

# SEMI E79-1106

## SPECIFICATION FOR DEFINITION AND MEASUREMENT OF EQUIPMENT PRODUCTIVITY

This standard was technically approved by the global Metrics Committee. This edition was approved for publication by the global Audits and Reviews Subcommittee on August 24, 2006. It was available at [www.semi.org](http://www.semi.org) in October 2006 and on CD-ROM in November 2006. Originally published February 1999; previously published March 2005.

### 1 Purpose

- 1.1 The purpose of this specification is to provide metrics for measuring equipment productivity.

### 2 Scope

- 2.1 This specification defines metrics and calculations for measurement of equipment productivity.
- 2.2 In the context of this specification, it is important to note that “equipment productivity” is impacted greatly by factors far beyond the equipment itself, including operator actions, recipe settings, facility issues, material availability, scheduling requirements, etc.
- 2.3 Effective application of this specification requires that equipment performance is tracked using the metrics for equipment Reliability, Availability, and Maintainability (RAM) established in SEMI E10. Additionally, the Automated Reliability, Availability, and Maintainability Standard (ARAMS) SEMI E58 can be used for equipment with ARAMS capability.

NOTE 1: Several terminology changes were made during this revision to harmonize with SEMI E10 including changing fixed-sequence cluster tool to single-path cluster tool and flexible-sequence cluster tool to multi-path cluster tool.

- 2.4 Productivity metrics for multi-path cluster tools require tracking of SEMI E10 equipment states and recipes at the level of individual processing modules. The Equipment Performance Tracking (EPT) Standard SEMI E116 assists SEMI E79 by providing the status of the major modules of the equipment, which allows the tracking of performance metrics at the module level. SEMI E116 also assists SEMI E79 by providing task-level detail of the equipment or module’s current activity, which allows the tracking of performance metrics at the task level. Productivity performance of a multi-path cluster tool is then calculated as the aggregate productivity performance of the multi-path cluster tool’s individual processing modules.

- 2.5 This specification is currently limited to measuring equipment productivity using Overall Equipment Efficiency (OEE) as the metric, and does not address the impact of productivity changes on cost, cycle time, or other measures. This specification does not address any RAM issues over and above those in SEMI E10.

NOTE 2: While traditional total productive maintenance (TPM) literature (some examples are given in § 7) calculates overall equipment *effectiveness* (also using the same acronym OEE) based on units of production, overall equipment *efficiency* (OEE) is the more correct term for the time-based calculations defined in this specification. Traditional unit-based overall equipment *effectiveness* calculations and the time-based OEE calculations within this specification yield essentially the same results.

**NOTICE:** This standard does not purport to address safety issues, if any, associated with its use. It is the responsibility of the users of this standard to establish appropriate safety and health practices and determine the applicability of regulatory or other limitations prior to use.

### 3 Referenced Standards and Documents

#### 3.1 SEMI Standards

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

SEMI E38 — Cluster Tool Module Communications (CTMC)

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

SEMI E116 — Provisional Specification for Equipment Performance Tracking

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

## 4 Terminology

### 4.1 Acronyms

- 4.1.1 *ARAMS* — Automated Reliability, Availability, and Maintainability Standard
- 4.1.2 *CD-SEM* — Critical Dimension Scanning Electron Microscope
- 4.1.3 *CMP* — Chemical Mechanical Polish
- 4.1.4 *CTMC* — Cluster Tool Module Communications
- 4.1.5 *CVD* — Chemical Vapor Deposition
- 4.1.6 *DEE* — Demand Equipment Efficiency
- 4.1.7 *E-OEE* — Engineering Overall Equipment Efficiency
- 4.1.8 *EPT* — Equipment Performance Tracking
- 4.1.9 *ETHT* — Engineering Theoretical Production Time per Unit
- 4.1.10 *IEE* — Intrinsic Equipment Efficiency
- 4.1.11 *LPCVD* — Low Pressure Chemical Vapor Deposition
- 4.1.12 *OEE* — Overall Equipment Efficiency
- 4.1.13 *PEE* — Production Equipment Efficiency
- 4.1.14 *PVD* — Physical Vapor Deposition
- 4.1.15 *R-OEE* — Reference Overall Equipment Efficiency
- 4.1.16 *RAM* — Reliability, Availability, and Maintainability
- 4.1.17 *RTHT* — Reference Theoretical Production Time per Unit
- 4.1.18 *RTP* — Rapid Thermal Process
- 4.1.19 *THT* — Theoretical Production Time per Unit
- 4.1.20 *THTP* — Theoretical Unit Throughput by Recipe
- 4.1.21 *TPM* — Total Productive Maintenance
- 4.1.22 *VA-OEE* — Value-Added In-Process Overall Equipment Efficiency
- 4.1.23 *VTHT* — Value-Added In-Process Theoretical Production Time per Unit

