *Operational Efficiency* — The fraction of uptime that an equipment system is performing its intended function.

$$\textit{operational efficiency} = (\textit{production time}) / (\textit{uptime}) \quad (21)$$

~~NOTE 19:~~NOTE 17: For a noncluster tool, an SPCT, or an individual processing equipment module, operational efficiency is the same as the SEMI E10 metric operational utilization, but expressed as a decimal fraction. However, for an IPS/MPCT, operational efficiency is based on aggregated sums in the numerator and denominator, and the SEMI E10 metric operational utilization is based on temporal-mapped SEMI E10 equipment states.

8.1.5 *Rate Efficiency* — The fraction of production time that an equipment system is processing actual units at theoretically efficient rates.

$$\textit{rate efficiency} = (\textit{theoretical production time for actual units}) / (\textit{production time}) \quad (22)$$

8.1.6 *Quality Efficiency* — The fraction of theoretical production time for actual units that an equipment system is processing effective units at theoretically efficient rates.

$$\textit{quality efficiency} = (\textit{theoretical production time for effective units}) / (\textit{theoretical production time for actual units}) \quad (23)$$

8.1.7 *Performance Efficiency* — The fraction of uptime that an equipment system is processing actual units at theoretically efficient rates. This metric is the same as the product of operational efficiency and rate efficiency.

$$\textit{performance efficiency} = (\textit{theoretical production time for actual units}) / (\textit{uptime}) \quad (24)$$

$$= (\textit{operational efficiency}) \times (\textit{rate efficiency}) \quad (25)$$

~~NOTE 20:~~NOTE 18: Some variations of OEE in TPM literature have performance efficiency as a single component metric, whereas SEMI E79 has separate component metrics for operational efficiency and rate efficiency. Also, performance efficiency may still be calculated in cases when accurate SEMI E10 productive time is unavailable.

8.2 *Loss Metrics*

8.2.1 *Availability Loss* — The fraction of total time the equipment system is not available to operate on actual units.

$$\textit{availability loss} = (\textit{total time} - \textit{uptime}) / (\textit{total time}) \quad (26)$$

8.2.2 Operational Loss — The fraction of total time the equipment system is available but is not operating on actual units.

$$\textit{operational loss} = (\textit{uptime} - \textit{production time}) / (\textit{total time}) \quad (27)$$

8.2.3 Rate Loss — The fraction of total time the equipment system is operating on actual units at less than theoretical rates.

$$\textit{rate loss} = (\textit{production time} - \textit{theoretical production time for actual units}) / (\textit{total time}) \quad (28)$$

8.2.4 Assignable Quality Loss — The fraction of total time the equipment system is processing actual units (assuming theoretically efficient time standards) that are not effective units.

$$\textit{assignable quality loss} = (\textit{theoretical production time for actual units} - \textit{theoretical production time for effective units}) / (\textit{total time}) \quad (29)$$

8.2.5 The four metrics in this section are components of equipment productivity loss with each expressed as a fraction of total time. The sum of these four component metrics plus OEE is 100% of total time.

$$\begin{aligned} &\textit{availability loss} + \textit{operational loss} \\ &+ \textit{rate loss} + \textit{assignable quality loss} \\ &+ \textit{overall equipment efficiency (OEE)} \\ &= \textit{100\% of total time} \end{aligned} \tag{30}$$

8.3 Additional supplemental efficiency metrics that shall~~will~~ enable users to assess more specific aspects of equipment system productivity are as follows:

- optimized-recipe OEE (OROEE)
- value-added in-process OEE (VAOEE)
- reference OEE (ROEE)
- total effective units OEE (TEUOEE)
- production equipment efficiency (PEE)
- demand equipment efficiency (DEE)
- intrinsic equipment efficiency (IEE)
- IPS/MPCT parallel productivity efficiency (IPS/MPCT PPE)

8.3.1 Definitions and equations for these additional metrics are provided in Appendix 1.

9 Related Documents

9.1 Nakajima, S., *Introduction to TPM: Total Productive Maintenance*, Productivity Press, Cambridge, MA. 1988.

9.2 *TPM in Process Industries*, Edited by Tokutaroo Suzuki, Productivity Press, 1994. (Originally published as *Sochi Kogyo no TPM*, Japan Institute of Plant Maintenance, 1992).

9.3 *TPM Encyclopedia*, Edited by Japan Institute of Plant Maintenance, 1996.

9.4 "TPM Focused Improvement." Loss Assessment Training Module, International SEMATECH, Available to International SEMATECH and SEMI-SEMATECH member companies, 1999.

9.5 "TPM New Implementation Program in Fabrication and Assembly Industries." Edited by Kunio Shirose, Japan Institute of Plant Maintenance, 1996.

9.6 Konopka, John M., "Improvement Output in Semiconductor Manufacturing Environments." doctoral dissertation, Arizona State University, Tempe, Arizona, 1996.

9.7 Konopka, John., Trybula, Walt., "Overall Equipment Effectiveness (OEE) and Cost Measurement." *Proceedings of the 1996 IEEE/CPMT 19th International Electronics Manufacturing Technology Symposium*, Austin, TX, USA, 1996.

9.8 Leachman, Robert C., "Closed-Loop Measurement of Equipment Efficiency and Equipment Capacity." IEE Trans. Sem. Manuf. 10(1), 84097, 1997.

9.9 Busing, David P., "Automated Procedures for Characterizing Specific Productivity Losses with Applications in the Semiconductor Manufacturing Industry." doctoral dissertation, University of California, Berkeley, 1998.

9.10 CSM 21 — Closed-Loop Measurement of Equipment Efficiency and Equipment Capacity. Engineering Systems Research Center, University of California, Berkeley, 1997.

9.11 CSM 42 — Productivity Metrics for Flexible Sequence Cluster Tools. Engineering Systems Research Center, University of California, Berkeley, 1998.

9.12 CSM 44 — Performance Models of Theoretical and Average Process Times for Selected Semiconductor Fabrication Equipment. Engineering Systems Research Center, University of California, Berkeley, 1999.

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APPENDIX 1
SUPPLEMENTAL PRODUCTIVITY METRICS FOR FOCUSED PRODUCTIVITY STUDIES

NOTICE: The material in this Appendix is an official part of SEMI E79 and was approved by full letter ballot procedures on May 12, 2014.

A1-1 Supplemental Productivity Metrics with Total Time as the Denominator

A1-1.1 *Background*

A1-1.1.1 OEE is based on 'as-is' assumptions with respect to recipes, equipment type, and equipment design. In this way, OEE measures the performance of the organizations of the manufacturer and the equipment system supplier as they attempt to drive equipment system performance to a potential defined by given recipes and the given equipment system type and design.

A1-1.1.2 This section presents four variations on the OEE calculation that additionally measure the performance of engineering and design organizations as they attempt to improve recipes, equipment selection, and equipment design. These four variants are each based on more discriminating definitions of the theoretical production time per unit (THT), as shown in Figures A1-1 and A2-1. Total time is the denominator for each metric.

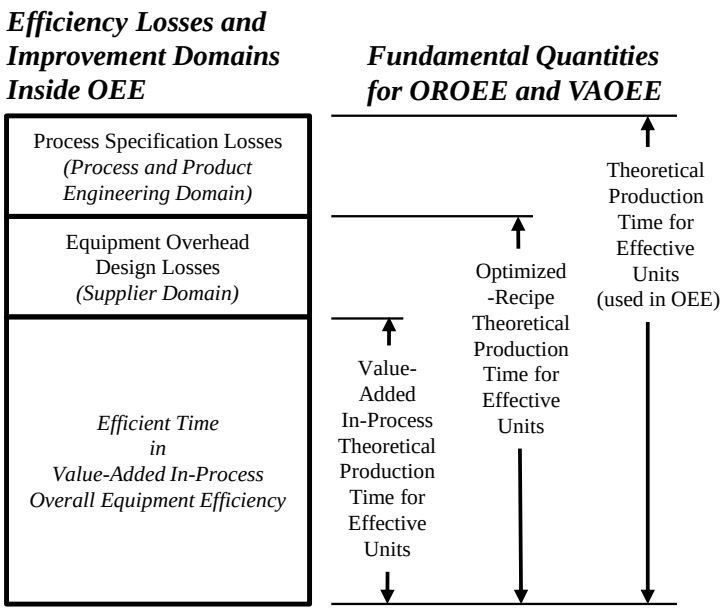

Figure A1-1
Stack Chart of Efficiency Losses for Optimized-Recipe OEE and Value-Added In-Process OEE

A1-1.2 *Optimized-Recipe OEE (OROEE)* — A metric that provides a measure of equipment system productivity assuming recipes are optimized for minimum theoretical production time (see Figure A1-1). The optimized-recipe theoretical production time per unit for a given recipe i ($ORTHT_i$) is the time required to process the recipe assuming the recipe specification is optimized for minimum theoretical production time. ORTHT shall be defined to be less than or equal to the THT used in calculating standard OEE. ORTHT may include minimum durations for the objective processing steps (e.g., implant time for ion implanters) and minimum allowances for any additional supporting process steps (e.g., heating, cooling, gas stabilization) only if those steps are deemed absolutely necessary. Time to run test wafers, sample wafers, send-aheads, clean cycles, seasoning cycles, and allowances for noncontinuous cascading of lots through equipment system are specifically excluded.

