SEMI E35-0618
GUIDE TO CALCULATE COST OF OWNERSHIP (COO) METRICS FOR SEMICONDUCTOR MANUFACTURING EQUIPMENT

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1 Purpose

1.1 The purpose of this Guide is to provide standard cost of ownership (COO) metrics for evaluating unit production cost effectiveness of manufacturing equipment in the semiconductor and related industries.

1.2 This Guide establishes a procedure to facilitate an understanding of equipment-related costs, including costs related to environmental, health, and safety (EHS) factors, by providing definitions, classifications, algorithms, methods, and example values necessary to build a comprehensive, constrained, or monitor COO calculator.

NOTE 1: Related Information 1 provides a graphical representation of calculating COO to expand upon the Guide text.

2 Scope

2.1 This Guide is applicable to any type of equipment for processing semiconductor units, which may be integrated circuit (IC) wafers and devices. It may also be applicable to any type of manufacturing equipment for processing of a flat panel display (FPD), photovoltaic (PV), micro electro-mechanical systems (MEMS), high-brightness light emitting diode (HB-LED), hard disk drive (HDD), or other types of production units. Some terms are specialized to IC wafer and device production.

2.2 Effective use of the metric to build a COO model requires identification of constraints and data values. Where possible, use direct values for inputs rather than deriving them from secondary models or using example values.

NOTE 2: Related Information 2 provides some example data.

2.3 Full calculation of COO often requires data held proprietary and is coupled to the overall factory yield and the related cost of yield loss. It is envisioned that this Guide will be used for internal factory and equipment optimization, investment evaluation, and equipment design and process improvements.

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 Certain cost factors are more difficult than others to accurately determine. Figure 1 depicts the relationship of some of the COO model input factors to the ability to collect and validate them. The accuracy of a COO calculation may be prone to a variety of errors or omissions.

3.2 Bottleneck, cycle time, and line balance interrelationships are not included in the COO calculation. They are not included because it is difficult, in an individual COO model, to show the impact of equipment being modeled on the complete manufacturing factory. A factory-level cost and/or simulation model should be used for these purposes.

3.3 A COO calculation may have more detail than presented explicitly in this Guide. The structure of the Guide, however, allows for these situations.

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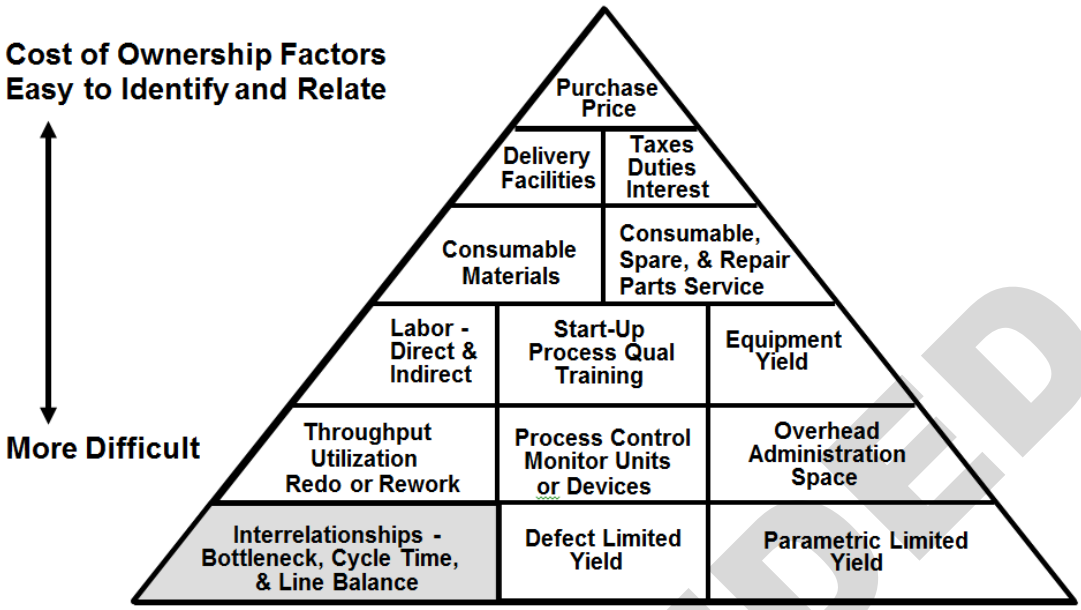