### 4.2 Terminology Applicable to Calculation of the OEE Metric

- 4.2.1 *actual unit output* (units) — the number of units processed by the equipment during production time.
- 4.2.2 *availability efficiency* (time divided by time) — the fraction of total time that the equipment is in a condition to perform its intended function.
- 4.2.3 *cluster tool* — a manufacturing system made up of integrated processing modules mechanically linked together (the modules may or may not come from the same supplier) (SEMI E10).
- 4.2.4 *downtime (equipment downtime)* (time) — the time when the equipment is not in a condition, or is not available, to perform its intended function. It does not include any portion of non-scheduled time (SEMI E10).
- 4.2.5 *effective unit output* (units) — the number of units processed by the equipment 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.
- 4.2.6 *equipment-assignable rework* (units) — any units being reworked due to a fault or defect assignable to the subject equipment. The units may be reworked at the equipment where the fault or defect occurred, or at other equipment.
- 4.2.7 *equipment-assignable scrap* (units) — any units that are permanently removed from production due to a fault or defect assignable to the subject equipment. The units may be removed from production at the operation where the fault or defect occurred, or at a subsequent operation.
- 4.2.8 *equipment module* — an indivisible entity within a system. An equipment module may be either a non-processing module or a processing module.
  - 4.2.8.1 *non-processing module* — an indivisible equipment entity that supports the movement or conditioning of units through the system. Examples of non-processing modules include robotic handlers, load/unload locks, and pre-aligners.

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

4.2.9 *host* — the factory computer system or an intermediate system that represents the factory and the operator to the equipment (SEMI E116).

4.2.10 *multi-path cluster tool* — a cluster tool in which the units visit a subset of the equipment modules in sequences that may vary from unit to unit.

4.2.11 *non-scheduled time* (time) — the time when the equipment is not scheduled to be used in production (SEMI E10).

4.2.12 *operational efficiency* (time divided by time) — the fraction of equipment uptime that the equipment is processing actual units.

4.2.13 *operations time* (time) — the total time minus non-scheduled time (SEMI E10).

4.2.14 *overall equipment efficiency (OEE)* (time divided by time) — a metric of equipment performance, expressing the theoretical production time for the effective unit output divided by the total time (CSM 21).<sup>1</sup>

NOTE 3: The OEE metric accounts for all losses that reduce equipment performance from its maximum potential performance, assuming no alterations to the existing equipment design or recipe specifications.

4.2.15 *performance efficiency* (time divided by time) — the fraction of equipment uptime that the equipment is processing actual units at theoretically efficient rates.

4.2.16 *processing module recipe* — all processing steps of a recipe performed within a single processing module without requiring reloading of that processing module (CSM42).<sup>2</sup>

4.2.17 *production time* (time) — the sum of all periods of time in which a processing module is performing its intended function.

- For a non-cluster tool, a single-path cluster tool, or an individual processing module within a multi-path cluster tool, production time is equivalent to the SEMI E10 productive time for that entity.
- For a multi-path cluster tool, production time is the sum of the productive times of all processing modules encompassed by the cluster tool in combination with the transport mechanisms that serve the processing modules (CSM 42).

4.2.18 *productive state* — a period of time (productive time) when the equipment is performing its intended function (SEMI E10).

4.2.19 *quality efficiency* (time divided by time) — the theoretical production time for effective units divided by the theoretical production time for actual units.