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optimized-recipe OEE (OROEE)

= (*optimized-recipe theoretical production time for effective units*) / (*total time*)

$$= [\sum_i (\textit{effective units of recipe } i \times ORTHT_i)] / (\textit{total time}) \quad \text{(A1-1)}$$

where $ORTHT_i$ = optimized-recipe theoretical production time per unit of recipe i.

~~NOTE 21:~~NOTE 19: In previous versions of SEMI E79, optimized-recipe OEE and optimized-recipe THT were called engineering OEE and engineering THT, respectively. The new names more accurately reflect the objective of the metric.

A1-1.3 *Value-Added In-Process OEE (VAOEE)* — A metric that provides a measure of equipment system productivity assuming only the value-added portion of processing cycles for effective units is efficient (see Figure A1-1). The goal of this metric is to drive long-term continuous improvement of equipment system designs by reducing or eliminating nonvalue-added time. The value-added in-process theoretical production time per unit (VTHT) of a given recipe is the time that credits only the objective processing steps that add value to products. VTHT shall be defined to be less than or equal to the ORTHT used in calculating OROEE.

value-added in-process OEE (VAOEE)

= (*value-added in-process theoretical production time for effective units*) / (*total time*)

$$= [\sum_i (\textit{effective units of recipe } i \times VTHT_i)] / (\textit{total time}) \quad \text{(A1-2)}$$

where $VTHT_i$ = value-added in-process theoretical production time per unit of recipe i.

A1-1.3.1 VTHT credits time for only the objective processing steps. The objective processing steps for recipes performed by major types of wafer fabrication equipment systems are indicated in Table A1-1.

A1-1.3.2 VTHT specifically excludes the following items (partial list):

- All wafer handling time
- All load-lock time
- Pre-etch and predeposition time
- Thermal stabilization time
- Gas stabilization time
- Wafer heating and cooling time
- Time for clean cycles
- Seasoning time

Table A1-1 Example Objective Processing Steps for Recipes Performed by Major Types of Wafer Fabrication Equipment Systems

Equipment System Type	*$VTHT_i$ Includes*	*$VTHT_i$ Excludes*
Resist Processing	Coat, Develop, Bake, Cool Time at Process Temperature	Temperature Ramp Up/Down
Photolithography Exposure	Exposure Time	Prealignment, Align, Stepping Time
Etch – Oxide, Metal, Polysilicon, …	Etching Time, Flood Expose Time	Chamber Clean Time
Asher, Dry	Ashing Time	
Clean Wet Processing Station	Acid, Rinse, and Dry Time	
Furnace Atmospheric Process, Furnace Low Pressure Chemical Vapor Deposition (LPCVD) Process, and Rapid Thermal Process (RTP)	Main Oxidation, Anneal Time at Defined Fixed Process Temperatures Resulting in Thermal (Film) Treatment	Ramp Up/Down, Boat Push/Pull

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Equipment System Type	*$VTHT_i$ Includes*	*$VTHT_i$ Excludes*
Implanter – High Current, Medium Current, High Energy, …	Implant Time	Beam Setup Time
Metal Deposition – Physical Vapor Deposition (PVD), Chemical Vapor Deposition (CVD)	Metal Deposition Time	Chambers Clean Time
Dielectric Deposition – CVD	Dielectric Deposition Time	Chambers Clean Time
Chemical Mechanical Polish (CMP) Planarization	Polishing Time	Pad Dressing Dedicated Time
Measure – Critical Dimension Scanning Electron Microscope (CD-SEM)	Measurement Time	Pattern Recognition Time
Measure – Overlay	Measurement Time	Pattern Recognition Time
Defect Detection Measure – Patterned Wafers	Scanning Measurement Time	Pattern Recognition Time
Defect Detection Measure – Unpatterned Wafers	Scanning Measurement Time	
Measure – Film Thickness	Measurement Time	Pattern Recognition Time

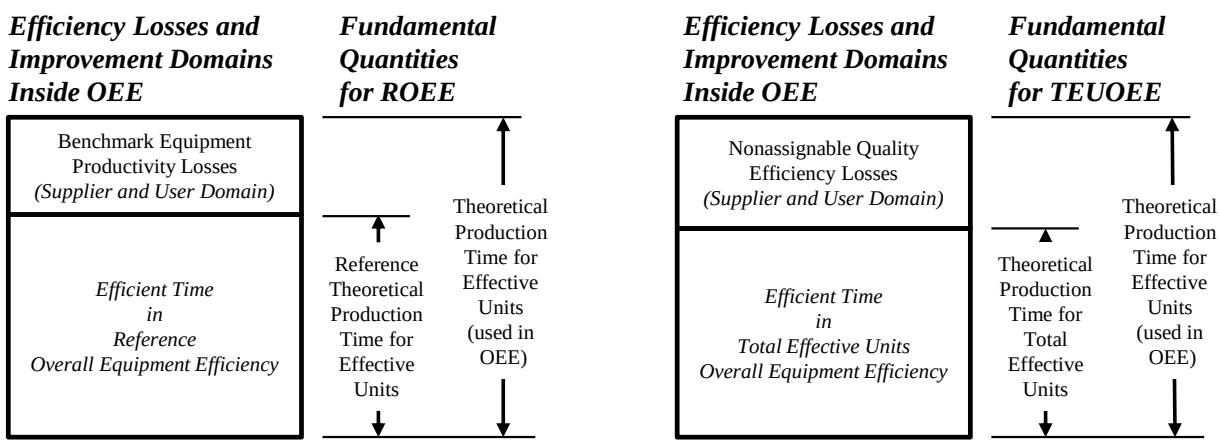

Figure A1-2
Stack Charts of Efficiency Losses for Reference OEE and Total Effective Units OEE

A1-1.4 *Reference OEE (ROEE)* — A metric that provides a measure of equipment system productivity relative to a benchmark theoretical production time (see Figure A1-2). The reference theoretical production time per unit for a given recipe i ($RTHT_i$) is the theoretically efficient time for a benchmark equipment system (i.e., the fastest equipment system model of similar type) to run a recipe with comparable product and process specifications. $RTHT_i$ shall be defined to be less than or equal to each THT_i used in calculating standard OEE. The ROEE may be compared against the standard OEE to assess the productivity loss arising from the application of an inferior equipment system.

$$\begin{aligned} &\textit{reference OEE (ROEE)} \\ &= (\textit{reference theoretical production time for effective units}) \,/\, (\textit{total time}) \\ &= [\textstyle\sum_i (\textit{effective units of recipe } i \times RTHT_i)] \,/\, (\textit{total time}) \end{aligned} \tag{A1-3}$$

where *RTHTi* = reference theoretical production time per unit of recipe i.

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A1-1.4.1 ROEE utilizes a definition of THT_i that is incompatible with the definition utilized in optimized-recipe OEE (OROEE) and value-added in-process OEE (VAOEE). Productivity losses indicated by ROEE and by OROEE and VAOEE may overlap.

A1-1.5 *Total Effective Units OEE (TEUOEE)* — A metric that provides a measure of equipment system productivity assuming total effective units (see Figure A1-2). This metric reflects the effect on a subject equipment system of quality losses external to the subject equipment system.

A1-1.5.1 TEUOEE uses the same set of theoretical times per recipe, THT_i, as OEE.

