Semiconductor Manufacturing Productivity

Overall Equipment Effectiveness (OEE) Guidebook
Revision 1.0

SEMATECH
Technology Transfer 95032745A-GEN

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Abstract: This document defines SEMATECH's approach to Overall Equipment Effectiveness (OEE) methodology. OEE incorporates metrics from all semiconductor equipment manufacturing states into a measurement system that can help manufacturing and operations teams improve equipment performance and, therefore, reduce equipment cost of ownership (COO). This guidebook describes how to begin deploying OEE methodology. It is designed to help SEMATECH member companies and their equipment suppliers implement a manufacturing productivity improvement process. A SEMI E10 guidelines summary, instructions for using the OEE diskette, a description of the SEMATECH Capacity Utilization Bottleneck Efficiency System (CUBES), a glossary, and a list of related references are appended. The accompanying DOS-format diskette contains Microsoft Excel (v 4.0 or later) files that help calculate OEE values. This document is distributed with a companion case study, *Rockwell Telecommunications OEE Success Story*, technology transfer #95032750A-XFR.

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List of Abbreviations

ACT	actual cycle time
CIM	computer-integrated manufacturing
COO	cost of ownership
CPD	concurrent product development
CUBES	Capacity Utilization Bottleneck Efficiency System (model)
FM	foreign material
ICT	ideal cycle time
IHT	ideal handler time
IPT	ideal process time
MTBF	mean time between failures
OEE	overall equipment effectiveness
RS	resistivity sheet film thickness
TPM	total productive manufacturing
WIP	work in process

1 EXECUTIVE SUMMARY

This guidebook defines SEMATECH's approach to SEMATECH's overall equipment effectiveness (OEE) methodology and describes how to get started in the deployment of collaborative OEE methods. OEE methodology incorporates metrics from all semiconductor equipment manufacturing states in the SEMI E10 guidelines into a measurement system that can help manufacturing and operations teams improve equipment performance and, therefore, reduce equipment cost of ownership (COO).

In today's competitive market place, semiconductor manufacturers need flexible manufacturing methods and optimum manufacturing productivity. They and their suppliers must be able to measure and improve the productivity of the complex hardware and software systems that are used within current and future manufacturing processes.

The COO model simplifies these complex processes and functions into a template of five basic elements: capital cost, utilization, throughput, yield, and consumables cost (see Figure 1). Metrics captured for these elements can determine in product cost (dollars per square centimeter or appropriate units) the total cost of purchasing, learning, operating, and maintaining each tool or process. To increase productivity, however, additional data must be collected and evaluated to gauge the level of improvement.

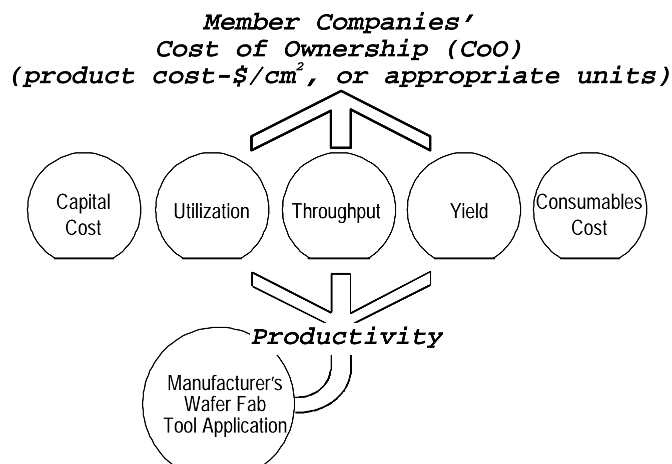

Figure 1 Cost of Ownership (COO)

OEE offers a measurement tool to evaluate equipment corrective action methods and ensure permanent productivity improvement. Based on SEMI guideline E10, OEE separates equipment productivity into three basic corrective action categories: availability, performance, and quality (see Figure 2).

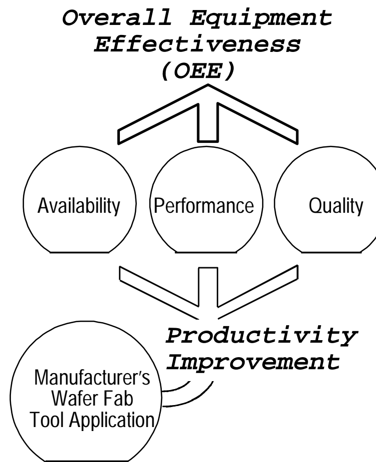

Figure 2 Overall Equipment Effectiveness (OEE)

These three categories encompass all equipment states and result in an OEE percentage based on the following formula:

$$\text{OEE\%} = \text{Availability} \times \text{Performance Efficiency} \times \text{Rate of Quality} \times 100$$

A unique key to success with this methodology is to include the equipment supplier as part of the factory floor corrective action team to reduce equipment cost and improve customer satisfaction. Customer/supplier collaboration will provide rapid and creative solutions in implementing OEE productivity gains.

Once the customer and supplier identify the root causes for equipment productivity loss and implement appropriate corrective action, productivity can improve rapidly. The supplier can use the OEE improvement process to identify and document a product history file that records the product improvements on current equipment. The improvement information can then become part of the next-generation product requirements. The combination of concurrent product development (CPD) and OEE learning will sustain customer satisfaction and lead to improved next-generation products.

2 INTRODUCTION

2.1 Purpose of This Guidebook

The purpose of this guidebook is two-fold:

1. To define SEMATECH's approach to OEE methodology
2. To describe how to get started in the deployment of collaborative OEE methods

This guidebook is intended to help SEMATECH member companies and their equipment suppliers ensure a successful manufacturing productivity improvement process. It is *not* intended to provide detailed team training. Training tools are being developed and will be detailed in a future document from the Manufacturing Methods division of SEMATECH.

2.2 Who Should Use This Guidebook?

The first users should be management. Implementing OEE, like implementing any major initiative that requires significant change, must be initiated with management's full awareness, support, and commitment.

The primary intended user of this guidebook is the manufacturing team, which should include process engineers, maintenance technicians, operations personnel, and the equipment supplier. Production managers and technicians, maintenance and equipment engineers, operational scheduling, and industrial engineers will find this guidebook useful to collectively improve total factory productivity.

2.3 What Is Overall Equipment Effectiveness?

OEE is an all-inclusive measurement of semiconductor equipment and manufacturing productivity. OEE approaches the problem of equipment manufacturing complexity with a methodology to deduce and implement permanent productivity improvement. Initially, these corrective action methods are best applied to bottleneck equipment that constrain the entire factory's productivity. Eventually, corrective action methods are expanded to include other factory floor equipment.

OEE is the product of six equipment losses grouped into three categories—availability, performance efficiency, and rate of quality—as follows:

Availability	1. Unscheduled equipment down time 2. Scheduled equipment down time
Performance Efficiency	3. Idling and minor stoppages 4. Reduced speed of equipment
Rate of Quality	5. Rework 6. Wafer or yield losses

The three groups of losses are then multiplied to determine the OEE% value:

OEE% = Availability X Performance Efficiency X Rate of Quality X 100

2.4 Who Benefits from OEE?

Both SEMATECH member companies (customers) and equipment manufacturers (suppliers) will benefit from implementing OEE. Mutual involvement in the OEE process will increase the supplier's equipment productivity; equipment productivity will improve the customer's factory productivity, reduce the equipment's cost of ownership, and increase both the customer's and the supplier's business profits. The following sections provide a non-prioritized listing of short-term and long-term OEE benefits.