Figure 1
Relationship of Factors to Difficulty of Collection and Validation

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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 E72 — Specification and Guide for Equipment Footprint, Height, and Weight

SEMI E89 — Guide for Measurement System Analysis (MSA)

SEMI E79 — Specification for Definition and Measurement of Equipment Productivity

SEMI S12 — Environmental, Health, and Safety Guideline for Manufacturing Equipment Decontamination

SEMI S16 — Guide for Semiconductor Manufacturing Equipment Design for Reduction of Environmental Impact at End of Life

SEMI S23 — Guide for Conservation of Energy, Utilities and Materials Used by Semiconductor Manufacturing Equipment

4.2 *ISO Documents*[1]

ISO/IEC Guide 99 — International Vocabulary of Metrology – Basic and General Concepts and Associated Terms (VIM)

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

5 Terminology

5.1 *Abbreviations and Acronyms*

5.1.1 *AA* — active area of the device

[1] International Organization for Standardization, ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland; Telephone: +41.22.749.01.11, http://www.iso.org

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5.1.2 *CDF* — cumulative distribution function

5.1.3 *CEO* — cost of equipment ownership

5.1.4 *COO* — cost of ownership

5.1.5 *CYL* — cost of yield loss

5.1.6 *DD* — defect density

5.1.7 *DLY* — defect limited yield

5.1.8 *DY* — defect yield

5.1.9 *EHS* — environmental, health and safety

5.1.10 *ER* — equipment required (integer number)

5.1.11 *EY* — equipment yield

5.1.12 *FP* — fault probability

5.1.13 *FPD* — flat panel display

5.1.14 *GUE* — good unit equivalents

5.1.15 *HB-LED* — high-brightness light emitting diode

5.1.16 *HDD* — hard disk drive

5.1.17 *IC* — integrated circuit

5.1.18 *IEC* — International Electrotechnical Commission

5.1.19 *IPS* — intended process set

5.1.20 *ISO* — International Organization for Standardization

5.1.21 *LSL* — lower specification limit

5.1.22 *MEMS* — micro electro-mechanical system

5.1.23 *MPCT* — multi-path cluster tool

5.1.24 *MS* — measurement system

5.1.25 *MSA* — measurement system analysis

5.1.26 *OEM* — original equipment manufacturer

5.1.27 *OU* — operational uptime

5.1.28 *P/T* — precision-to-tolerance (ratio)

5.1.29 *PDF* — probability density function

5.1.30 *PLY* — parametric limited yield

5.1.31 *PRY* — product yield

5.1.32 *PV* — photovoltaic

5.1.33 *PY* — process yield

5.1.34 *SR* — sampling rate

5.1.35 *TP* — throughput

5.1.36 *TU* — total utilization

5.1.37 *USL* — upper specification limit

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5.2 *Definitions*

5.2.1 *alpha error* — the error that occurs when a conforming item is incorrectly reported as nonconforming. This is also called Type I error.

5.2.2 *alpha probability, α* — the probability of an alpha error, also called the alpha error rate.

5.2.3 *baseline cost of ownership* — a constrained version of cost of ownership (COO) that only includes equipment yield (i.e., defect limited yield and parametric limited yield are not included).

5.2.4 *beta error* — the error that occurs when a nonconforming item is incorrectly reported as conforming. This is also called Type II error.

5.2.5 *beta probability, β* — the probability of a beta error, also called the beta error rate.

5.2.6 *bias* — difference between the population mean of the test results from a measurement process and the true (accepted reference) value of the property being measured. [SEMI E89].

NOTE 3: In many cases the true value of bias is unknown. An accepted reference value established by reference measurement systems or a consensus value may be used as a substitute.

5.2.7 *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]

5.2.8 *comprehensive cost of ownership* — cost of ownership (COO) calculated with no constraints.

5.2.9 *constrained cost of ownership* — cost of ownership (COO) version with a set of defined restrictions to facilitate comparisons or to remove ambiguity.

5.2.10 *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]

5.2.11 *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 equipment to perform its intended function. [SEMI E10]

5.2.12 *cost footprint rectangle area, Acf* — the area of the cost footprint rectangle, calculated as ($Dcf \times Wcf$). [SEMI E72]

NOTE 4: The details for calculating *Acf* are completely defined in SEMI E72 and are not repeated here in SEMI E35.