4.2.20 *rate efficiency* (time divided by time) — the fraction of production time that equipment is processing actual units at theoretically efficient rates.

4.2.21 *recipe* — the pre-planned 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 material. Recipes may be subject to change between runs or processing cycles (SEMI E38).

4.2.22 *single-path cluster tool* — a cluster tool in which all units follow only one process path.

4.2.23 *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.

NOTE 4: Within the scope of this specification, the term “state” generally refers to one of the six equipment states defined by SEMI E10 and used in the ARAMS state model: productive, standby, engineering, scheduled downtime, unscheduled downtime, and non-scheduled time (SEMI E58).

4.2.24 *system* — an integrated structure of components and subsystems capable of performing, in aggregate, one or more specific functions. For the purpose of this specification, a system consists of one or more processing or non-processing modules.

4.2.25 *theoretical production time* (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

<sup>1</sup> CSM 21: Closed-Loop Measurement of Equipment Efficiency and Equipment Capacity, Engineering Systems Research Center, University of California, Berkeley, 1997. Telephone: 510.642.4994, Fax: 510.643.0966, Website: <http://esrc.berkeley.edu>.

<sup>2</sup> CSM 42: Productivity Metrics for Flexible Sequence Cluster Tools, Engineering Systems Research Center, University of California, Berkeley, 1998. Telephone: 510.642.4994, Fax: 510.643.0966, Website: <http://esrc.berkeley.edu>.

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 (CSM 21, CSM 42). For multi-path cluster tools, theoretical production time is the sum of the theoretical production times for all processing modules encompassed by the cluster tool in combination with the transport mechanisms that serve the processing modules.

4.2.26 *theoretical production time per unit (THT)* (time per unit) — the minimum rate of time per unit to complete processing, given the following:

- The specified recipe
- The equipment design
- Continuous operation
- No efficiency losses

NOTE 5: Recipe specifications and settings for THT are the ones actually used in production and are not idealized. Equipment of the same design (e.g., same make and model) are expected to have the same THTs, whereas equipment of a different design may have different THTs even if they perform the same intended function. Continuous operation requires that equipment loading is optimized for throughput and there are no internal or external interruptions or delays to processing. Given the constraints of a specified recipe, an equipment design, and continuous operation, THT 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, or moments in the life-cycle of a consumable).

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

4.2.28 *total time* (time) — all time (at the rate of 24 hrs/day, 7 days/wk) during the period being measured. In order to have a valid representation of total time, all six basic equipment states must be accounted for and tracked accurately (SEMI E10). For a multi-path cluster tool, total time is defined as the aggregate total time of all processing modules encompassed by the cluster tool in combination with the transport mechanisms that serve the processing modules.

4.2.29 *unit* — any wafer, die, packaged device, or piece part thereof (includes product and non-product units) (SEMI E10).

4.2.30 *uptime (equipment uptime)* (time) — the time when the equipment is in a condition to perform its intended function. It includes productive, standby, and engineering time, and does not include any portion of non-scheduled time (SEMI E10). For a multi-path cluster tool, uptime is defined as the aggregate uptime of all processing modules encompassed by the cluster tool in combination with the transport mechanisms that serve the processing modules (CSM 42).

4.2.31 *virtual machine* — an individual processing module within a multi-path cluster tool, in combination with the transport module(s) serving that processing module. A multi-path cluster tool has one virtual machine defined for each of its processing modules (CSM 42).

### 4.3 Terminology Applicable to Calculation of Additional Productivity Metrics Defined in Appendix 2

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

4.3.2 *engineering overall equipment efficiency (E-OEE)* (time divided by time) — a measure of equipment productivity assuming process specifications are optimized for minimum theoretical production time.

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

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

4.3.5 *intrinsic equipment efficiency (IEE)* (time divided by time) — a measure of equipment productivity that considers the combined effect of rate efficiency losses, recipe design, and equipment design.

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

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

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

NOTE 6: One application of PEE is to measure the productivity of non-constraint equipment, which are expected to have periods of idle time due to lack of available work.