Inherent in this methodology is the powerful leverage to be gained from cross-functional team problem solving. Productivity improvement teams can develop long-term customer/supplier partnering. Additionally, suppliers can apply the equipment corrective action OEE tool throughout the customer base and document a significant product design history database to use for enhancing next-generation technology. Through OEE partnering and the OEE improvement process, suppliers should experience an improvement in customer satisfaction.

2.4.1 OEE Benefits for SEMATECH Member Companies

- Maximized equipment availability, performance efficiency, and rate of quality for optimal OEE value and improved factory productivity.
- Improved factory operational teamwork for improved operational management and efficiency.
- Improved maintenance skills for operators, maintenance, technicians, and engineers.
- Improved rate of quality by reducing the effects of equipment failure (wafer scrap and rework).
- Improved bottleneck wafer equipment throughput for improved factory wafer capacity, which can reduce the need for redundant equipment.
- Focused corrective action resources that rapidly identify permanent fixes to the equipment. Permanent fixes reduce repair cost and increase productive time.
- More productive teaming with suppliers to find permanent solutions and to eliminate recurring equipment failures.
- Less frequent repair, shorter repair time, fewer spare parts, and lower field service cost, which all improve factory operating costs.
- Reduced need for maintenance personnel to repair equipment failure.
- Improved throughput to reduce wafer work in process (WIP), which reduces inventory cost.
- More cooperative maintenance efforts that involve operators to correct daily equipment deterioration and to assume a larger ownership of preventive maintenance through team ownership.
- Improved maintenance technician skills as a result of analyzing root causes and implementing corrective actions.

2.4.2 OEE Benefits for Equipment Suppliers

- Improved customer satisfaction through improved partnership in analyzing failures, driving to root cause, and rapidly delivering permanent corrective action to customers.
- Improved current and future equipment that is more productive and that demonstrates lower equipment COO because current product corrective actions will be incorporated into the design of next-generation equipment, promoting rapid design development with fewer inherent problems.
- Improved new product design that will lower new equipment development cost and reduce time-to-market of next generation equipment.
- Better designs for next-generation equipment that will maximize manufacturability, serviceability, and maintainability and will yield optimal OEE% values.
- Improved teamwork within the supplier's cross-functional design team.

2.5 Calculating OEE

The metrics that make up OEE include all SEMI E10 equipment states plus reduced speed and yield. To assist member companies and suppliers with learning and applying OEE calculated values, all available time is accounted for in this definition of OEE.

Table 1 OEE Metrics

METRIC	OEE
Non-Scheduled Time	X
Unscheduled Downtime	X
Scheduled Downtime	X
Engineering Time	X
Standby/Idle	X
Productive Time	X
Breakdowns	X
Setups/Adjustments	X
Reduced Speed	X
Idling/Minor Stoppages	X
Defects/Rework	X
Yield	X

The formulas associated with the SEMATECH method of calculating OEE include planned maintenance (scheduled downtime) and nonscheduled time. All equipment states data are obtained using the method stated in the SEMI E10 guidelines (see Appendix A for a summary of equipment states). The OEE diskette included in this document calculates OEE from the data. The user will need to provide the data from the company's computer-integrated manufacturing (CIM) database history files or other sources.

Details for calculating OEE follow.

2.5.1 Availability

$$\text{Availability} = \frac{\text{Total Time - Downtime*}}{\text{Total Time}}$$

* *Downtime* = scheduled downtime + unscheduled downtime (unanticipated failures) + nonscheduled time (holidays, shutdhown, for example)

Example:

Total Time =	168 hr	Scheduled Time =	28 hr
Nonscheduled Time =	0 hr	Unscheduled Time =	8 hr

Scheduled downtime consists of

Planned maintenance	10 hr
Production setup	12 hr
Chemical/gas change	2 hr
Maintenance delay	4 hr

$$\text{Availability} = \frac{168 - (28 + 8)}{168} \text{ X } 100 = \mathbf{78.6\%}$$

2.5.2 Performance Efficiency

Performance efficiency is determined first by calculating the following:

$$\text{Rate Efficiency} = \frac{\text{Ideal Cycle Time}}{\text{Actual Cycle Time}}$$

$$\text{Operational Efficiency} = \frac{\text{Total Productive State Time (Regular Prod/Engr Prod/Rework)}}{\text{Equipment Operational Uptime (Productive, Standby \& Engr States)}}$$

Then by calculating:

Performance Efficiency = Rate Efficiency X Operational Efficiency

Guidelines:

Ideal Cycle Time (ICT): Equipment supplier specification for machine cycle time, as best determined from experience or time study measurements (includes handler load/unload), plus the process time of a good wafer (minutes per wafer). This metric may include multiple processes using the same tool and may be specific to a specific tool application.

Ideal Cycle Time (ICT) = Supplier-specified minutes/wafer

Actual Cycle Time (ACT): Actual process time of a good wafer measured in the production environment.

$$\text{Actual Cycle Time (ACT)} = \frac{\text{Prod Time}_1 \text{ x } 60\text{min/(hr x \# waf}_1) + \ldots + \text{Prod Time}_n \text{ x } 60\text{min/(hr x \# waf}_n)}{n}$$

Productive Time (Prod Time) is in hours.

1 to n = number of processes (a machine may be running more than one process)

Batch size: Furnace or other batch operations assume a maximum load for each recipe.

Maximum lot size is assumed for every operation.

Example:

Process A (ICT = 2.5 min/wafer)			Process B (ICT = 3.3 min/wafer)		
E10 State	**Run Time**	**Wafers Processed**	**E10 State**	**Run Time**	**Wafers Processed**
Reg Prod	20.4 hr	427	Reg Prod	68.7 hr	1033
Engr Prod	4.7 hr	99	Engr Prod	0.0	0
Rework	3.0 hr	47	Rework	5.6 hr	68
Total Product A	28.1 hr	573	Total Product B	74.3 hr	1101

Total Time	= 168.0 hr
Engineering State	= 5.0 hr
Standby State	= 24.6 hr
Production Time	= 102.4 hr (28.1 hr + 74.3 hr)

$$\text{Ideal Cycle Time (ICT)} = \frac{2.5 \text{ min/wafer} + 3.3 \text{ min/wafer}}{2} = 2.9 \text{ min/wafer}$$

$$\text{Actual Cycle Time (ACT)} = \frac{(28.1 \text{ X } 60)/573 + (74.3 \text{ X } 60) / 1101}{2} = 3.5 \text{ min/wafer}$$

$$\text{Rate Efficiency} = \frac{2.9 \text{ min/wafer}}{3.5 \text{ min/wafer}} = 0.829$$

$$\text{Operational Efficiency} = \frac{102.4 \text{ hr}}{102.4 \text{ hr} + 5.0 \text{ hr} + 24.6 \text{ hr}} = 0.776$$

Performance Efficiency = 0.829 X 0.776 X 100 = **64.3%**

NOTE: ICT in this example is being averaged for simplicity. The OEE diskette calculation will weight the ICT based on the actual percentages of the product mix that was run during the measurement period.