A1-1.5.2 Total effective units used in this metric are a subset of effective units used in OEE that additionally discounts nonequipment-assignable scrap units and nonequipment-assignable rework units. The count of total effective units is always less than or equal to the count of effective units.

$$\begin{aligned} &\textit{total effective units OEE (TEUOEE)} \\ &= (\textit{theoretical production time for total effective units}) \,/\, (\textit{total time}) \\ &= [\textstyle\sum_i (\textit{total effective units of recipe } i \times THT_i)] \,/\, (\textit{total time}) \end{aligned} \tag{A1-4}$$

where *THTi* = theoretical production time per unit of recipe i.

A1-1.5.3 For purposes of this metric, nonequipment-assignable scrap units shall~~must~~ be actual, confirmed whole scrap units. Estimates or projections of scrap units are not permitted. Partial credit for units taking into account die yields, for example, is not permitted. Generally, these are units that are determined to be scrap subsequent to processing by the subject equipment system but through no assignable fault of the subject equipment system.

A1-1.5.3.1 Nonequipment-assignable scrap units include units that are rendered scrap by prior (i.e., upstream) processing on other equipment systems, but were not determined to be scrap until after processing by the subject equipment system.

A1-1.5.3.2 Nonequipment-assignable scrap units include units that are rendered scrap by subsequent (i.e., downstream) processing on other equipment systems.

A1-1.5.3.3 Nonequipment-assignable scrap units may result from any reasons known or unknown, as long as the subject equipment system is not assigned responsibility for the scrap.

A1-1.5.4 Nonequipment-assignable rework units are rework units processed by the subject equipment system where the subject equipment system is not assigned responsibility for the rework.

A1-1.5.5 At the time total effective units is calculated, some of the effective units processed by the subject equipment system may still be in process and may yet be rendered scrap or determined to be scrap. Some of the effective units may yet incur misprocessing that requires them to revisit the subject equipment system as nonequipment-assignable rework. Hence, the count of total effective units for a fixed observation period may decline over time until all effective units for the equipment system and observation period exit processing as either finished good units or scrap. In this way, this metric reflects only the nonequipment-assignable scrap that is confirmed at the time of calculation.

A1-2 Additional Productivity Metrics with Denominators Other Than Total Time

A1-2.1 *Background*

A1-2.1.1 This section presents four productivity metrics for assessing efficiency of the equipment system relative to a time frame less than total time.

A1-2.1.2 Production equipment efficiency (PEE) and demand equipment efficiency (DEE) exclude portions of no product time from productivity losses, as depicted in Figure A1-3. Note that, while the idle time due to no product is excluded from the operational losses in these particular measures of equipment system efficiency, the additional productivity losses due to suboptimal load or batch sizes may be present as rate efficiency losses. Such losses, which result from fluctuations in product flow or equipment system loading policies, are considered in any equipment efficiency calculation that uses THT.

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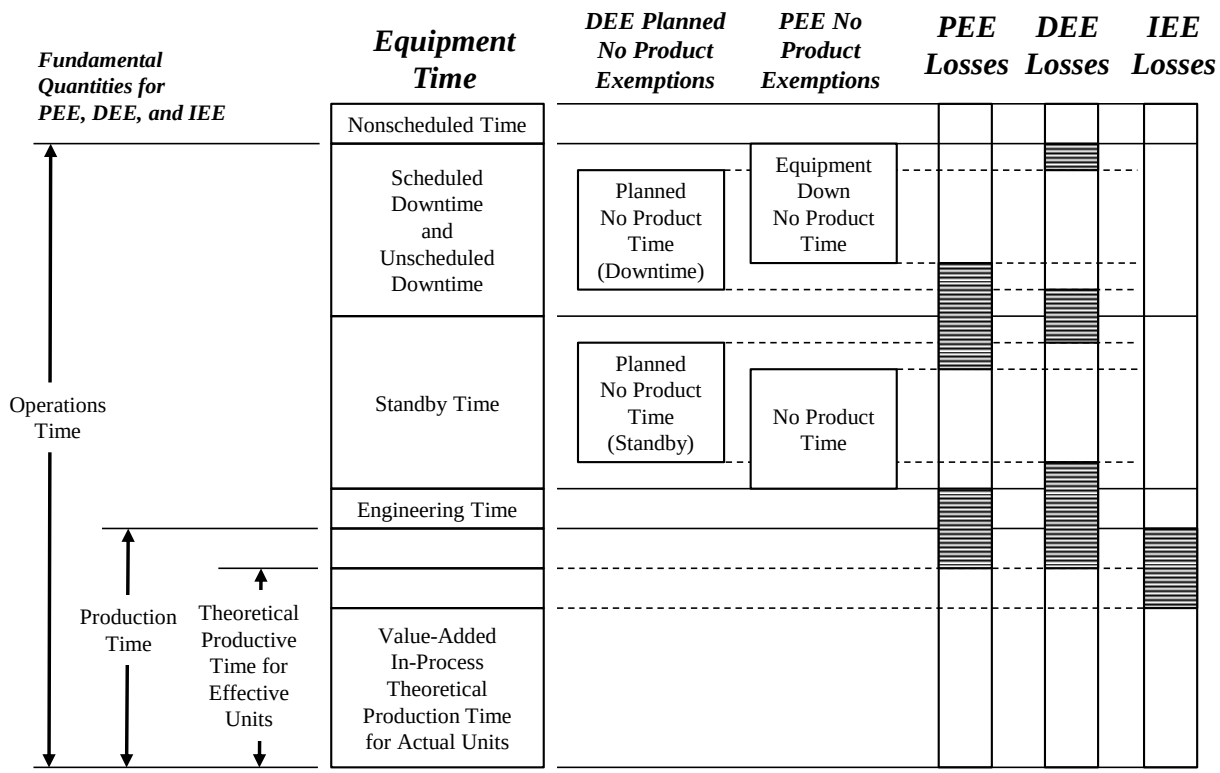

Figure A1-3
Productivity Losses Included in PEE, DEE, and IEE Metrics (Shaded Regions)

A1-2.2 *Production Equipment Efficiency (PEE)* — A measure of equipment system productivity during the time that products are available to process at the equipment system (see Figure A1-3). One application of PEE is to measure the productivity of a nonconstraint equipment system, which is expected to have periods of idle time due to lack of available work.

$$\textit{production equipment efficiency (PEE)} = (\textit{theoretical production time for effective units}) / [(\textit{operations time}) - (\textit{no product time}) - (\textit{equipment down no product time})] \quad \text{(A1-5)}$$

$$= \textit{overall equipment efficiency} \times \textit{total time} / [(\textit{operations time}) - (\textit{no product time}) - (\textit{equipment down no product time})] \quad \text{(A1-6)}$$

A1-2.2.1 PEE treats the following as productivity losses:

- Unscheduled downtime when product is available
- Scheduled downtime when product is available
- Standby when product is available
- Engineering time, regardless of product availability
- Rate efficiency loss and quality efficiency loss (production time minus theoretical production time for effective units)

A1-2.3 *Demand Equipment Efficiency (DEE)* — A measure of equipment system productivity during the time that products are planned to be available to process at the equipment system (see Figure A1-3). A factory model or production schedule that defines the expected or planned idle time of the equipment system is required to calculate

DEE. DEE measures the productivity of the equipment system relative to the requirements of the factory model or production schedule.

$$\textit{demand equipment efficiency (DEE)} = (\textit{theoretical production time for effective units}) / [(\textit{operations time}) - (\textit{planned no product time})] \quad \text{(A1-7)}$$

$$= \textit{overall equipment efficiency} \times \textit{total time} / [(\textit{operations time}) - (\textit{planned no product time})] \quad \text{(A1-8)}$$

A1-2.3.1 DEE treats the following as productivity losses:

- Unscheduled downtime when product is planned to be available
- Scheduled downtime when product is planned to be available
- Standby time when product is planned to be available
- Engineering time when product is planned to be available
- Rate efficiency loss and quality efficiency loss (production time minus theoretical production time for effective units)

A1-2.4 *Intrinsic Equipment Efficiency (IEE)* — A measure of equipment system productivity that measures the combined productivity losses due to rate efficiency, recipe design, and equipment system design (see Figure A1-3).

$$\textit{intrinsic equipment efficiency (IEE)} = (\textit{value-added in-process theoretical production time for actual units}) / (\textit{production time})$$

$$= [\textstyle\sum_i (\textit{actual units of recipe } i \times VTHT_i)] / (\textit{production time}) \quad \text{(A1-9)}$$

where $VTHT_i$ = value-added in-process theoretical production time per unit for recipe i.