4.3.9 *reference overall equipment efficiency (R-OEE)* (time divided by time) — a measure of equipment productivity relative to a benchmark theoretical production time.

4.3.10 *reference theoretical production time per unit (RTHT)* (time per unit) — the theoretical production time per unit required to process a given recipe on benchmark equipment (i.e., the fastest equipment model 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.

4.3.11 *value-added in-process overall equipment efficiency (VA-OEE)* (time divided by time) — a measure of equipment productivity assuming all time except the value-added portion of processing cycles is wasted equipment time.

4.3.12 *value-added in-process theoretical production time per unit (VTHT)* (time per unit) — 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 engineering theoretical production time per unit (ETHT) used in calculating engineering overall equipment efficiency (E-OEE).

## 5 Equipment Productivity Measurement

### 5.1 Background

5.1.1 The OEE calculation has been stated in terms that are consistent with SEMI E10, as shown in Figure 1.

5.1.2 Figure 2 indicates how total time may be divided into portions representing theoretical production time for effective units and various sources of productivity loss. The domain for productivity improvement of all losses except operational efficiency is shared between the equipment supplier and equipment user. Productivity improvement of operational efficiency is the exclusive domain of the equipment user.

5.1.3 The formulas introduced in this section require as inputs the following fundamental quantities:

- Theoretical production time
- Production time
- Equipment uptime
- Total time

Sample calculations for each of the formulas are provided in Related Information 1.

5.1.4 For efficiency measurement of individual processing modules or of single-path cluster tools, the fundamental quantities may be determined in a straightforward manner. Consequently, the formulas of this section may be used to calculate the efficiency of an individual processing module or single-path cluster tool in a straightforward manner.

5.1.5 For efficiency measurement of multi-path cluster tools, determination of the fundamental quantities requires more involved calculations. Formulas for calculating the fundamental quantities for multi-path cluster tools are provided in § 6. These fundamental quantities may then be used as inputs to the formulas of this section to calculate the efficiency of a multi-path cluster tool.