2.5.3 Rate of Quality

$$\text{Rate of Quality} = \frac{\text{Total Wafers Processed - Rejects}}{\text{Total Wafers Processed}} \text{ X 100}$$

Guideline:

Rejects include (1) process scrap and (2) reworked wafers.

Example:

Process	Good Wafers	Reworked	Scrap	Total Processed
A	524	47	2	573
B	1030	68	3	1101
Total	1554	115	5	1674

$$\text{Rate of Quality} = \frac{1674 - (115 + 5)}{1674} \text{ X } 100 = \mathbf{92.8\%}$$

2.5.4 Final Calculation

The final calculation is the product of availability, performance efficiency, and rate of quality.

OEE% = 0.786 (Avail) X 0.643 (Perf) X 0.928 (Qual) X 100 = **46.9%**

2.5.5 Using OEE Calculations

These OEE calculations should be used to obtain the OEE measurement on a particular tool. In the short term, continuous improvement of OEE—with incremental targets to achieve the desired metric goals—should be the goal of the cross-functional team. Reaching a particular world-class OEE numeric value or benchmarking other factory floor tools should be long-term goals.

2.6 Other Ways to Use and Calculate OEE

There are many different ways to use OEE, and several modifications have been made to the equations by other companies. Some companies, such as Harris Semiconductor, measure their effectiveness of meeting demand; others use guidelines that further define the data so more root cause analysis can be done, particularly in the quality part of the equation. Rockwell Telecommunication is using a simple method of measuring OEE that allows them to examine the entire production line and measure bottleneck tool performance. A case study of Rockwell's success is in the *Rockwell Telecommunications Overall Equipment Effectiveness (OEE) Success Story*, SEMATECH Technology Transfer #95032750A-XFR.

2.7 OEE Calculation Diskette

This guidebook includes a 3.5-inch diskette in DOS format of Microsoft Excel (version 4.0 or later) files that can be used to perform the calculations in Section 2.5. The user must manually enter all data into the spreadsheet. A detailed procedure for using the diskette is in Appendix B.

2.8 OEE Calculation Support Tool - CUBES

The CUBES model was developed at SEMATECH to analyze manufacturing bottlenecks by calculating tool availability, performance efficiency, and rate of quality so the cross-functional manufacturing team can identify and fix bottleneck tools. This model is simple to use and quickly evaluates changes to tool operating conditions and their effects on tool efficiency and throughput. Appendix C contains a brief description of CUBES. Instructions are in *Capacity Utilization Bottleneck Efficiency System (CUBES): Release 2.0*, SEMATECH Technology Transfer #94112634A-ENG.

3 HOW TO GET STARTED USING OEE

The SEMATECH method of implementing OEE progresses through three basic steps: management support, manufacturing OEE teams, and supplier concurrent product development. These three general steps are first introduced through a flow diagram (Section 3.2). The steps are described more fully in relation to the manufacturing equipment productivity learning curve in Section 3.3. A list of subprocesses that should occur within each step is in Section 3.4. Once you understand the process, Section 3.5 helps your company determine appropriate short-term and long-term goals. Figure 3 graphically depicts this progression.

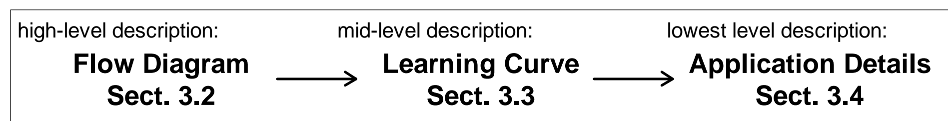

Figure 3 Overview of How to Get Started Using OEE

3.1 Before You Begin

The productivity improvement process begins by having the following in place before starting to examine the OEE% of a particular tool:

1. Identify current bottleneck tools (those with persistent large wafer queues, frequent equipment failure [short mean time between failure], and excessive repair time [long mean time to repair]).
2. Have data available, preferably in automated form (data collection should provide accurate, real-time information). The data collected should include idle time and other non-equipment-related categories. This data can usually be obtained from an existing CIM tracking system.
3. Have an equipment improvement program in place.
   - Establish a cross-functional team activity to address problem areas.
   - Do an aggressive Pareto analysis of equipment failures on tools with low mean time between failures (MTBFs).
   - Foster a long-term improvement culture. Take the time to find the root cause and insist on equipment improvement. Do not “reset and run” the equipment.
4. Encourage active supplier participation. Supplier representatives should be members of the cross-functional teams.

3.2 Implementation Process

OEE methodology is a productivity improvement process (Figure 4) that starts with management's awareness of total productive manufacturing (TPM) and commitment to focus on teamwork and cross-functional problem solving. Equipment suppliers participate as team members.

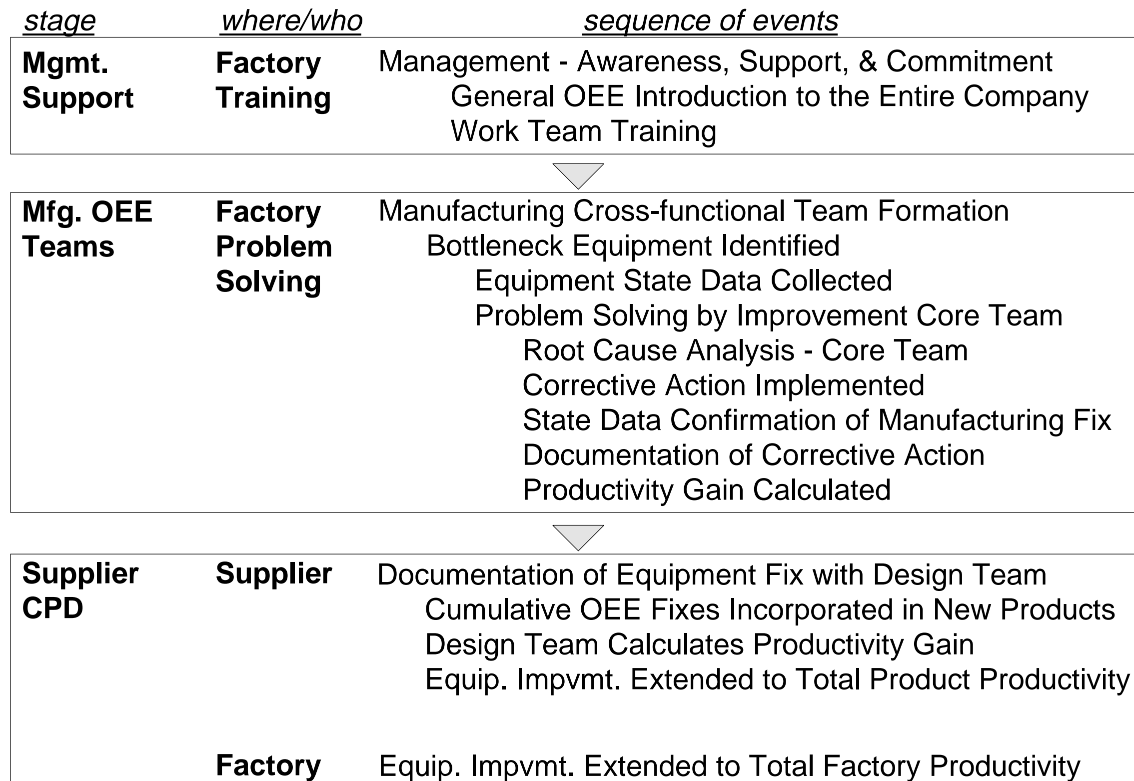

Figure 4 OEE Process Flow Diagram

3.3 Manufacturing Equipment Productivity Learning Curve

The Manufacturing Equipment Productivity Learning Curve in Figure 5 serves as a general guide to deploying the OEE methodology. It identifies the three integrated learning steps that lead to total *predictive* manufacturing, the mature form of TPM. Productivity gains that focus on optimal cost of ownership are identified for each learning curve step.