A1-2.4.1 IEE productivity losses include rate efficiency loss, suboptimal recipe specifications losses for actual units, and nonvalue-added losses for actual units. These are encapsulated in the difference between production time and value-added in-process theoretical production time for actual units.

A1-2.5 *IPS/MPCT parallel productivity efficiency (IPS/MPCT PPE)* — A measure of equipment system efficiency during productive time where idling in parallel processing equipment modules is discounted as an efficiency loss. The numerator for this metric is the aggregate productive time for all processing modules, where a time interval is 100% productive if all processing modules are simultaneously productive. The denominator for this metric is based on the temporal-mapped productive time used in SEMI E10 where a time interval is 100% productive if one or more process modules is productive; the denominator is normalized for comparison with the numerator by multiplying the SEMI E10 temporal-mapped productive time by the number of processing modules in the equipment system. This metric is only meaningful for IPS/MPCT equipment systems that have processing equipment modules operating in parallel.

$$\textit{IPS/MPCT parallel productivity efficiency (IPS/MPCT PPE)} = \frac{\textit{SEMI E79 aggregate process module production time}}{(\textit{SEMI E10 temporal-mapped productive time} \times \textit{number of processing modules in equipment system})} \quad \text{(A1-10)}$$

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RELATED INFORMATION 1
METRICS EXAMPLE CALCULATIONS

NOTICE: This Related Information is not an official part of SEMI E79 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 Example Calculations for a Noncluster Tool, a Single-Path Cluster Tool, or an Individual Processing Equipment Module

R1-1.1 *Example Data* — The calculations in this section are based on the following example data. The example data is for a seven-day observation period.

nonscheduled time	0.00 hours
unscheduled downtime	4.00 hours
scheduled downtime	8.00 hours
engineering time	3.00 hours
standby time	6.00 hours
production time	147.00 hours
total time	168.00 hours

Table R1-1 Example Data for *THT*$_i$, Actual Units, and Effective Units

Recipe	*Theoretical Production Time Per Unit (THTi) (hours per unit)*	*Actual Units*	*Effective Units*
A	0.03333	1420	1400
B	0.04000	600	600
C	0.05000	800	800
D	0.06667	500	480

R1-1.2 *Fundamental Quantities*

R1-1.2.1 *Equipment Uptime*

= (*production time*) + (*standby time*) + (*engineering time*)
= (147.00 hours) + (6.00 hours) + (3.00 hours)
= 156.00 hours

R1-1.2.2 *Production Time (Given)*

R1-1.2.3 *Theoretical Production Time for Actual Units*

$= \sum_i$ (*actual units of recipe i* × THT_i)
= [(1420 units × 0.03333 hr/unit)
+ (600 units × 0.04000 hr/unit)
+ (800 units × 0.05000 hr/unit)
+ (500 units × 0.06667 hr/unit)]
= 144.66 hours

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R1-1.2.4 *Theoretical Production Time for Effective Units*

= $\sum_i$ (*effective units of recipe i* × THT_i)
= [(1400 units × 0.03333 hr/unit)
+ (600 units × 0.04000 hr/unit)
+ (800 units × 0.05000 hr/unit)
+ (480 units × 0.06667 hr/unit)]
= 142.66 hours

R1-1.3 *Productivity Metrics*

R1-1.3.1 *Efficiency Metrics*

R1-1.3.1.1 *Availability Efficiency*

= (*equipment uptime*) / (*total time*)
= (156.00 hours) / (168.00 hours)
= 0.9286

R1-1.3.1.2 *Operational Efficiency*

= (*production time*) / (*equipment uptime*)
= (147.00 hours) / (156.00 hours)
= 0.9423

R1-1.3.1.3 *Rate Efficiency*

= (*theoretical production time for actual units*) / (*production time*)
= (144.66 hours) / (147.00 hours)
= 0.9841

R1-1.3.1.4 *Performance Efficiency*

= (*operational efficiency*) × (*rate efficiency*)
= (0.9423) × (0.9840)
= 0.9272

R1-1.3.1.5 *Quality Efficiency*

= (*theoretical production time for effective units*) / (*theoretical production time for actual units*)
= (142.66 hours) / (144.66 hours)
= 0.9862

R1-1.3.1.6 *Overall Equipment Efficiency (OEE)*

= (*theoretical production time for effective units*) / (*total time*)
= (142.66 hours) / (168.00 hours)
= 0.8492

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R1-1.3.2 *Loss Metrics*

R1-1.3.2.1 *Availability Loss*

= (*total time* − *uptime*) / (*total time*)
= (168 hours − 156.00 hours) / (168.00 hours)
= 0.0714

R1-1.3.2.2 *Operational Loss*

= (*uptime* − *production time*) / (*total time*)
= (156.00 hours − 147.00 hours) / (168.00 hours)
= 0.0536

R1-1.3.2.3 *Rate Loss*

= (*production time* − *theoretical production time for actual units*) / (*total time*)
= (147.00 hours − 144.66 hours) / (168.00 hours)
= 0.0139

R1-1.3.2.4 *Assignable Quality Loss*

= (*theoretical production time for actual units* − *theoretical production time for effective units*) / (*total time*)
= (144.66 hours − 142.66 hours) / (168.00 hours)
= 0.0119

R1-2 Example Calculations for a Multi-p~~P~~ath Cluster Tool

R1-2.1 *Example Data* — The calculations in this section are based on the following example data. The example data is over a seven-day period for an MPCT encompassing three processing equipment modules (i.e., Process Modules A, B, and C). Units are processed according to four process sequences, S1–S4, where S1 and S3 are processed by one IPS (requiring Process Modules A and B) and S2 and S4 are processed by another IPS (requiring Process Modules B and C). Calculations in this example are shown for all three processing equipment modules and the MPCT.

	Process Module A	*Process Module B*	*Process Module C*
nonscheduled time	0.00 hours	0.00 hours	0.00 hours
unscheduled downtime	5.00 hours	5.00 hours	0.00 hours
scheduled downtime	0.00 hours	5.00 hours	0.00 hours
engineering time	3.00 hours	5.00 hours	0.00 hours
standby time	10.00 hours	5.00 hours	88.00 hours
production time	150.00 hours	148.00 hours	80.00 hours
total time	168.00 hours	168.00 hours	168.00 hours

Process Sequence for MPCT	*Process Module A Recipe*	*Process Module B Recipe*	*Process Module C Recipe*	*Actual Units of Sequence*	*Effective Units of Sequence*
S1	R1	R2		300	275
S2		R2	R4	100	100

S3	R2	R3		250	240
S4		R3	R4	400	400

Process Module Recipe	*Theoretical Production Time Per Unit (THT_i) (hours per unit)*
R1	0.3000
R2	0.2000
R3	0.1000
R4	0.1500

R1-2.2 *Fundamental Quantities*

R1-2.2.1 *Theoretical Production Time for Actual Units*

R1-2.2.1.1 For each process module, theoretical production time for actual units;

$= \sum_i$ (*actual units of recipe i* × THT_i)

Sequence	*Actual Units*	*Process Module A*	*Process Module B*	*Process Module C*
S1	300	300 units × 0.3000 hr/unit	300 units × 0.2000 hr/unit	
S2	100		100 units × 0.2000 hr/unit	100 units × 0.1500 hr/unit
S3	250	250 units × 0.2000 hr/unit	250 units × 0.1000 hr/unit	
S4	400		400 units × 0.1000 hr/unit	400 units × 0.1500 hr/unit
theoretical production time for actual units =		Σ = 140.00 hours	Σ = 145.00 hours	Σ = 75.00 hours

R1-2.2.1.2 For the MPCT, theoretical production time for actual units

$= \sum_j$ (*theoretical production time for actual units for process module j*)

= (140.00 hours) + (145.00 hours) + (75.00 hours)

= 360.00 hours

R1-2.2.2 *Theoretical Production Time for Effective Units*

R1-2.2.2.1 For each process module, theoretical production time for effective units

$= \sum_i$ (*effective units of recipe i* × THT_i)

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Sequence	*Effective Units*	*Process Module A*	*Process Module B*	*Process Module C*
S1	275	275 units × 0.3000 hr/unit	275 units × 0.2000 hr/unit	
S2	100		100 units × 0.2000 hr/unit	100 units × 0.1500 hr/unit
S3	240	240 units × 0.2000 hr/unit	240 units × 0.1000 hr/unit	
S4	400		400 units × 0.1000 hr/unit	400 units × 0.1500 hr/unit
theoretical production time for effective units =		Σ = 130.50 hours	Σ = 139.00 hours	Σ = 75.00 hours

R1-2.2.2.2 For the MPCT, *theoretical production time for effective units*

= $\sum_j$ (*theoretical production time for effective units for process module j*)
= (130.50 hours) + (139.00 hours) + (75.00 hours)
= 344.50 hours

R1-2.2.3 *Production Time*

R1-2.2.3.1 For each process module, *production time* is given.