5.2.13 *cost of equipment ownership (CEO)* — a factor in cost of ownership that includes all costs not associated with yield loss.

5.2.14 *cost of ownership (COO)* — full cost of embedding, operating, and decommissioning in a factory environment equipment needed to accommodate the required volume of units actually processed through the equipment.

5.2.15 *cost of yield loss (CYL)* — a unit lost at the end of a given step represents the loss of the cost of the starting unit and the manufacturing to that point. In addition, units leaving a step may be lost at some later step. Calculating CYL therefore requires knowing the starting unit cost and the accumulated cost of manufacturing before the unit is lost. Therefore, CYL should be tracked as a separate cost for factory optimization.

5.2.16 *cumulative distribution function (CDF)* — mathematical formula that describes the probability a measurable event occurs at or below a specific value.

5.2.17 *defect limited yield (DLY)* — the fraction of units that are not lost from defects added by the equipment. For wafer processing, defect yield is usually derived from a model.

5.2.18 *distribution* — a characterization of the probability of realization for a measurable event over the range of values that the measurements may assume.

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5.2.19 *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]

5.2.20 *equipment required (ER)* — the integer number of equipment required to obtain the throughput for the step.

5.2.21 *equipment throughput* — see throughput.

5.2.22 *equipment yield (EY)* — the fraction of units received by the equipment that can be passed to the next step based on any criteria such as damaged units, or units determined to be defective by inspection or test. Inclusion of equipment yield results in a decreasing population of units flowing through the factory. At later steps, equipment will process fewer units than the full factory unit starts. For test and measurement equipment, validly rejected units are scrap, but not a component of equipment yield.

5.2.23 *example value* — a value to be used if actual data are not available. Also sometimes called default or default value.

5.2.24 *fault probability* (*FP)* — probability that a defect caused by processing through the equipment will be fatal.

5.2.25 *fixed costs* — costs incurred once and usually associated with the acquisition and incorporation of equipment into the factory.

5.2.26 *good unit equivalents (GUE)* — the calculated number of equivalent units required to produce the same number of units output if product yield was 100%.

5.2.27 *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]

5.2.28 *joint probability* — a probability density or cumulative distribution function comprised of two or more random variables.

5.2.29 *lifetime* — the time over which the fixed and recurring costs are spread on an annualized basis.

5.2.29.1 *production lifetime* — the number of years the equipment is used for manufacturing.

5.2.29.2 *tax lifetime* — the number of years as defined in compliance with local tax or accounting depreciation practices.

5.2.30 *lower specification limit (LSL)* — value of an attribute below which a product is said to be nonconforming. [SEMI E89]

5.2.31 *measurand* — particular attribute of a phenomenon, body, or substance subject to measurement [VIM].

5.2.32 *measurement system (MS)* — all entities, procedures, and conditions that can influence the test result obtained with a given measurement process. [SEMI E89]

5.2.33 *measurement variability* — differences associated with making multiple measurements on a given measurand under specific conditions.

NOTE 5: Common (general) estimators of measurement variability are the variance, standard deviation, and variance components. Specific estimators include repeatability and reproducibility.

5.2.34 *monitor cost of ownership* — effective cost of ownership (COO) per production unit based on the sampling rate for performing measurements, inspections, or tests on samples.

5.2.35 *monitor unit* — test or filler unit (e.g., wafer, device) consumed in the support of the equipment. Also called test unit.

5.2.36 *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]

5.2.37 *nonconsumable part* — component part of the equipment that is not normally consumed by the process operation of the equipment. It may require replacement (e.g., due to a failure) with another component part to allow equipment to perform its intended function. [SEMI E10]

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5.2.38 *operational uptime (OU)* — the percentage of time the equipment is in a condition to perform its intended function during the period of operations time. This calculation is intended to reflect overall operational performance for the equipment.

5.2.38.1 *Discussion* — As defined, OU has components attributable to both the unit manufacturer and the equipment supplier.

5.2.39 *parametric limited yield (PLY)* — the fraction of units that are not lost from device parameters being outside the required range.

5.2.40 *part* — see component part. [SEMI E149]

5.2.41 *precision-to-tolerance (P/T) ratio* — ratio of the precision of a measurement system (MS) to the tolerance (i.e., absolute magnitude of the full range of the product specification). [SEMI E89]

5.2.42 *probability density function (PDF)* — a mathematical formula that specifies the relationship between values that a random variable may assume and their likelihood of occurrence. It is the first derivative of the CDF.