Rapid equipment productivity improvement depends on the following:

1. Management commitment to using OEE methodology
2. Rapid core team equipment problem identification
3. Root cause problem characterization
4. Permanent equipment solutions by the diverse work teams

The following sections describe each learning step.

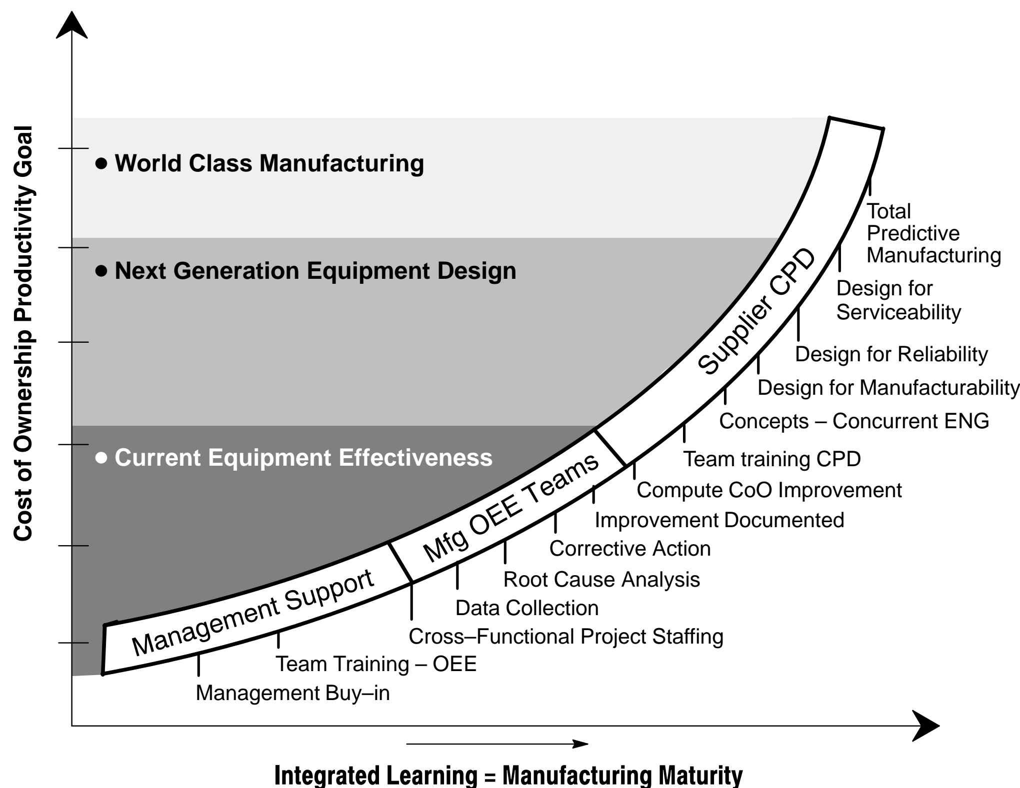

Figure 5 Manufacturing Equipment Productivity Learning Curve

3.3.1 Step 1: Management Support

Implementing OEE, like any major initiative dealing with change in semiconductor manufacturing or equipment supplier environments, requires significant commitment from all elements of a company's management if there is to be consistent and lasting OEE productivity gain. The OEE learning curve thus commences with management's awareness and commitment to ensure necessary funding for OEE training throughout the manufacturing and appropriate cross-functional areas. Specific factory floor training support, which is not a part of this guidebook, should include the following topics, where appropriate, for both the member company and equipment supplier cross-functional teams:

1. Working in teams
2. Data collection
3. Problem solving

3.3.2 Step 2: Manufacturing OEE Teams

With the basic team training completed in data collection and problem solving, cross-functional teams need to be formed from common manufacturing equipment process disciplines. These teams need to include supplier engineering representatives who will participate in the OEE improvement of their equipment. To operate efficiently with the factory team, supplier representatives must also have an understanding of data collection and problem-solving techniques. Accurately identifying bottleneck tools is a critical part of this step. Focusing on a non-bottleneck tool will not provide any increase in productivity at the factory level.

Other key elements of this step are collecting accurate and timely data, identifying the root cause of a failure, and implementing appropriate corrective action.

3.3.3 Step 3: Supplier Concurrent Product Development (CPD)

The learning curve for the equipment suppliers and member companies continues with the supplier's design team joining forces with the manufacturing team to ensure that root cause corrective action is fully captured in the current equipment fix. The supplier's design team will incorporate these OEE improvements in its new product's design phase requirements. The cumulative OEE product improvements must be included with the next-generation technology requirements to ensure optimal design productivity gain.

At the upper end of the learning curve is a mature semiconductor factory and supplier equipment manufacturing process that demonstrates optimal productivity and optimal COO. At this point, supplier and customer are collaborating in a TPM environment. Total productive manufacturing, in its mature form, becomes total predictive manufacturing, in which *capital expenditures* versus *capacity and costs* are predictive.

3.4 Learning Curve Application Details

3.4.1 Step 1: Management Support

Management support includes the allocation of time, resources, and team success criteria. Activities include the following:

- Ensure management commitment to manufacturing quality and continuous improvement
- Provide top management with an understanding of OEE principles and obtain commitment to productivity improvement
- Determine general OEE deployment strategy
- Train manufacturing work teams for a teamwork culture
- Identify cross-functional teams, which may include purchasing, marketing, receiving, design, software, process engineering, maintenance, finance, operators, and specific equipment suppliers
- Ensure the OEE equipment vision and objectives with implementation time schedule are communicated throughout the organization
- Formulate an OEE training deployment plan
- Deliver a generic OEE training orientation overview to appropriate company personnel

3.4.2 Step 2: Manufacturing OEE Teams

The following list contains events during this step; data collection, root causes, and corrective actions are discussed more fully in the following subsections.

- Establish programs for equipment preventive maintenance, equipment improvement, and engineering process improvement.
- Select appropriate tools to support OEE training (data collection, CIM, and CUBES).
- Launch OEE methodology training with manufacturing using equipment failure data.
- Collect equipment losses, determine the leading wafer loss, and prioritize equipment improvement efforts.
- Analyze OEE loss data, for example, using the CUBES equipment modeling tool.
- Use a failure analysis process to determine equipment wafer losses and identify root cause.
- Define improvement opportunities to include all known root causes.
- Plan and implement corrective actions with supplier.
- Train to support corrective action process and implement corrective action plans.
- Collect data and then measure and document equipment loss improvement progress.
- Review progress to ensure sustained corrective action improvements.
- Document equipment improvement details for case study training and integration with supplier's database for new designs.
- Review with suppliers their documented equipment corrective action plan. This will ensure that improvements are incorporated into next-generation equipment designs for sustained productivity gains.