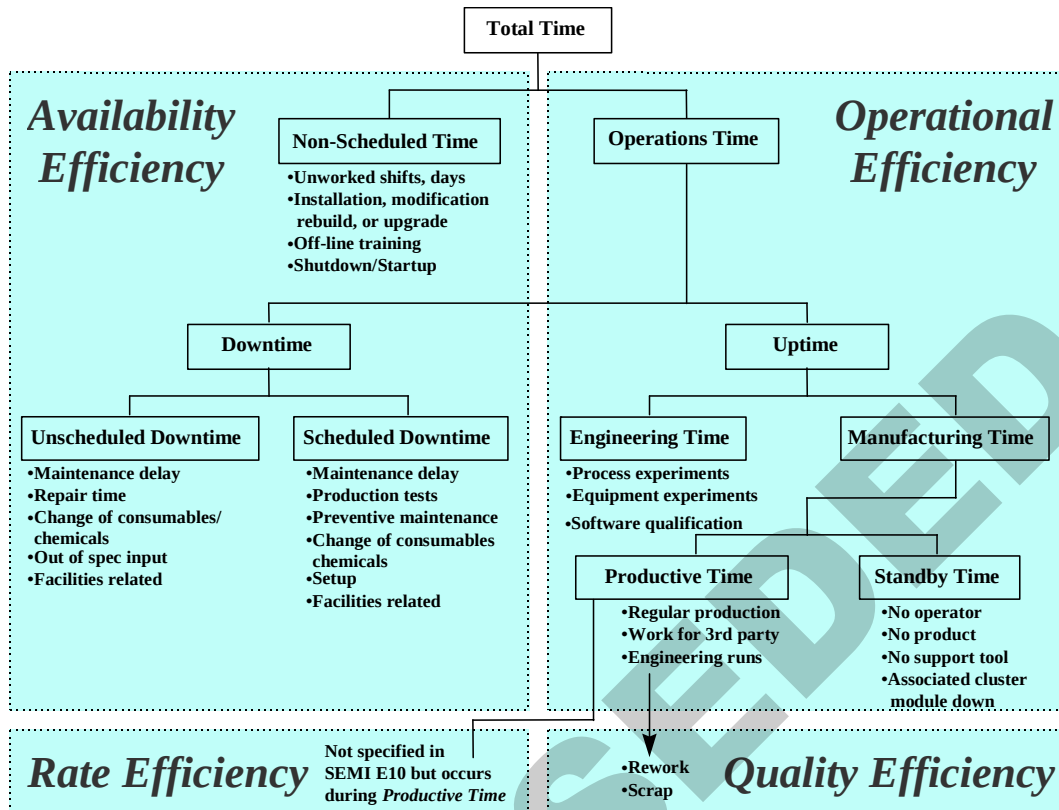


Figure 1  
Relationship Between SEMI E10 and OEE

## E10 States

## E79 Productivity Losses and Improvement Domains

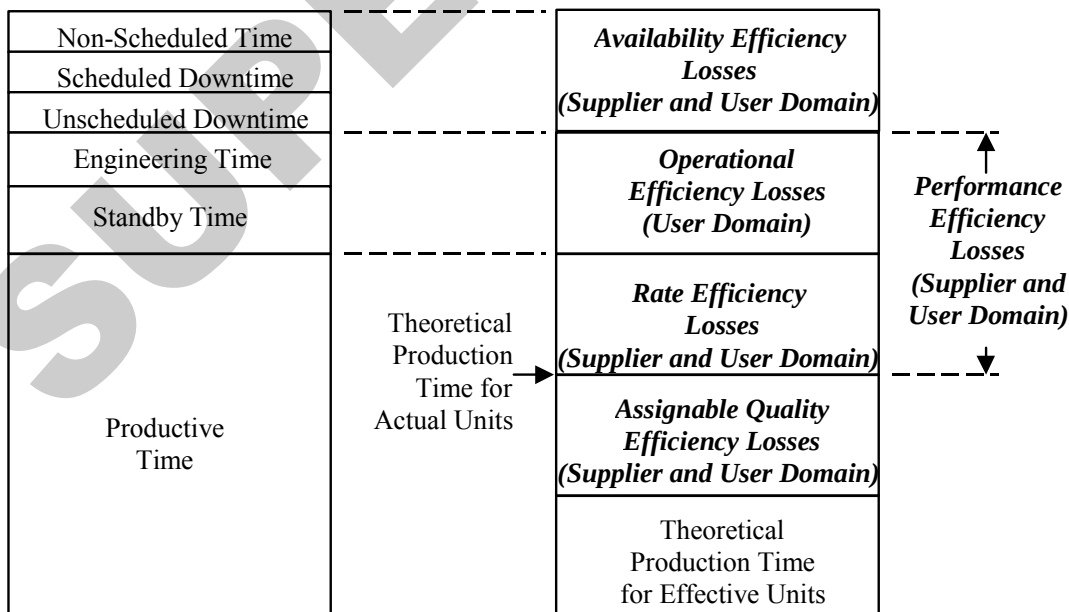


Figure 2  
Stack Chart of Productivity Losses and Improvement Domains

5.1.6 Additional supplemental efficiency metrics that will enable users to assess more specific aspects of equipment productivity are:

- Reference OEE (R-OEE)
- Engineering OEE (E-OEE)
- Value-Added In-Process OEE (VA-OEE)
- Demand Equipment Efficiency (DEE)
- Production Equipment Efficiency (PEE)
- Intrinsic Equipment Efficiency (IEE)

Definitions and formulas for these metrics are presented in Appendix 1.

