Early Equipment Evaluation (E^3) Methodology

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Abstract: This report from the MFGM009 program provides process, automation, and development engineers and their managers a basic understanding of the requirements of the International SEMATECH (ISMT) Early Equipment Evaluation (E^3) process. The E^3 process emphasizes fact-based decision-making with statistically valid data at any stage of 300 mm semiconductor equipment development. Its primary intent is to initiate improvement activities when the results of equipment performance do not meet end user expectations and/or metrics.

Keywords: Equipment Testing, Procedures, Equipment Performance

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Table of Contents

List of Figures

List of Tables

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1 EXECUTIVE SUMMARY

The International SEMATECH (ISMT) Early Equipment Evaluation (E^3) process is a method for early and efficient determination of semiconductor manufacturing equipment performance against expectations of the 300 mm tool set. It is designed to accelerate the delivery of manufacturing worthiness to ISMT member companies before extensive production-level deployment of equipment. The E^3 process is applicable to all aspects of semiconductor manufacturing equipment such as process, metrology, and automated material handling equipment. The E^3 process also addresses the implementation of hardware, software, and facilities standards related to 300 mm semiconductor equipment. The process is composed of three stages: 1) determining the amount of available data related to the equipment selected for evaluation; 2) selecting and executing the appropriate testing; and 3) improving or modifying the equipment for optimized system performance.

The approach is to gather performance results and associated evidence to comprehend the state of the 300 mm tool technology and subsequently provide feedback to the supplier for improvement or modification. It is important to distinguish the E^3 methodology from other activities, such as product demonstrations or field improvement, since the methodology is designed to specifically focus on equipment at any maturity level of its product life cycle.

Within the context of the ISMT consortium, early performance evaluation of semiconductor equipment should take into account all possible data against established metrics, standards, guidelines, and procedures. This methodology presents a means of doing so on a consistent basis.

2 INTRODUCTION

2.1 Document Scope

This document provides process, automation, and development engineers and their managers a basic understanding of the requirements of the ISMT E^3 process. The E^3 process emphasizes fact-based decision-making with statistically valid data at any stage of semiconductor equipment development. The intent is to facilitate high level reviews of complex process or automated material transfer equipment, thereby initiating improvement activities related to equipment performance when results do not meet end user expectations and/or metrics. The methodology may also provide an enabling mechanism to facilitate the selection of equipment for the ISMT Advanced Tool Development Facility (ATDF) and/or a member company.

The processes described herein are generic enough to enable broad application of the methodology and can be updated periodically to reflect any change in the methods. This document is not a process or hardware development procedure. In addition, it cannot replace formal statistical analysis, engineering training, or competent management. The document also does not address supplier infrastructure although it does assume a supplier's commitment to sound project management, factual-based decision-making, and total quality management.

2.2 Reference Documents

Several documents reference standards, test methods, and metrics throughout the context of the E^3 process. Most ISMT documents are available on the public website at http://www.sematech.org, while others (such as industry standards) may be found at http://www.semi.org. Documents cited in this report are as follows:

1. *Joint Unified Equipment Performance Metrics – Rev. 3*, International SEMATECH/Selete, Technology Transfer # 97033265C-ENG.
2. *I300I Factory Guidelines*, International SEMATECH, Technology Transfer # 97063311G-ENG.
3. *Equipment Class Application Guideline*, International SEMATECH, Technology Transfer # 97033270B-ENG.
4. *Unified Equipment Performance Metrics for 0.25 um Technology*, International 300 mm Initiative/Selete, November 25, 1997.
5. *Unified Equipment Performance Metrics for 0.18 μm Technology*, Technology Transfer # 99093826A-TR, International SEMATECH, November 19, 1999.
6. *Unified Equipment Performance Metrics for 130 nm Technology*, Version 2.0, Technology Transfer # 99123857B-ENG, International SEMATECH, July 10, 2000.
7. *Metrics for 300 mm Automated Material Handling Systems (AMHS) and Production Equipment Interfaces: Revision 1.0*, Technology Transfer # 97123416B-TR, International SEMATECH, December 15, 1998.
8. *Overhead Hoist Safety Guidelines (Version 2.0A)*, International SEMATECH/Selete, October 3, 2001, http://www.sematech.org/public/resources/stds/supplierguide/documents/OHTSafetyfinal2.0A.pdf.
9. *EEC Guidebook (Phase 2.0): Version 2*, International SEMATECH/JEITA/Selete, December 2001, http://www.sematech.org/public/resources/ediag/guidelines/eecguide_rev2.0.pdf.
10. *E-Diagnostics Guidebook (update) V1.1b*, International SEMATECH, December 2001, http://www.sematech.org/public/resources/ediag/guidelines/guidebook_1.1b.pdf.
11. *Engineering Statistics Internet (ESI) Handbook*, NIST/International SEMATECH, http://www.sematech.org/public/resources/stats/Handbook/engststhndbk0.htm, http://www.itl.nist.gov/div898/handbook/.
12. *Demonstration Test Method – Revision 1*, Technology Transfer # 97063297B-XFR, International 300 mm Initiative, September 30, 1997.
13. *SEMATECH IRONMAN Guideline*, SEMATECH Technology Transfer # 95113028A-GEN, December 21, 1995, http://www.sematech.org/public/docubase/abstracts/3028agen.htm.
14. *300 mm Best-Known Practices (300 BKP) for 300 mm Factory Integration*, Technology Transfer # 00124063B-ENG, International SEMATECH, November 30, 2001.
15. *Equipment Class Application Guideline*, Technology Transfer # 97033270B-ENG**,** International SEMATECH, March 30, 2001.
16. *Overhead Transfer System Test Methodology*, Technology Transfer # 01064132A-ENG, International SEMATECH, June 29, 2001.
17. *International SEMATECH Equipment Maturity Assessment (EMA) Handbook*, # 01044107A-ENG, April 12, 2001.
18. The *International Technology Roadmap for Semiconductors (ITRS)*, NIST/International SEMATECH.
19. SEMI E1.9, Provisional Mechanical Specification for Cassettes Used to Transport and Store 300 mm Wafers.
20. SEMI E15.1, Provisional Specification for 300 mm Tool Load Port.

21. SEMI E47.1, Provisional Mechanical Specification for Boxes and Pods Used to Transport and Store 300 mm Wafers.
22. SEMI E57, Provisional Mechanical Specification for Kinematic Couplings Used to Align and Support 300 mm Wafer Carriers.
23. SEMI E62, Provisional Specification for 300 mm Front-Opening Interface Mechanical Standard (FIMS).
24. SEMI E106, Overview Guide to SEMI Standards for 300 mm Physical Interfaces and Carriers.
25. SEMI E10, Standard for Definition and Measurement of Equipment Reliability, Availability, and Maintainability (RAM).
26. SEMI E35, Cost of Ownership for Semiconductor Manufacturing Equipment Metrics.
27. SEMI E78, Electrostatic Compatibility - Guide to Assess and Control Electrostatic Discharge (ESD) and Electrostatic Attraction (ESA) for Equipment.
28. SEMI E79, Standard for Definition and Measurement of Equipment Productivity.
29. SEMI E89, Guide For Measurement System Capability Analysis.
30. SEMI E113, Specification For Semiconductor Processing Equipment RF Power Delivery Systems.
31. SEMI E5, SEMI Equipment Communications Standard 2 Message Content (SECS-II).
32. SEMI E30, Generic Model for Communications and Control of SEMI Equipment (GEM).
33. SEMI E37.1, High-Speed SECS Message Services Single-Session Mode (HSMS-SS).
34. SEMI E40, Standard for Processing Management.
35. SEMI E58, Automated Reliability, Availability, and Maintainability Standard (ARAMS): Concepts, Behavior, and Services.
36. SEMI E84, Specification for Enhanced Carrier Handoff Parallel I/O Interface.
37. SEMI E87, Provisional Specification for Carrier Transfer Standard (CTS).
38. SEMI E90, Specification for Substrate Tracking.
39. SEMI E94, Provisional Standard for Control Job Management Component.
40. SEMI S2, Safety Guidelines for Semiconductor Manufacturing Equipment.
41. SEMI S8, Safety Guidelines for Ergonomics/Human Factors Engineering of Semiconductor Manufacturing Equipment.
42. SEMI E6, Facilities Interface Specifications Guideline and Format.
43. SEMI E72, Provisional Specification and Guide for 300 mm Equipment Footprint, Height, and Weight.
44. SEMI F47, Specification for Semiconductor Processing Equipment Voltage Sag Immunity.
45. SEMI F49, Guide for Semiconductor Factory Systems Voltage Sag Immunity.