5.2.43 *process step* — the smallest unit of processing activity that can be defined in a process flow. One or more process steps are sequenced to define an operation set. [SEMI E81]

5.2.44 *product yield (PRY)* — the fraction of units that pass through the factory and result in good product. Product yield for units is the composite of all sources of yield loss.

5.2.45 *random variable* — a measurable event occurring such that any value from its distribution is equally likely to take place.

5.2.46 *recurring cost* — cost that is incurred on an ongoing basis, based on time and/or usage.

5.2.47 *redo* — see rework.

5.2.48 *repair part* — component part to service the equipment purchased at the time of repair.

5.2.49 *rework* — the percentage of units being reprocessed by the equipment because of a fault or defect. Also called redo.

5.2.50 *sample* — production or monitor unit(s) selected for measurement, inspection, or testing that are representative of the process step.

5.2.51 *sampling rate (SR)* — the percentage of samples relative to the total number of units passing through the process step.

5.2.52 *service contract* — an agreement for the supplier to provide equipment service or maintenance under specified terms and conditions beyond that which is supplied with the equipment.

5.2.53 *spare part* — prepurchased inventory of a component part maintained to service the equipment.

5.2.54 *standard deviation, σ* — the positive square root of the variance.

NOTE 6: The standard deviation of a population may be estimated from experimentally obtained data by the sample standard deviation (s):

$$s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2} \quad (1)$$

where:

n = number of data values,

x_i = value of the ith data point, and

$\bar{x}$ = mean of the data distribution.

5.2.55 *step* — see process step.

5.2.56 *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]

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5.2.57 *test unit* — see monitor unit.

5.2.58 *throughput (TP)* — the number of units (e.g., wafers, devices) per hour the equipment delivers to the factory, including all input, output, and internal overhead operation. TP includes all test or monitor units processed, since the cost of these nonproduct units is accounted for directly.

5.2.59 *tool* — often used synonymously with equipment or system in the silicon wafer processing industry.

5.2.60 *tooling* — fixtures and adaptors required to modify the equipment to the requirements of a specific unit, test, or operation.

5.2.61 *total utilization (TU)* — the percent of productive time during total time.

5.2.62 *unit* — any wafer, die, packaged device, or piece part thereof (includes product and nonproduct units).

5.2.63 *upper specification limit (USL)* — value of an attribute above which a product is said to be nonconforming. [SEMI E89]

5.2.64 *variance* — a statistical estimator that quantifies spread around the mean of a probability density function.

5.2.65 *volume requirement* — the number of units required to be processed by the equipment in a specific time period, normally units per week.

5.2.66 *yield* — see product yield.