5.2 *Overall Equipment Efficiency (OEE)* — The fraction of total time that equipment is producing effective units at theoretically efficient rates.

$$\text{Overall Equipment Efficiency (OEE)} = (\text{Theoretical Production Time for Effective Units}) / (\text{Total Time}) \quad (1)$$

$$= (\text{Availability Efficiency}) \times (\text{Performance Efficiency}) \times (\text{Quality Efficiency}) \quad (2)$$

5.2.1 *Theoretical Production Time (for Effective Units)* — The production time (for effective units) during a period of observation that is earned at strictly theoretically efficient rates and assumes no efficiency losses.

$$\text{Theoretical Production Time for Effective Units} = \sum_i (\text{Effective Units of Recipe } i \times \text{THT}_i) \quad (3)$$

where

$$\text{THT}_i = \text{Theoretical Production Time Per Unit of Recipe } i \quad (4)$$

NOTE 7: Theoretical production time (for effective units) may be calculated in terms of theoretical unit throughput by recipe.

$$\text{Theoretical Production Time for Effective Units} = \sum_i (\text{Effective Units of Recipe } i / \text{THTP}_i) \quad (5)$$

where

$$\text{THTP}_i = \text{Theoretical Unit Throughput by Recipe of Recipe } i \quad (6)$$

5.2.2 *Availability Efficiency* — The fraction of total time that the equipment is in a condition to perform its intended function.

$$\text{Availability Efficiency} = (\text{Equipment Uptime}) / (\text{Total Time}) \quad (7)$$

5.2.3 *Performance Efficiency* — The fraction of equipment uptime that the equipment is processing actual units at theoretically efficient rates.

$$\text{Performance Efficiency} = (\text{Operational Efficiency}) \times (\text{Rate Efficiency}) \quad (8)$$

5.2.3.1 *Operational Efficiency* — The fraction of equipment uptime that the equipment is processing actual units.

$$\text{Operational Efficiency} = (\text{Production Time}) / (\text{Equipment Uptime}) \quad (9)$$

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

$$\text{Rate Efficiency} = (\text{Theoretical Production Time for Actual Units}) / (\text{Production Time}) \quad (10)$$

5.2.3.2.1 *Theoretical Production Time (for Actual Units)* — The production time (for actual units) during a period of observation that is earned at strictly theoretically efficient rates and assumes no efficiency losses.

$$\text{Theoretical Production Time for Actual Units} = \sum_i (\text{Actual Units of Recipe } i \times THT_i) \quad (11)$$

where

$$THT_i = \text{Theoretical Production Time Per Unit of Recipe } i \quad (12)$$

NOTE 8: Theoretical production time (for actual units) may be calculated in terms of theoretical unit throughput by recipe.

$$\text{Theoretical Production Time for Effective Units} = \sum_i (\text{Effective Units of Recipe } i / THTP_i) \quad (13)$$

where

$$THTP_i = \text{Theoretical Unit Throughput by Recipe of Recipe } i \quad (14)$$

5.2.4 *Quality Efficiency* — The theoretical production time for effective units divided by the theoretical production time for actual units.

$$\text{Quality Efficiency} = (\text{Theoretical Production Time for Effective Units}) / (\text{Theoretical Production Time for Actual Units}) \quad (15)$$

## 6 Calculation of Fundamental Quantities for Multi-Path Cluster Tools

6.1 This section provides definitions and formulas for calculating the following fundamental quantities for multi-path cluster tools:

- Theoretical production time
- Production time
- Equipment uptime
- Total time

These fundamental quantities serve as inputs to the formulas in § 5 for equipment efficiency measurement.

6.1.1 Fundamental quantities for a multi-path cluster tool are measured at the individual processing module level of detail using the virtual machine model described in ¶ 6.2. The fundamental quantity for the entire multi-path cluster tool is then calculated as the aggregate fundamental quantities of the cluster tool's individual processing modules, as determined using the virtual machine model.

NOTE 9: Evaluation of multi-path cluster tool productivity does not necessarily apply to the evaluation of multi-path cluster tool RAM.

### 6.2 Virtual Machine Model

6.2.1 A virtual machine is an individual processing module in combination with the transport mechanisms that serve that processing module. When a transport mechanism is engaged in a material handling operation that does not involve a particular processing module, it is not considered to be operating as part of the virtual machine defined for that processing module.

6.2.2 Theoretical production time, a fundamental quantity for a virtual machine, is the sum of theoretical times for all required operational elements:

- Wafer loading
- Operational elements occurring within the virtual machine's processing module
- Wafer unloading

NOTE 10: Wafer loading and unloading are significant operational elements in a virtual machine when calculating theoretical production time and production time.