3.4.2.1 Importance of Accurate, Timely Data

Obtaining an accurate OEE% value can be a time-consuming and difficult process. Generating a data history file on every bottleneck tool in the factory requires dedicated, trained team personnel who capture *all* equipment state OEE data. Without accurate data, the root causes identified will be erroneous, which will lead to delays in applying the correct, permanent corrective action. This can be a key *barrier* to implementing the OEE methodology.

Team members must be trained in TPM methodology, OEE metrics, and the *accurate* and *timely* entry of the equipment state data.

3.4.2.2 Equipment Failure Root Cause Analysis

A *root cause* is the source or original cause of a failure mode. If you can prevent or reduce the probability of a root cause occurring, you can significantly reduce the probability of, or eliminate entirely, the failure mode occurring. Root cause analysis is a process for identifying fundamental failure mode sources. Some tools for conducting equipment failure root cause analysis include fault tree analysis and the Ishikawa cause and effects diagram (fishbone).

3.4.2.3 Equipment Corrective Action Using SEMI E10 Equipment States

SEMI E10 guidelines has six equipment states: nonscheduled, unscheduled downtime, scheduled downtime, engineering, standby, and productive. OEE maps the E10 equipment states into the three OEE loss categories: availability, equipment performance, and rate of quality (see Figure 6).

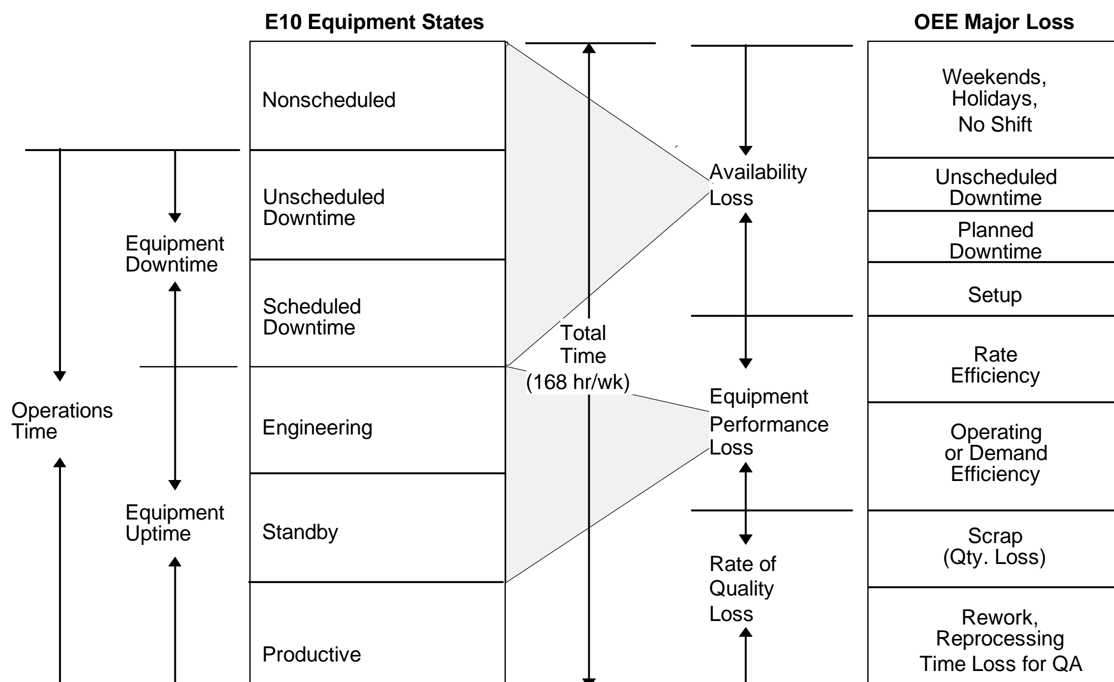

Figure 6 Mapping E10 Equipment States into OEE Loss Categories

The emphasis in using OEE is on equipment *improvement*, not on requiring that all six equipment states be used to implement the OEE process. Generally, as corrective actions are applied to equipment, the focus moves more toward detailed, subtle root causes. The OEE% value will depend on the equipment states included in your definition. Because of this, OEE% cannot be used to compare different customers' productivity levels, but they can provide an understanding of the relative improvement in productivity over time for a given piece of equipment.

Suppliers must keep this in mind when relating their equipment OEE values to customers: list the equipment states used to calculate and validate your OEE% value. You should also track and emphasize improvement over time when partnering with your customer. Equipment corrective action data tracking will be a part of a future CUBES model release.

3.4.3 Step 3: Supplier Concurrent Product Development

During this step, the supplier fully utilizes concurrent product development. CPD is a well defined, team-driven, new product development process that is consistently applied to accomplish product planning, product definition, design engineering, manufacturing engineering, test engineering, field service engineering, and quality engineering activities involved in the design, development, and manufacturing of new products.

Total Predictive Manufacturing represents the mature stage of the OEE process. Among the things that should occur during Step 3 are the following:

- Ensure the actions listed in Step 2 (above) become the team's continuous improvement process. The equipment improvement team then moves up the bottleneck equipment sets that are constricting wafer production.
- Identify computer-integrated manufacturing platforms and methods to automate the OEE data collection and sustain performance over time. The sharing of progress and a sense of ownership by team personnel is important to the overall process.
- Benchmark team productivity against world-class industry competitors for future productivity goals, market share, and profitability.

3.5 OEE Measurement Goals

The goals set by member companies and equipment suppliers who embark on the OEE methodology will depend on where they enter the learning curve (discussed in Section 3.3). The short and long-term goals listed in the following sections are suggestions to promote common discussion within a company and, perhaps, throughout the SEMATECH community.

3.5.1 Suggested Goals for SEMATECH Member Companies

Short-term productivity goals:

- Obtain top management commitment to OEE productivity improvement methodologies.
- Establish cross-functional operational teams that include equipment suppliers.
- Establish an OEE problem-solving culture that takes time to get to a problem's root cause and permanently solves all known equipment productivity losses.

- Negotiate new technology contracts with equipment suppliers to include equipment acceptance beta testing with an OEE goal of 70% (not including standby/idle-wait time).
- Incorporate the 70% goal into SEMATECH thrust projects' statements of work (SOWs) (assuming a manufacturing site location).
- Calculate the equipment COO for each equipment type used.

3.5.2 Suggested Goals for Equipment Suppliers

Short-term OEE goals:

- Establish OEE performance goals.
- Train the entire organization in the use of OEE.
- Design for reliability and maintainability from a manufacturing perspective.
- Provide rapid response to down equipment and hold monthly customer review meetings.
- Use corrective action responses to improve the equipment designs.
- Participate with customers in joint OEE bottleneck equipment productivity improvement.
- Transfer all equipment corrective action fixes to new equipment designs.
- Conduct new equipment design reviews with customers and relate these to OEE value goals.
- Jointly develop (with the customer) a vision and deployment plan to achieve the long-term productivity goals of the customer.
- Continuously improve strategic and tactical joint OEE methodology with customers.