R1-2.2.3.2 For the MPCT, *production time*

= $\sum_j$ (*production time for process module j*)
= (150.00 hours) + (148.00 hours) + (80.00 hours)
= 378.00 hours

R1-2.2.4 *Equipment Uptime*

R1-2.2.4.1 For each process module, *equipment uptime*

= (*production time*) + (*standby time*) + (*engineering time*)

	Process Module A	*Process Module B*	*Process Module C*
engineering time	3.00 hours	5.00 hours	0.00 hours
standby time	10.00 hours	5.00 hours	88.00 hours
production time	+150.00 hours	+148.00 hours	+80.00 hours
equipment uptime	163.00 hours	158.00 hours	168.00 hours

R1-2.2.4.2 For the MPCT, *equipment uptime*

= $\sum_j$ (*equipment uptime for process module j*)
= (163.00 hours) + (158.00 hours) + (168.00 hours)
= 489.00 hours

R1-2.2.5 *Total Time*

R1-2.2.6 For each process module, *total time* is given.

R1-2.2.7 For the MPCT, *total time*

= (*number of process modules*) × (*total time observed*)
= (3 process modules) × (168 hours)
= 504 hours

R1-2.3 *Productivity Metrics*

R1-2.3.1 *Efficiency Metrics*

R1-2.3.1.1 *availability efficiency = (equipment uptime) / (total time)*

Process Module A	*Process Module B*	*Process Module C*
= (163.00 hours) / (168.00 hours)	= (158.00 hours) / (168.00 hours)	= (168.00 hours) / (168.00 hours)
= 0.9702	= 0.9405	= 1.0000

MPCT

= (489.00 hours) / (504.00 hours)
= 0.9702

R1-2.3.1.2 *operational efficiency = (production time) / (equipment uptime)*

Process Module A	*Process Module B*	*Process Module C*
= (150.00 hours) / (163.00 hours)	= (148.00 hours) / (158.00 hours)	= (80.00 hours) / (168.00 hours)
= 0.9202	= 0.9367	= 0.4762

MPCT

= (378.00 hours) / (489.00 hours)
= 0.7730

R1-2.3.1.3 *rate efficiency = (theoretical production time for actual units) / (production time)*

Process Module A	*Process Module B*	*Process Module C*
= (140.00 hours) / (150.00 hours)	= (145.00 hours) / (148.00 hours)	= (75.00 hours) / (80.00 hours)
= 0.9333	= 0.9797	= 0.9375

MPCT

= (360.00 hours) / (378.00 hours)
= 0.9524

R1-2.3.1.4 *quality efficiency = (theoretical production time for effective units) / (theoretical production time for actual units)*

Process Module A	*Process Module B*	*Process Module C*
= (130.50 hours) / (140.00 hours)	= (139.00 hours) / (145.00 hours)	= (75.00 hours) / (75.00 hours)
= 0.9321	= 0.9586	= 1.0000

MPCT
= (344.50 hours) / (360.00 hours)
= 0.9569

R1-2.3.1.5 *overall equipment efficiency (OEE) = (theoretical production time for effective units) / (total time)*

Process Module A	*Process Module B*	*Process Module C*
= (130.50 hours) / (168.00 hours)	= (139.00 hours) / (168.00 hours)	= (75.00 hours) / (168.00 hours)
= 0.7768	= 0.8274	= 0.4464

MPCT
= (344.50 hours) / (504.00 hours)
= 0.6835

R1-2.3.2 *Loss Metrics*

R1-2.3.2.1 *availability loss = (total time − equipment uptime) / (total time)*

Process Module A	*Process Module B*	*Process Module C*
= (168.00 hours − 163.00 hours) / (168.00 hours)	= (168.00 hours − 158.00 hours) / (168.00 hours)	= (168.00 hours − 168.00 hours) / (168.00 hours)
= 0.0298	= 0.0595	= 0.0000

MPCT
= (504.00 hours − 489.00 hours) / (504.00 hours)
= 0.0298

R1-2.3.2.2 *operational loss = (equipment uptime − production time) / (total time)*

Process Module A	*Process Module B*	*Process Module C*
= (163.00 hours −150.00 hours) / (168.00 hours)	= (158.00 hours − 148.00 hours) / (168.00 hours)	= (168.00 hours − 80.00 hours) / (168.00 hours)
= 0.0774	= 0.0595	= 0.5238

MPCT
= (489.00 hours − 378.00 hours) / (504.00 hours)
= 0.2202

R1-2.3.2.3 *rate loss = (production time − theoretical production time for actual units) / (total time)*

Process Module A	*Process Module B*	*Process Module C*
= (150.00 hours − 140.00 hours) / (168.00 hours)	= (148.00 hours − 145.00 hours) / (168.00 hours)	= (80.00 hours − 75.00 hours) / (168.00 hours)
= 0.0595	= 0.0179	= 0.0298

MPCT
= (378.00 hours − 360.00 hours) / (504.00 hours)
= 0.0357

R1-2.3.2.4 *assignable quality loss = (theoretical production time for actual units − theoretical production time for effective units) / (process module total time)*

Process Module A	*Process Module B*	*Process Module C*
= (140.00 hours − 130.50 hours) / (168.00 hours)	= (145.00 hours − 139.00 hours) / (168.00 hours)	= (75.00 hours − 75.00 hours) / (168.00 hours)
= 0.0565	= 0.0357	= 0.0000

MPCT
= (360.00 hours − 344.50 hours) / (360.00 hours)
= 0.0308

R1-3 Calculating Supplemental Productivity Metrics with Total Time as the Denominator

R1-3.1 *Example Data* — The example calculations in this section are based on the following example data:

operations time	168.00 hours
production time	155.00 hours
theoretical production time for effective units	146.00 hours
no product time	6.00 hours
equipment down no product time	4.00 hours
planned no product time	8.00 hours

Table R1-2 Example Data for THT_i, $RTHT_i$, $ORTHT_i$, $VTHT_i$, Actual Units, Effective Units, and Total Effective Units

Recipe	*THTi (hours per unit)*	*RTHTi (hours per unit)*	*ORTHTi (hours per unit)*	*VTHTi (hours per unit)*	*Actual Units*	*Effective Units*	*Total Effective Units*
A	0.03333	0.03333	0.02500	0.01000	1500	1500	1250
B	0.04000	0.03333	0.02000	0.00500	600	600	550
C	0.05000	0.03333	0.01500	0.00500	800	800	725
D	0.06667	0.03333	0.03250	0.01000	500	480	450

where:

THTi = theoretical production time per unit.

RTHTi = reference theoretical production time per unit.

ORTHTi = optimized-recipe theoretical production time per unit.

VTHTi = value-added in-process theoretical production time per unit.

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R1-3.2 *Optimized-Recipe OEE (OROEE)*

= [$\sum_i$ (*effective units of recipe i* × $ORTHT_i$) / (*total time*)
= [(1500 units × 0.02500 hr/unit)
+ (600 units × 0.02000 hr/unit)
+ (800 units × 0.01500 hr/unit)
+ (480 units × 0.03250 hr/unit)] / (168.00 hours)
= (77.10 hours) / (168.00 hours)
= 0.4589

R1-3.3 *Value-Added In-Process OEE (VAOEE)*

= [$\sum_i$ (*effective units of recipe i* × $VTHT_i$)] / (*total time*)
= [(1500 units × 0.01000 hr/unit)
+ (600 units × 0.00500 hr/unit)
+ (800 units × 0.00500 hr/unit)
+ (480 units × 0.00500 hr/unit)] / (168.00 hours)
= (26.80 hours) / (168.00 hours)
= 0.1595

R1-3.4 *Reference OEE (ROEE)*

= [$\sum_i$ (*effective units of recipe i* × $RTHT_i$)] / (*total time*)
= [(1500 units × 0.03333 hr/unit)
+ (600 units × 0.03333 hr/unit)
+ (800 units × 0.03333 hr/unit)
+ (480 units × 0.03333 hr/unit)] / (168.00 hours)
= (112.66 hours) / (168.00 hours)
= 0.6706