3 GLOSSARY AND ACRONYMS

AGV	Automated guided vehicle
AMC	Airborne molecular contaminants
AMHS	Automated material handling systems
Batch	The number of wafers >1 that are processed simultaneously by the production equipment
BKP	Best known practice
CIM	Computer integrated manufacturing
CAM	Computer aided manufacturing
COO	Cost of ownership
DTM	Demonstration test method
E^3	Early equipment evaluation
ECAG	Equipment Class Application Guideline
EMI	Electromagnetic interference
EPITs	Equipment Productivity Improvement Team
EPM	Equipment performance metrics
ESH	Environment, safety, and health
FIMA	Factory integration maturity assessment
FMEA	Failure mode and effects analysis
FOSB	Front opening shipping box
FOUP	Front opening unified pod wafer carrier
FOUPfor1	Front opening unified pod for a single wafer
FRACAS	Failure Reporting, Analysis and Corrective Action System
Gauge	Metrology equipment that is traceable to standards. This equipment is typically used for measuring the output (or product) of a tool
Gauge Study	A study of a metrology tool to determine its stability
I & C	Information and control
I300I	International 300 mm Initiative
Input parameter	Equipment parameters that can be adjusted or monitored and that affect operational performance
Interbay	Between fab processing bays
Intrabay	Within a processing bay
IRONMAN	Improving reliability of new machine at night
ISMT	International SEMATECH

ITRS	International Technology Roadmap for Semiconductors
Life Cycle	The measure of a semiconductor equipment existence from design concept to end of its productive viability or realized obsolescence as measured in time, usually in years
LPC	Liquid particle counter
MCS	Material control system
MDC	Mechanical dry cycle
MM&P	Manufacturing Methods & Productivity
MMC	Manufacturing Methods Council
NIST	National Institute of Standards and Technology
OHV	Overhead hoist vehicle
OTS	Overhead transport system
Output parameter	The result (typically measured on product) of the equipment process
P/T ratio	The ratio of precision to tolerance of a metrology tool. Reference SEMI M27
PAG	Program Advisory Group
PDC	Passive data collection
PGV	Person guided vehicle
PIC	Physical interfaces and carriers
RGV	Rail guided vehicle
RMS	Reticle management system
ROI	Return on investment
SOW	Statement of Work
SPC	Statistical process control
TBD	To be determined at a later date when data and/or detail become available
Type 1	A portion of the E^3 process that uses existing data or benchmarking only
Type 2	A portion of the E^3 process that involves additional testing (a specific tool) against one or more criteria
Type 3	A portion of the E^3 process that involves improvement and additional testing to optimize tool performance against certain criteria
WIP	Work in progress. This term is used to describe the inventory in an IC manufacturing environment

4 DESCRIPTION OF THE E³ METHOD

The ISMT E³ process is a method for early and efficient determination of equipment performance against expectations of the 300 mm tool set.