Long-term OEE goals (mature predictive manufacturing):

- Conduct acceptance testing of customer equipment with OEE values greater than 70% and minimal COO.
- Validate and document equipment COO at acceptance testing and with accurate predictive installation time and resources, and predict the first year of usage cost data.
- Design next-generation equipment for reliability, maintainability, safety, space reduction, fail-safe mechanisms, and quick setup.
- Use concurrent product development to ensure that manufacturability, serviceability, and reliability are included in all design requirements at the concept stage.

3.6 Summary of OEE Implementation Process

The SEMATECH method of implementing OEE progresses through three basic steps: management support, manufacturing OEE teams, and supplier concurrent product development. This section has described, from a high level to a detailed level, the process of implementing Overall Equipment Effectiveness within a manufacturing factory. To help you set realistic goals for your organization, this section also listed some suggested short-term and long-term goals. For more in-depth reading, a list of references is provided at the back of this book. For SEMATECH assistance, a list of contacts is also provided in the back of the book.

4 GLOSSARY

bottleneck equipment—Manufacturing equipment that is persistently constraining the entire daily wafer production schedule. Bottleneck equipment is identified by persistent large wafer queues, frequent equipment failure (short MTBF), and excessive repair time (long mean time to repair).

Capacity Utilization Bottleneck Efficiency System (CUBES)—A modeling tool that was developed to quickly analyze bottleneck equipment throughput and speed efficiency losses using the E10 equipment states. From these state efficiency losses, CUBES also helps prioritize wafer losses for solving by a focused team.

computer-integrated manufacturing (CIM)—The application of computers to the needs of manufacturing business for the purpose of integrating aspects of the business such as production, sales, marketing, and product engineering.

concurrent product development (CPD)—A well defined, team-driven new product development process that is consistently applied to accomplish product planning, product definition, design engineering, manufacturing engineering, test engineering, field service engineering, and quality engineering activities.

corrective action—A procedure for documenting improvement that is implemented and proven to correct the root cause of a failure or design deficiency.

failure—An event in which an item does not perform its required function within the specified limits under specified conditions.

failure analysis—A determination of failure cause made by logical reasoning and examination of data, system, and available physical evidence.

mean time to repair (MTTR)—Measure of equipment maintainability. The sum of corrective maintenance times at any specific level of repair, divided by the total number of failures within an item repaired at that level, during a particular interval under stated conditions.

mean time between failure (MTBF)—Measure of reliability for repairable items. The total number of units of an item divided by the total number of failures with that population, during a particular measurement interval under stated conditions.

Overall Equipment Effectiveness (OEE)—An all-inclusive measurement of semiconductor equipment and manufacturing productivity. Productivity is measured by availability, performance efficiency, and rate of quality. The factors used in the SEMATECH calculation of OEE go beyond the E10 and traditional total productive manufacturing factors to include nonscheduled and scheduled equipment downtime metrics.

OEE methodology—OEE methodology is a productivity improvement process that starts with management awareness of total productive manufacturing and their commitment to focus the factory work force on training in teamwork and cross-functional equipment problem solving. Equipment suppliers participate on factory teams to identify and fix equipment failures.

reliability—The duration or probability of failure-free performance under stated conditions.

root cause—The reason for the primary and most fundamental failure, faults, or errors that have induced other failures and for which effective permanent corrective action can be implemented.

E10 equipment states—E10 divides total equipment time into six basic states: productive, engineering, standby, scheduled downtime, unscheduled downtime, and nonscheduled time. Uptime includes the time spent in productive, engineering, and standby. Downtime is the time spent in scheduled downtime and unscheduled downtime.

total productive manufacturing (TPM)—A comprehensive manufacturing strategy to improve equipment productivity. The strategy elements include cross-functional teams to eliminate barriers to machine uptime, rigorous preventive maintenance programs, improved maintenance operations management efficiency, equipment maintenance training to the lowest level, and information systems to support the development of imported equipment with lower cost and higher reliability.

uptime—Time when equipment is in a condition to perform its intended function. It does not include any portion of scheduled downtime or nonscheduled time.

work team—Equipment operational team represented by the operator, engineers (process and equipment), maintenance, schedulers, and supplier members. The team's primary focus is implementing OEE in the work environment to identify root cause equipment losses, implement corrective action, and document the OEE% value improvement over time.

5 REFERENCES

5.1 SEMATECH Documents, TPM-Related Technology

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--. *Harris Utilization and Implementation of Total Productive Maintenance (TPM) Statement of Work.* Technology Transfer #92051136A-SOW. Austin, TX: SEMATECH. June 23, 1992.

--. *Total Productive Maintenance (TPM) Equipment Baseline and Initial Clean Report Overview.* Technology Transfer #92101358A-ENG. Austin, TX: SEMATECH. November 23, 1992.

--. *Total Productive Maintenance (TPM) Equipment Baseline and Initial Clean Report Summary.* Technology Transfer #92101358A-SUM. Austin, TX: SEMATECH. November 23, 1992.

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--. *Total Productive Maintenance (TPM) Phase 1 Summary Report: Equipment Performance Improvements*. Technology Transfer #93011472A-ENG. Austin, TX: SEMATECH. February 22, 1993.

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Buratti, Ed. *Overall Equipment Effectiveness (OEE).* (video) Technology Transfer #93092032A-GEN. Austin, TX: SEMATECH. October 6, 1994.

Schey, Dennis. *Total Productive Maintenance (TPM): The Varian 3290 Quick Change Over.* Technology Transfer #92031025A-GEN. April 2, 1992.

5.3 SEMATECH Documents, CUBES

Fekel, Kim and John Konopka. *Capacity Utilization Bottleneck Efficiency System (CUBES) Release 2.0.* Technology Transfer #94112634A-ENG. January 5, 1995.

5.4 Other References

Gotoh, Fumio. *Equipment Planning for TPM*. Cambridge, MA: Productivity Press. 1988.

Hartmann, Edward H. *Successfully Installing TPM in a Non-Japanese Plant*. Pittsburgh, PA: TPM Press. 1992.

Nakajima, Seiichi. *Introduction to TPM*. Cambridge, MA: Productivity Press. 1984.

Shirose, Kunio. *TPM for Work Shop Leaders*. Cambridge, MA: Productivity Press. 1984.

Suzuki, Tokutaro. *New Direction for TPM*. Cambridge, MA: Productivity Press. 1992.

6 CONTACTS

topic	*contact organization*
TPM/OEE Methodology	SEMATECH Manufacturing Methods Division
Member company OEE focus	SEMATECH Manufacturing Methods Division
Supplier OEE focus	SEMATECH Total Quality Division
CUBES model	SEMATECH Modeling, CAD, and Statistical Methods Division
Capital productivity	SEMATECH Factory Integration and Productivity Analysis Division

All of these divisions can be contacted through SEMATECH's customer service number, (512) 356-SEMA.