R1-3.5 *Total Effective Units OEE (TEUOEE)*

= [$\sum_i$ (*total effective units of recipe i* × THT_i)] / (*total time*)
= [(1250 units × 0.03333 hr/unit)
+ (550 units × 0.04000 hr/unit)
+ (725 units × 0.05000 hr/unit)
+ (450 units × 0.06667 hr/unit)] / (168.00 hours)
= (129.91 hours) / (168.00 hours)
= 0.7733

R1-4 Calculating Supplemental Productivity Metrics with Denominators Other Than Total Time

R1-4.1 *production equipment efficiency (PEE)*

= (*theoretical production time for effective units*)
/ [(*operations time*) − (*no product time*) − (*equipment down no product time*)]
= (146.00 hours) / [(168.00 hours) − (6.00 hours) − (4.00 hours)]
= 0.9241

R1-4.2 *demand equipment efficiency (DEE)*

= (*theoretical production time for effective units*)
/ [(*operations time*) − (*planned no product time*)]
= (146.00 hours) / [(168.00 hours) − (8.00 hours)]
= 0.9125

R1-4.3 *intrinsic equipment efficiency (IEE)*

= [$\sum_i$ (*actual units of recipe i* × $VTHT_i$)] / (*production time*)
= [(1500 units × 0.01000 hr/unit)
+ (600 units × 0.00500 hr/unit)
+ (800 units × 0.00500 hr/unit)
+ (500 units × 0.00500 hr/unit)] / (155.00 hours)
= (27.00 hours) / (155.00 hours)
= 0.1741

R1-4.4 *IPS/MPCT Parallel Productivity Efficiency (IPS/MPCT PPE)*

R1-4.4.1 *Example Case Data* — This case is for an MPCT with two processing equipment modules (i.e., Process Module A and Process Module B) that processes three units during the observation period. Each unit visits Process Module A followed by Process Module B. Process Module A is productive for 6 hours and Process Module B is productive for 8 hours. Using the temporal-mapping method for productive time from SEMI E10, at least one process module is productive during the entire observation period of 10 hours; hence the MPCT productive time is 10 hours.

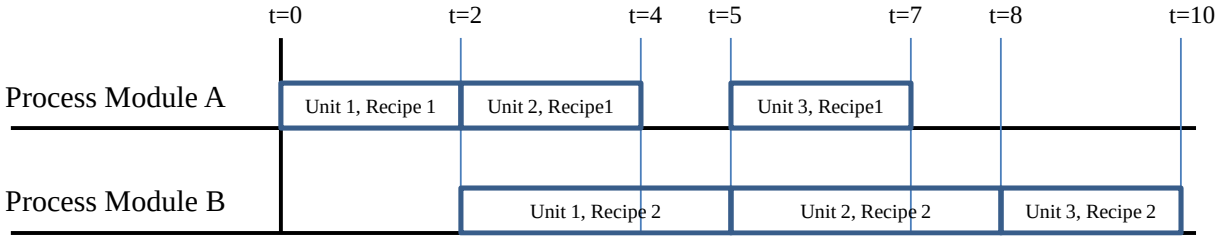

Figure R1-1
Scenario for Example Calculation of IPS/MPCT PPE

R1-4.4.2 *Example Calculation*

$$\textit{IPS/MPCT parallel productivity efficiency (IPS/MPCT PPE)} = \frac{\textit{SEMI E79 aggregate process module production time}}{\textit{(SEMI E10 temporal-mapped productive time} \times \textit{number of processing modules in equipment system)}}$$

$$= \frac{14 \text{ hours}}{(10 \text{ hours} \times 2 \text{ processing modules})}$$

= 14.00 hours / 20.00 hours
= 0.7000

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RELATED INFORMATION 2
GUIDELINES FOR DETERMINING THEORETICAL PRODUCTION TIME PER UNIT

NOTICE: This Related Information is not an official part of SEMI E79 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.

R2-1 Background

R2-1.1 Overall equipment efficiency (OEE) is intended to express the true efficiency of the equipment system. An OEE score of 0.50 (50%) indicates that exactly half of the maximum productive potential of the equipment system resource is being realized. An OEE score of 1.00 (100%) indicates that no further increase in productivity is feasible, assuming that there are no alterations to the existing equipment system design or recipe specifications.

R2-1.2 OEE is calculated in terms of the theoretical production time per unit (THT) for each recipe performed. This THT is based on the actual recipe, the actual equipment system design in use, and an assumed load size that optimizes equipment system throughput (expressed in units of output per hour) for that recipe.

R2-1.3 According to now-classical industrial engineering practice, standards for ideal performance are determined by application of the following:

- Breaking work methods down into their operational elements.
- Studying each of these operational elements separately to determine its ideal duration.
- Designing a new ideal method offering the shortest sequence of only the necessary operational elements (where the term 'sequence' may involve parallel performance of some or all operational elements).

R2-1.4 If the sequence of operational elements is not ideal, then ideal overall performance cannot be achieved even when the durations of all operational elements are ideal. Based on this understanding, THT for an equipment system recipe shall be based on both an ideal sequence as well as ideal durations for all operational elements, where THT is the theoretical duration for the sequence divided by the number of units processed during the sequence.

$$\textit{theoretical production time per unit for recipe i } (THT_i) = (\textit{theoretical duration for the operational element sequence}) / (\textit{number of units processed during sequence}) \quad \text{(R2-1)}$$

R2-1.4.1 Accurately calculating OEE requires that THT be accurately defined. In particular, THT shall be defined so that the speed losses are always nonnegative, i.e.,

$$\textit{speed losses} = (\textit{production time}) - (\textit{theoretical production time for actual units}) \geq 0 \quad \text{(R2-2)}$$

R2-2 Modeling Sequences

R2-2.1 *Modeling with Resource Utilization Charts* — A resource utilization chart is a Gantt chart displaying a separate timeline (i.e., sequence of operational elements) for each primary resource (e.g., processing equipment module) within the equipment system. Sequences displayed for each primary resource may be used to show how each resource within an equipment system is utilized, and how resources may interact. This graphical model of a sequence can be used to design the sequence required for determining THT. A resource utilization chart has operational elements, repeated groups, and subsequences.

R2-2.1.1 *Operational Elements* — A box-shaped bar with a label that depicts an operational element occurring within a sequence. The time for this operational element to execute may be fixed, recipe-dependent, or calculated from parameters.

R2-2.1.1.1 Operational elements that are not related to material-handling operations have a thick outline, as shown in the following example:

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Operational Element

R2-2.1.1.2 Material-handling operational elements have a thin outline, as shown in the following example:

Material Handling
Operational Element

R2-2.1.2 *Repeated Groups* — A bracket underneath a group of operational elements that indicates that the group repeats multiple times based on the parameter shown. For operational elements that occur conditionally, the number of repetitions may be zero. These repetitions apply to all operational elements in all timelines positioned in the vertical range of the bracket. The following example shows a repeated group bracket for an operational element:

Repeated
Operational Element(s)

x (# repetitions)

R2-2.1.3 *Subsequences* — A number in front of an operational element label that indicates that the operational element represents a subsequence (i.e., a group of operational elements defined elsewhere). The following example shows a subsequence number for an operational element:

1.1 Subsequence
Operational Element

R2-2.2 *Allowing for Nonsteady-State Processing* — For complicated batch-load equipment system models, it is useful to divide sequences into a beginning phase, a steady-state phase, and an ending phase. For modeling THT, it is important to determine what allowances to make, if any, for the beginning and ending phases. For equipment systems that are limited in the number of lots that can be processed in a continuous cascade, appropriate allowances shall be made for the beginning and ending phases. However, for equipment systems that are capable of running continuously, the beginning and ending phases shall not be considered in determining THT.

R2-2.2.1 Under certain conditions, setup-type operations that are not tracked as part of downtime shall be considered as part of the sequence for an equipment system. These conditions include operations that occur in every equipment system cycle (e.g., recipe download) as well as operations that occur on other regular intervals (e.g., 1 clean cycle every 75 wafers). In general, any support activities such as heating, cooling, purging, pump down, cleaning, etc., that are specified as part of production recipes and/or required for ideal equipment operation should be considered in the sequence for determining THT.