6.2.2.1 Where appropriate, a combined wafer loading and unloading time may be replaced with a single theoretical value for a wafer exchange.

### 6.3 Calculating Fundamental Quantities for Multi-path Cluster Tools Using Virtual Machines

6.3.1 This section provides formulas for calculating fundamental quantities for a multi-path cluster tool using the individual virtual machines within a multi-path cluster tool. A fundamental quantity for each individual virtual machine within a multi-path cluster tool is first calculated. The fundamental quantity for the entire multi-path cluster tool is then calculated as the sum of the fundamental quantities for all the individual virtual machines within the cluster tool.

NOTE 11: It is recognized that application-specific interactions between virtual machines within multi-path cluster tools may impose varying amounts of standby time on the individual virtual machines. This approach treats these interactions as standby losses for the multi-path cluster tool and does not make any allowances for the interactions in either theoretical production time or production time.

#### 6.3.2 Calculating Theoretical Production Time (for Actual Units and for Effective Units)

6.3.2.1 *Virtual Machine Theoretical Production Time (for Actual Units and for Effective Units)* — The theoretical production time earned by an individual virtual machine.

$$\begin{aligned} \text{Virtual Machine Theoretical Production Time for Actual Units} = \\ \Sigma_i [(\text{Theoretical Production Time Per Unit for Virtual Machine Recipe } i) \\ \times (\text{Actual Units of Virtual Machine Recipe } i)] \end{aligned} \quad (16)$$

$$\begin{aligned} \text{Virtual Machine Theoretical Production Time for Effective Units} = \\ \Sigma_i [(\text{Theoretical Production Time Per Unit for Virtual Machine Recipe } i) \\ \times (\text{Effective Units of Virtual Machine Recipe } i)] \end{aligned} \quad (17)$$

6.3.2.2 *Multi-path Cluster Tool Theoretical Production Time (for Actual Units and for Effective Units)* — The aggregate theoretical production time earned by all the multi-path cluster tool's virtual machines.

$$\begin{aligned} \text{Multi-path Cluster Tool Theoretical Production Time for Actual Units} = \\ \Sigma_j (\text{Theoretical Production Time for Actual Units for Virtual Machine } j) \end{aligned} \quad (18)$$

$$\begin{aligned} \text{Multi-path Cluster Tool Theoretical Production Time for Effective Units} = \\ \Sigma_j (\text{Theoretical Production Time for Effective Units for Virtual Machine } j) \end{aligned} \quad (19)$$

#### 6.3.3 Calculating Production Time

6.3.3.1 *Virtual Machine Production Time* — The sum of all periods of manufacturing time in which a virtual machine is performing operations. When SEMI E10 equipment states are tracked at the virtual machine level, the virtual machine production time is equivalent to SEMI E10 productive time. Automated tracking is required for accurate results.

6.3.3.2 *Multi-path Cluster Tool Production Time* — The aggregate production time for all the multi-path cluster tool's virtual machines.

$$\text{Multi-path Cluster Tool Production Time} = \Sigma_j (\text{Production Time for Virtual Machine } j) \quad (20)$$

NOTE 12: In this quantity, elapsed times for transport operations that reposition units from one virtual machine to another are intentionally credited to both virtual machines. Also note that this aggregate measure for production time may be larger than the elapsed time observed and can be compared only with similar aggregate multi-path cluster tool measurements.

#### 6.3.4 Calculating Equipment Uptime

6.3.4.1 *Virtual Machine Equipment Uptime* — The total time, during a period of observation, that a virtual machine is in a condition to perform processing in some form.

$$\begin{aligned} \text{Virtual Machine Equipment Uptime} = \\ \text{Virtual Machine Production Time} + \text{Virtual Machine Engineering Time} + \text{Virtual Machine Standby Time} \end{aligned} \quad (21)$$

NOTE 13: SEMI E10 defines equipment uptime as including SEMI E10 productive time, engineering time, and standby time. In this calculation, production time is used in lieu of SEMI E10 productive time.