APPENDIX A
SEMI E10 GUIDELINES SUMMARY

TOTAL TIME (Operations Time + Nonscheduled Time)

Operations Time (Uptime + Downtime)

Equipment Uptime:

1. Productive State
   - Regular Production
   - Production Test (qualifications/FM check/RS/thickness)
   - Engineering (split lots/qualification lots/engineering work requests)
   - Rework
   - On-the-job Training (operator training)
   - Load/Unload
2. Standby State
   - No Operator (breaks, lunches, meetings)
   - No Product (includes those caused by a lack of measurement tools)
   - No Support Tools (cassettes, tote boxes, etc.)
   - Waiting for Results of Production Test
   - Cluster Tools: Associated Cluster Module Downtime
   - Host Computer/Cell Controller
3. Engineering State
   - Process Engineering (characterization/yield analysis)
   - Equipment Engineering (equipment evaluation)

Equipment Downtime

1. Scheduled Downtime State
   - Set-up (conversion/changeover → ready to run)
   - Preventive Maintenance (action → ready to run)
   - Change of Consumables/Chemical
   - Maintenance Delay (waiting on technicians, parts, management decision)
2. Unscheduled Downtime State
   - Predictive Maintenance (action → ready to run)
   - Facilities (temp/humidity/FM/power/gases/exhaust)
   - Repair (diagnosis/action → ready to run)
   - Change of Consumables/Chemicals
   - Maintenance Delay (waiting technicians, parts, management decision)

   - Out-of-spec Input (support tools, incoming product, test data, contaminated chemicals, etc.)
   - Facilities (temp/humidity/FM/power/gases/exhaust)
3. Nonscheduled State
   - Shutdowns/Holidays/Weekends/Unworked Shifts (includes shutdown and startup time)
   - Equipment: Install/Rebuild/Upgrade/Off-line Training

NOTE: Ready to run includes ramp down, ramp up, equipment test, and process test.

APPENDIX B
OEE DISKETTE DATA ENTERING AND ANALYSIS

NOTE: Before using the diskette, make a backup copy. Also, in the following instructions, the numbers provided in parentheses (for example, BB08) are the Excel spreadsheet cell locations.

To open the file:

1. Open one of the following applications: Microsoft Excel 4.0 or 5.0 or Lotus 1-2-3, version 4.
2. Put the diskette in the diskette drive and open the file a:\OEE.XLW. (This is an Excel file that contains the OEE spreadsheet.)

To enter data:

3. From the Summary Input Screen, enter “Tool Information,” the “Data Entry Date” (use current date), and “Date Range of Data.”

   NOTE: Previously entered data can be reset to zero by clicking on the “Clear Entries” button. Clearing entries will take from 2 to 20 minutes to reset, depending on the model of personal computer that you are using.
4. Access “Availability.” (All entries are measured in hours.)
5. Enter “Total Time.” (BB08)
6. Enter event hours in one of the following ways:
   a. Use “Detailed” (D) information. Enter “D” (BC10) then enter the number of hours for each event in its respective category (nonscheduled, scheduled, and unscheduled downtime). This list may be edited.
   b. Use “Summary” (S) information. Enter “S” (BC10) then enter the summarized data hours in the “Summary Information” box (BF9-13).

   NOTE: If you click on “OEE Optional Inputs,” you can include or exclude nonscheduled time and/or planned downtime in the OEE calculation. The program default is to include both of these times in the final calculation.
7. Access “Performance Efficiency.”
8. List each process run on this tool.
9. Determine the ideal process time (IPT) for each of these processes and enter that data. (BI10-24).
10. Determine the ideal handler time (IHT) and enter that data (BJ10-24)

    NOTE: Steps 8-10 must only be entered one time.
11. Enter the following, according to the process run:
    - Actual production time (hours) in the PROD TIME column (BL10-24)
    - Number of wafers processed (BM10-24)

12. Enter event hours

    OPTION A:

    - Use Detailed information. Enter “D” (BK26).
    - Enter hours in each event in their respective category (production, engineering, standby). List may be edited.

    OPTION B

    - Use Summary (S) information. Enter “S” (BK26).
    - Enter summarized data hours in the Summary Information box (BI29-30).

13. Access “Quality Rate.”
14. Enter data by process run
    - Number of good wafers
    - Number of reworked wafers
    - Scrap wafers (known scrap for this time period)
    - Other yield losses[1] (unknown status/lots on hold)

To review OEE results:

15. Access “OEE Calculation.”
16. Select “1” for OEE% (E308) or “2” for Rockwell OEE[2] (E318).

To analyze equipment loss:

17. Access “OEE Corrective Action Data.”
18. Access “Update with Today’s Data.”
19. Review OEE Efficiency Chart (the stacked bar). Enter “D” (AL338) to compare dates. Enter “T” (AL338) to compare tools.
20. Review OEE Tool Efficiency Analysis (the pie chart).
21. Review OEE Overall Effects Chart (a Pareto of losses).
22. Access “Corrective Action Log.”
23. Enter any corrective actions taken or planned that will affect future OEE results, as determined by the equipment improvement team.

To save your work:

24. Use the “Save As” option under the FILE menu, and name the new file with a date that will reflect this measurement period (for example, OEE03155.XLW for March 15, 1995).

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[1] When the status of the wafers becomes known at a later date, adjust data in the original measurement period and recalculate OEE results for an accurate history file.

[2] The Rockwell result can be easily obtained by using the results from steps 7 through 9, above. After entering the ICT (combination of IPT and IHT), simply enter the “Prod Time” and “Wafers Processed.” No other entries are necessary.

APPENDIX C
OEE CALCULATION SUPPORT TOOL—CUBES

The purpose of CUBES is to provide a software tool for a consistent methodology so all groups who influence bottleneck tool capacity can work together for improvement. These groups include manufacturing, management, equipment engineering, maintenance, production control, process engineering, manufacturing engineering, and industrial engineering. This appendix provides a brief description of the CUBES model. For more information, refer to *Capacity Utilization Bottleneck Efficiency System (CUBES): Release 2.0* (SEMATECH Technology Transfer #94112634A-ENG).

CUBES is a simple-to-use model that analyzes manufacturing bottlenecks by calculating tool throughput, tool efficiency, and efficiency losses. The analysis needs to address and identify all elements of tool efficiency loss. CUBES can be used by a variety of semiconductor personnel, so a team can quickly analyze a tool's capacity and provide information relating to where and how throughput is lost on this tool. It is capable of being used in a variety of scenarios and what-ifs to develop a plan of action to take for increasing throughput on a bottleneck tool.

The CUBES model was developed at SEMATECH to address these needs. CUBES quickly analyzes manufacturing tools. It focuses on two key metrics: 1) tool throughput and 2) tool efficiency. It quickly evaluates changes to tool operating conditions and their effects on tool efficiency and throughput. CUBES provides its analysis with both an analytical and graphical approach. It not only provides tool efficiency and tool throughput calculations but also details the efficiency and throughput losses from any of the factors affecting the tool. A two-dimensional approach was used to identify all key elements affecting tool efficiency and throughput. These two dimensions are *percentage of metric tool speed* and *percentage of hours of operation* (on the graph, these are the Y and X axes, respectively).

CUBES allows the user to evaluate OEE calculations in a three ways:

1. Three efficiency calculations of availability, performance efficiency, and rate of quality
2. The six big losses of TPM
3. Detailed analysis by speed factor and SEMI E10 equipment state

See Table 2 for the conversion of these metrics.