~~NOTE 22:~~NOTE 20: Any operations that are included in THT should also be included in the tracking of SEMI E10 productive time. This is necessary to assure that rate efficiency is always well defined and is never greater than 1 (100%) over any observation period. However, SEMI E10 productive time may track operations in the productive state (PRD) that are not part of THT and are considered rate efficiency loss.

R2-2.2.2 Operations that occur at irregular intervals or that apply to an unpredictable quantity of wafers, lots, or loads shall not be counted. An example of an operation that occurs at an irregular interval is a recipe changeover, when the equipment system is changed from the requirements of one process recipe to meet the needs of another (e.g., a species change on an ion implanter). The ideal frequency of these operations is zero.

R2-2.3 *Optimizing Equipment System Throughput* — Sequences shall be modeled to optimize equipment system throughput by using only the best configuration of operational elements and an optimal load size. Optimal sequences may differ for different recipes performed on the same equipment system. Optimal load sizes are not necessarily maximum load sizes.

R2-2.4 *Error-Checking Sequences* — Once a sequence is specified for an equipment system, it can be compared against actual equipment system operations to check for errors. If discrepancies are found, then three possibilities to investigate are as follows:

- The sequence contains extraneous operational elements.
- The sequence is missing necessary operational elements.
- The series and parallel relationships between operational elements are not correctly specified.

R2-2.4.1 What may at first appear to be sequence specification errors may in fact be undiscovered rate efficiency losses embedded in the sequence. Because sequences are fundamental to overall performance, it is important to rule out sequence specification errors to preclude erroneous assignment of rate efficiency losses to individual operational elements.

R2-2.5 *Example Resource Utilization Chart for a Sequence*

R2-2.5.1 An example of a resource utilization chart for a sequence is given in Figure R2-1. This example represents a particular instance of a photolithography stepper that exposes patterns from a reticle onto a wafer. This example assumes that the stepper receives individual unexposed wafers from a linked coat track and transfers individual exposed wafers to a linked develop track.

R2-2.5.2 First, a reticle box shall be loaded into the stepper reticle handling system (‘load box’). Before a wafer may be exposed, the reticle shall be set and aligned. A wafer shall also be loaded onto the prealign chuck, prealigned, and transferred to the exposure stage. Each wafer is exposed, then transferred to a postprocessing relay chuck. The transfer operation simultaneously removes an exposed wafer and replaces it with an unexposed wafer.

R2-2.5.3 The expose operation is represented by the subsequence shown in Figure R2-2. Depending on the recipe to be executed, the expose subsequence may consist of several different reticle images requiring changes of ‘blade’ positioning. For each image, there is one ‘align’ operation. For each individual exposure, there is a ‘step’ operation, a ‘level’ operation, and the ‘expose’ operation itself. Within the same image, different exposures may require different leveling times, as well as different stepping times.

R2-2.5.4 The operations indicated by dashed boxes represent the beginning phase of the main equipment system sequence. If the stepper is capable of processing wafers of the same reticle indefinitely, then the beginning phase shall not be included in THT. If, however, there is a hardware and/or software limit to the number of wafers that may be run consecutively, then the beginning phase shall be included in THT.

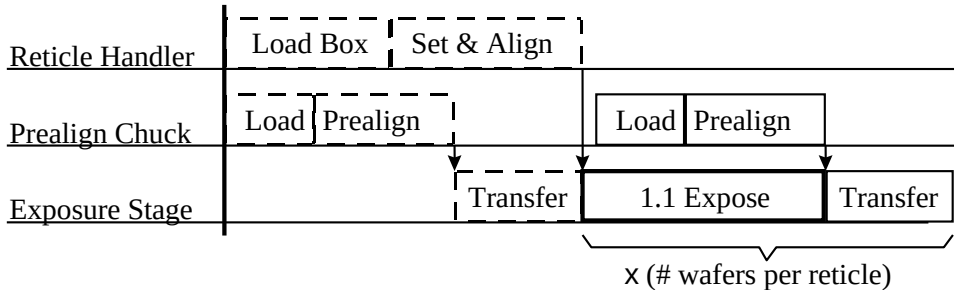

Figure R2-1
Example Resource Utilization Chart

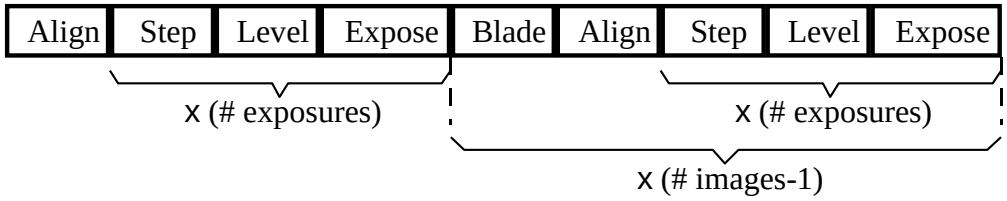

Figure R2-2
Example of Equipment System Subsequence

R2-3 Modeling Theoretical Durations for Operational Elements

R2-3.1 Once a sequence is defined, the next step is to measure and/or model the theoretical duration for each operational element in the sequence. As a rule, it is preferable to acknowledge in the model an operational elemental speed loss that can never be recovered in lieu of inadvertently overlooking another loss that could be reduced or eliminated.

R2-3.2 *Legitimate Observations* — Each theoretical duration for an operational element shall always be less than or equal to any legitimate observation for that operational element, where a legitimate observation is a traceable instance of an operational element that does not result in a loss of quality. The time for any legitimate observation that is less than the existing theoretical duration for an operational element shall become the new theoretical duration for the operational element. For traceable instances of the same operational element on different instances of identically configured equipment systems, the best time observed among all equipment systems of that type shall be used as the theoretical duration for the operational element.

R2-3.3 *Basis for Theoretical Durations for Operational Elements* — Theoretical durations for operational elements may be based on time studies, nominal parameters, and/or parametric modeling.

R2-3.3.1 *Time Studies* — Most mechanical operational elements that have fixed execution times (e.g., transport and load lock operations) can be accurately determined by time studies using stopwatches, equipment system data acquisition systems, timing systems built into the equipment system, or standalone data acquisition systems that use sensors to detect equipment system events and/or equipment state changes.

R2-3.3.1.1 When it is difficult to directly measure individual operational elements, collections of operational elements may be observed and timed instead. On an equipment system where a number of consecutive identical operational elements occur too fast to be measured individually, a set of operational elements may be timed, and the time shall be divided by the number of operational elements in the set. For even more complicated situations, operational element times may be derived algebraically from observations of several linearly independent sets of operational elements.

R2-3.3.2 *Nominal Parameters* — There are instances where it is desirable to use nominal parameters to represent theoretical conditions rather than using direct observations, such as in the following situations:

- Nominal parameters are more representative of the physical equipment system being studied.
- Nominal parameters are more representative of the desired equipment system performance.
- It is not practical to obtain reliable data.

R2-3.3.3 *Parametric Models* — In instances where the time for an operational element may have a range of values that are dependent on recipe specifications, THT is best represented by a parametric model. Parametric models for representing semiconductor operations may be based on mathematical formulas (e.g., implant time vs. beam current) and/or 'lookup' tables (e.g., best observed etch time vs. etch end point).

R2-3.3.3.1 For the photolithography example, one of the recipe parameters is the exposure energy (EE). Given the ideal or theoretical lamp intensity (LI) of the stepper, the theoretical duration per exposure (THT_{EX}) for the recipe is calculated using the following equation:

$$\textit{theoretical duration per exposure } (THT_{EX}) = EE / LI \qquad \text{(R2-3)}$$

INFORMATIONAL BALLOT

R2-4 Determining Theoretical Production Time (THT) with Activity-On-Node Networks

R2-4.1 Any sequence may also be modeled as an activity-on-node network derived from precedence constraints on the operational elements and precedence constraints on the allocation of equipment system resources to the operational elements. Using the network model, the duration of the sequence is simply the duration of the critical path through the network.

INFORMATIONAL BALLOT

RELATED INFORMATION 3
RAPID CHARACTERIZATION OF INTRINSIC EQUIPMENT EFFICIENCY (IEE) AND THE PRODUCTIVITY EFFICIENCY PLANE (PEP)

NOTICE: This Related Information is not an official part of SEMI E79 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.

R3-1 Rapid Characterization of Intrinsic Equipment Efficiency (IEE)

R3-1.1 Intrinsic equipment efficiency (IEE) may be rapidly characterized as follows using a limited number of production experiments.