5.3 *Symbols*

5.3.1 *Acf* — cost footprint rectangle area

5.3.2 α — alpha probability

5.3.3 β — beta probability

5.3.4 δ — bias

5.3.5 σ — standard deviation

6 Cost of Ownership Overview

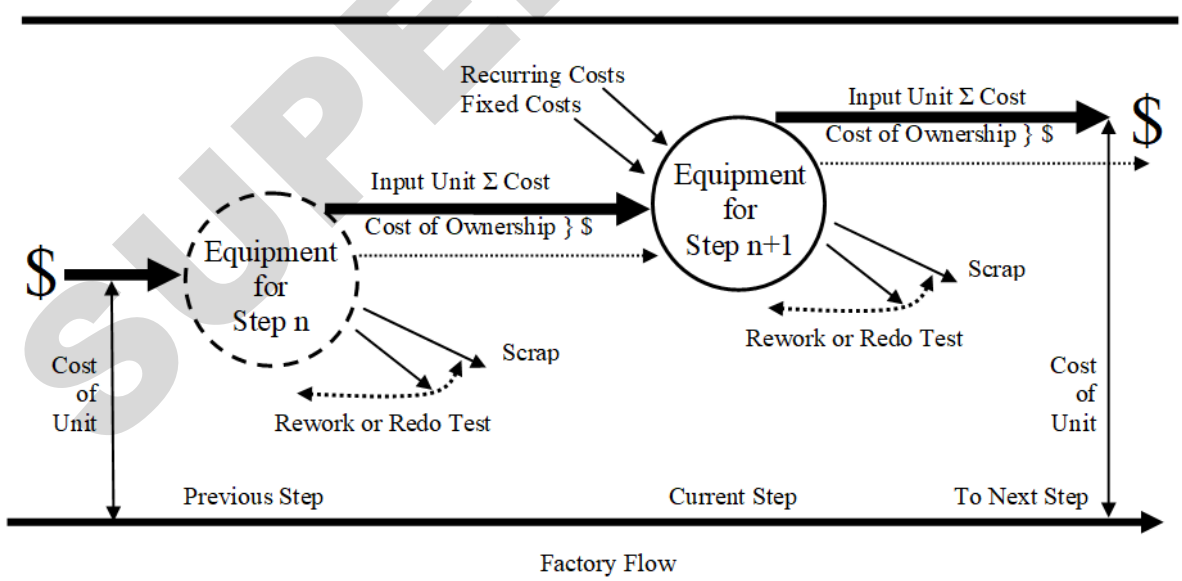

Figure 2
Accumulation of Cost during Factory Flow

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6.1 *Description of COO*

6.1.1 COO is a metric for evaluating the incremental cost added to a unit of good product flowing through equipment embedded in a factory environment for a specified lifetime, including the cost of yield loss (CYL). COO is calculated on an annualized basis. The metric is expressed as cost per good unit for one pass through the equipment. Figure 2 depicts this accumulation of cost that can be factored into two components, cost of equipment ownership (CEO) and CYL, as shown in Equation 2.

$$\text{Cost of Ownership} = \text{Cost of Equipment Ownership} + \text{Cost of Yield Loss}$$

$$COO = CEO + CYL \tag{2}$$

6.1.2 COO is the full cost of embedding, operating, and decommissioning in a factory environment equipment needed to accommodate the required volume of product units.

6.1.2.1 COO calculated with no constraints is referred to as comprehensive COO.

6.2 *Constrained Versions of COO*

6.2.1 A constrained version of COO imposes a set of defined restrictions to facilitate comparisons or to remove ambiguity. An example is a baseline COO that only includes equipment yield (EY) (i.e., defect limited yield [DLY] and parametric limited yield [PLY] are not included).

6.2.2 Constraints should be predefined by all stakeholders in a specific equipment COO model, prior to estimating COO, to minimize biasing of the COO estimate.

6.3 *Lifetimes*

6.3.1 The lifetime of the equipment is the time over which the fixed and recurring costs are considered for evaluating the annualized COO. The number of years that the equipment is planned to be used in manufacturing is the equipment's production lifetime.

6.3.2 Tax lifetime for depreciation allocation purposes is another measure of the equipment's lifetime that is customarily used in evaluating COO. Tax lifetime is based upon local tax or standard accounting practices.

6.3.3 The equipment usually remains in production much longer than the tax lifetime, so it is useful to consider both lifetimes in evaluating COO.

6.4 *CEO — Fixed and Recurring Costs*

6.4.1 Determining CEO requires enumerating all of the fixed and recurring costs that are incurred in the life cycle of the equipment. The calculation is shown in § 8.

6.4.2 Fixed costs are those incurred once and are usually associated with the acquisition and incorporation (e.g., installation, initial training, initial qualification) of the equipment into the factory.

6.4.2.1 End-of-life costs (e.g., decommissioning costs, decontamination costs, removal costs, disposal costs) are also part of fixed costs. Any salvage value may be deducted from the fixed costs associated with decommissioning.

NOTE 7: See SEMI S12 for equipment decontamination guidelines. See SEMI S16 for guidance on the recyclability and reusability of semiconductor manufacturing equipment, including materials and components.

6.4.2.2 Costs that are depreciated should be included as fixed costs.

6.4.3 Recurring costs are those that arise on a regular basis from the operation and maintenance of the equipment. Some infrequent recurring costs, including the costs of upgrading the equipment to new technologies may be included in fixed costs if the CEO is being calculated to compare an upgraded existing equipment with a new acquisition.

NOTE 8: See SEMI S23 for information on measuring energy, utilities, and materials to help determine the recurring costs related to them.

6.5 *Yield*

6.5.1 Yield is a metric of the percentage of the unit volume that results in good product. Yield affects the COO in a number of ways.

- Volume of units that must be processed for the required product requirements.

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