Table 2 CUBES: OEE to SEMI E10 Conversion Table

OEE Efficiency Calculations	OEE Losses	E10 Efficiency Calculations
Availability	Setups/Adjustments	Nonscheduled Time Scheduled Downtime
	Breakdowns	Unscheduled Downtime
Performance Efficiency	Idling/Minor Stoppages	Engineering Time Standby/Idle Time Other Time Losses
	Reduced Speed	Tool Speed Losses Average Batch Size
Rate of Quality	Defects/Rework Yield	Quality Losses

The CUBES Template

The CUBES model OEE template was designed to allow the user to quickly focus on the key parameters of tool efficiency losses. There are several sections on the template displayed in Figure 7. Begin by moving clockwise in the top half of the figure, starting on the top left with "Summarized Input." This input summarizes tool parameters and reflects the conversion of semiconductor floor control system output and SEMI E10 parameters into a form that is easily comprehensible. Factors include tool speed, total time, average batch size, other speed losses, other time losses, standby, unscheduled downtime, engineering time, scheduled downtime, and nonscheduled downtime. In this section, the user can view the general assumptions of the model input, which will aid in validating the model.

In the section labeled "Summarized Output," the analytical analysis of the tool throughput and efficiency are performed. First, the CUBES efficiency percentage and the tool throughput are displayed. Next, the speed and time efficiency percentages are displayed. Finally, for each type of efficiency loss to the tool, three important analyses to the tool have been calculated and displayed. They are the overall effect percentage, the individual effect percentage and the throughput increase analysis in wafers.

The *overall effect percentage* is the contribution of this efficiency loss to the entire tool performance. The *individual effect percentage* is the contribution to the tool efficiency, assuming this is the only effect being analyzed at this time. The *throughput increase analysis* in wafers is the number of wafers that can be added to the output of the tool if this efficiency loss were eliminated. These metrics allow users to rank what improvements are most beneficial and where concentrated effects should be placed to improve efficiency.

The last section, and perhaps the most useful, is the graphical analysis of the tool efficiency and the overall impact of each of the efficiency losses. This is shown in the bottom half of Figure 7. This graphical analysis allows visual comparisons between each of the efficiency losses.

CUBES Overall Equipment Effectiveness (OEE) ANALYSIS TOOL

SUMMARIZED INPUT	
SEMI E10 FACTORS	
Total Time	168.00
Non-Scheduled Time	15.00
Scheduled Downtime	12.00
Engineering Time	12.00
Unscheduled Downtime	18.00
Standby/Idle Time	18.00
Other Time Losses (e.g., Prod. Test)	10.00
SPEED/QUALITY FACTORS	
Plan Tool Speed(WPH)	25
Actual Tool Speed (WPH)	22
Average Batch Size (% Full)	90
Quality Losses (% Loss)	15

SUMMARIZED OUTPUT			THROUGHPUT
Overall Equipment Effectiveness			
OEE (%)	33.26		1397
	OVERALL EFFECT (%)	INDIVIDUAL EFFECT (%)	THROUGHPUT INCREASE ANALYSIS IN WAFERS
EFFICIENCY RATINGS			
Total Availability Efficiency (due to losses 1&2 below)		66.07	959
Performance Efficiency (due to losses 3&4)		59.22	962
Quality Efficiency (due to losses 5&6)(Rate of Quality)		85.00	247
LOSSES DUE TO:			
1) Setups/Adjustments/Non-Scheduled	10.12	23.21	656
2) Breakdowns	7.07	13.95	303
3) Idling/Minor Stoppages	17.09	25.23	471
4) Reduced Speed	17.80	20.80	367
5) Defects/Rework	6.94	7.50	113
6) Yield	7.50	7.50	113

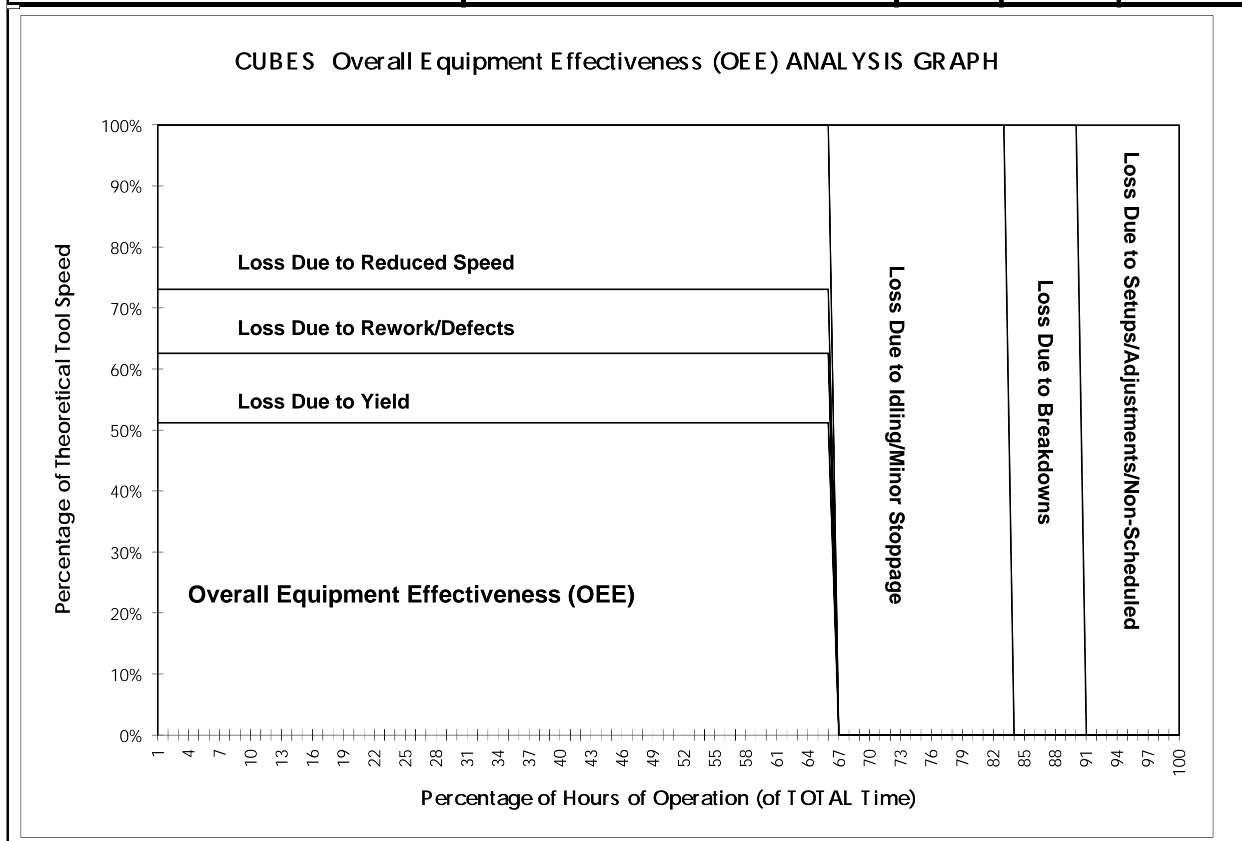

Figure 7 CUBES Model Template

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