R3-1.2 *Step 1: Design Equipment Experiments* — Select a limited number of scenarios to execute as equipment experiments. It may be of interest to characterize IEE according to operating modes, processing diversity, or a combination of operating modes and process diversity.

R3-1.2.1 For assessment of operating modes, select only a single typical recipe that is likely to be used most frequently. Each equipment experiment shall examine a separate operating mode, such as one of the following:

- Single wafer mode (e.g., for production monitor wafers).
- Batch mode, where a small number of lots or batches are run before the equipment system stops.
- Continuous (cascade) mode, where a large number of lots or batches are run before the equipment system stops.

R3-1.2.2 For assessment of process diversity, select a limited number of representative recipes that should~~will~~ be processed by an equipment system. This population should include at least one recipe representing the minimum expected processing duration and one representing the maximum.

R3-1.2.3 Determine the value-added in-process theoretical production time per unit (VTHT) for all recipes involved. This information is required for determining IEE. See Table A1-1.

R3-1.2.4 Each equipment experiment shall be designed and executed to eliminate rate efficiency losses to the greatest extent possible. It is further assumed that quality efficiency losses are zero. Under this approximation,

$$\textit{value-added in-process OEE (VAOEE)} = \textit{OEE} \times \textit{IEE} \qquad \text{(R3-1)}$$

R3-1.3 *Step 2: Execute Equipment Experiments* — Perform equipment experiments recording all relevant input variables, including the configuration of lots, wafers, and recipes. For each equipment experiment, record the elapsed production time using convenient means (e.g., a stopwatch, an existing data acquisition system).

R3-1.4 *Step 3: Calculate Results* — Calculate IEE and throughput for each equipment experiment.

$$\begin{aligned}\textit{intrinsic equipment efficiency (IEE)} = {} & (\textit{value-added in-process theoretical production time}) \\ & / (\textit{nonvalue-added overhead time} \\ & + \textit{value-added in-process theoretical production time}) \qquad \text{(R3-2)}\end{aligned}$$

R3-1.4.1 IEE may be used to measure the effect of nonvalue-added overhead time during equipment system processing.

$$\begin{aligned}\textit{nonvalue-added overhead time} = {} & [(\textit{production time}) \\ & - (\textit{value-added in-process theoretical production time})] \qquad \text{(R3-3)}\end{aligned}$$

R3-1.4.2 It should be the focus of efforts by the equipment system supplier and the user to reduce or eliminate nonvalue-added overhead time through improved equipment system design (including improved scheduling software) as well as through improved hardware components (e.g., carrier and wafer handling systems, valves, pumps, heaters, coolers).

R3-1.4.3 Results may be shown in either tabular form or plotted graphically on a Productivity Effectiveness Plane (PEP). (See ¶ R3-1.)

INFORMATIONAL BALLOT

R3-1.5 *Example Rapid Characterization of IEE* — Four equipment experiments were designed and executed with the following results:

Experiment	*Units of Recipe i Per Experiment*	*Value-Added In-Process Theoretical Production Time Per Unit ($VTHT_i$)*	*Production Time Per Experiment*
1	50 of recipe A	0.00670 hr/unit	3.3333 hr
2	100 of recipe B	0.00550 hr/unit	5.0000 hr
3	150 of recipe B	0.00550 hr/unit	6.0000 hr
4	300 of recipe A	0.00670 hr/unit	10.0000 hr

$$\textit{effective unit throughput per experiment} = (\textit{total units per experiment}) / (\textit{production time per experiment}) \quad \text{(R3-4)}$$

$$\textit{intrinsic equipment efficiency (IEE) per experiment} = [\Sigma_i\,(\textit{units of recipe i per experiment} \times VTHT_i) / (\textit{production time per experiment})]\ \cancel{\times 100} \quad \text{(R3-5)}$$

$$\textit{nonvalue-added overhead time per experiment} = [(\textit{production time per experiment}) - \Sigma_i\,(\textit{units of recipe i per experiment} \times VTHT_i)] \quad \text{(R3-6)}$$

Experiment	*Effective Unit Throughput*	*Intrinsic Equipment Efficiency (IEE)*	*Nonvalue-Added Time in Hours*
1	15 units/hr	0.1005	2.9983 hr
2	20 units/hr	0.1100	4.4500 hr
3	25 units/hr	0.1375	5.1750 hr
4	30 units/hr	0.2010	7.9900 hr

R3-2 Productivity Efficiency Plane (PEP)

R3-2.1 It is recognized that OEE and throughput are separate metrics with a relationship that may not be straightforward. Because theoretical production time per unit (THT) may vary widely by recipe, good throughput performance may not indicate correspondingly good performance in terms of OEE. Similarly, a high OEE score may not be indicative of high throughput. Given this disparity, it is essential that both metrics be analyzed and compared as separate entities.

R3-2.2 OEE and throughput can be analyzed and compared by first graphically displaying data from rapid characterization experiments (i.e., IEE and throughput) on a productivity efficiency plane (PEP) diagram, as shown in Figure R2-1.

R3-2.3 In a PEP diagram, IEE is plotted as a function of throughput. Points that appear further to the right have higher throughput and points that appear higher up have higher IEE. It is desired to have combined equipment and process designs with performance that appears in the upper right quadrant of the plane for the entire operating range of the equipment system.

R3-2.4 Points that are plotted in a PEP diagram are connected to approximate a curve that is referred to as an equipment system signature. In Figure R3-1, the four experimental data points from the example problem in ¶ R3-1.5 are plotted and, when connected, have an upward sloping equipment system signature.

R3-2.4.1 Equipment system signatures may be used to describe equipment system performance relative to isolated variables. This representation helps equipment system suppliers and users visualize the effects of equipment system operating modes on IEE and throughput. For more complex multidimensional experiment sets, the equipment system signature appears as a hypersurface.

R3-2.5 OEE can be plotted for comparison against equipment system signatures. In Figure R3-1, an OEE measurement of a typical week is plotted. For the known throughput corresponding to this OEE score, the value of IEE on the equipment system signature for the same throughput may be used to approximate the IEE score for the week without calculating IEE explicitly.

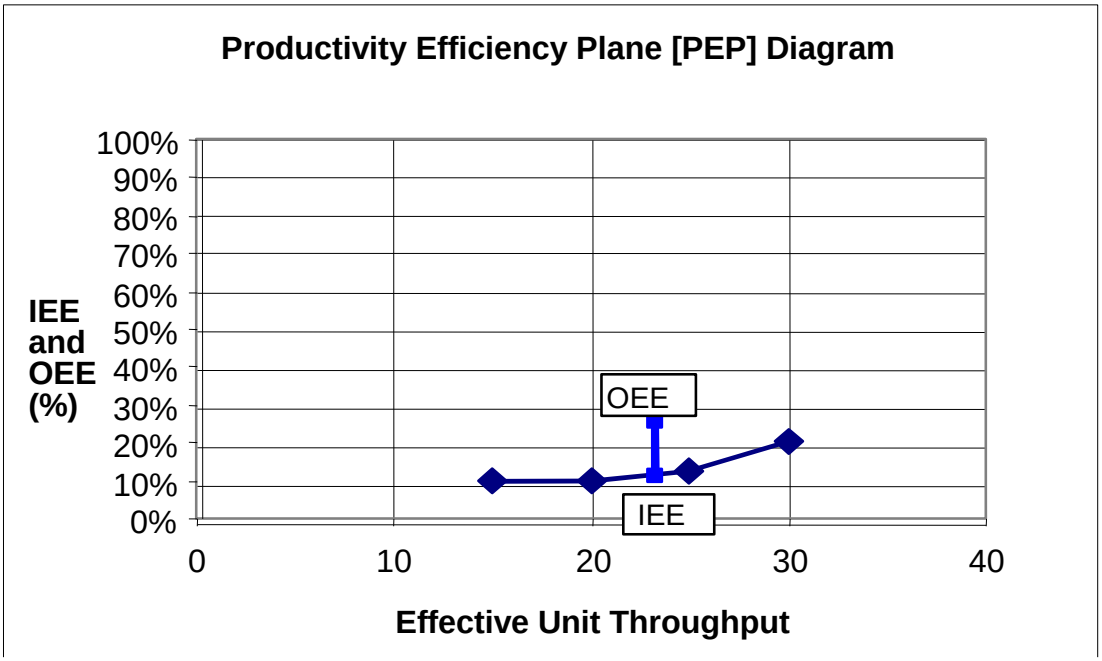

Figure R3-1
Example PEP Diagram

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