The E³ process is applicable to all aspects of semiconductor manufacturing equipment such as process, metrology, and automated material handling equipment. The E³ process also addresses hardware, software, and facilities standards implementation related to 300 mm semiconductor equipment. As stated earlier, the E³ process is designed for equipment with little or no field deployment. More information on equipment characteristics and maturity is in the *International SEMATECH Equipment Maturity Assessment (EMA) Handbook* (ISMT Technology Transfer # 01044107A-ENG).

The approach is to gather performance results and associated evidence to comprehend the state of the 300 mm tool technology and subsequently provide feedback to the supplier for improvement or modification purposes.

4.1 Depiction of the E³

The first step in the E³ process requires gathering equipment performance results. This information must be representative of the selected equipment to enable an evaluation team to make informed decisions about the next activity to be undertaken within a specific project. The E³ process is designed to focus on seven areas (see Figure 1) of equipment performance:

1. Process Performance (integrated circuit manufacturing as well as that of automated material transfer)
2. Reliability
3. Throughput and Cost of Ownership (COO)
4. Environment, Safety, and Health (ESH)
5. Facilities Standards and Guidelines
6. Hardware Standards and Guidelines
7. Software Standards and Guidelines

These areas have been selected by the ISMT member companies as high level indices crucial to equipment selection.

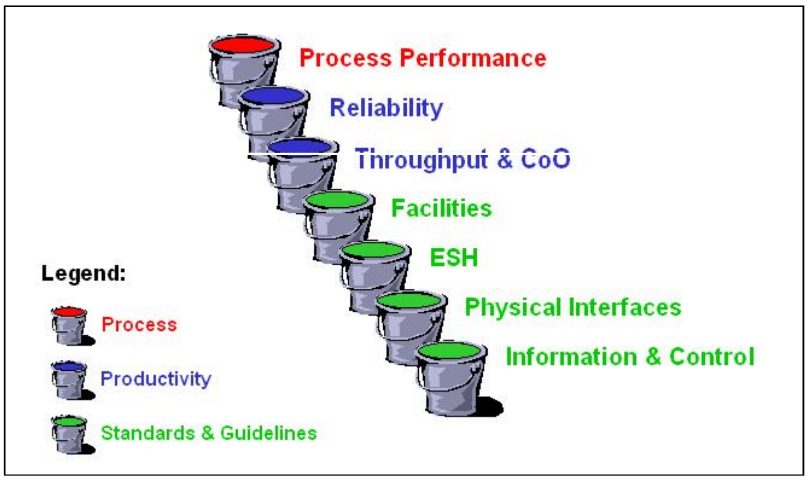

Figure 1 Key Equipment Performance Categories

The E^3 process begins with gathering and analyzing all available data on the targeted equipment. Evidentiary or supporting materials are also accessed to support the analysis process. As the performance results are analyzed, they are compared to the expected results in each of the seven categories (see Figure 1). Comparing those performance results to industry expectations highlights disparities in equipment performance to end user expectations. As those disparities or "gaps" are determined, they may be supplemented either by gathering more available data or by performing tests to generate additional data. In some cases, no data may be available. A case of "no data" may determine an area of evaluation or equipment improvement to be driven by the evaluation team.

For example, the performance result of a 180 nm uniformity process would be compared to the *180 nm Equipment Performance Metrics* document to determine if the supplier's equipment performance result met or surpassed the metric. Another example would be the results of automation software unit tests, which provide data relating to validated streams and functions sent to and from equipment for comparison to industry expectations in approved SEMI standards.

The E^3 process demands the use of sound statistical methods to establish data or information for submission in any of the seven areas. An E^3 evaluation should be operated in a cost-effective manner with minimal resources to obtain valid, representative, and meaningful results.

The following are some of the target outcomes of an equipment evaluation. Note that this section may depend upon the type of activity being performed.

- Identification of
  - Opportunities for improvement of equipment variability
  - Opportunities for improvement of equipment reliability
  - Major modes of failure and their root causes and solutions
- Determination of
  - Candidate areas of equipment design that are possible areas of improvement
  - Equipment selection
- Information on
  - The process, method, or procedure describing how the documented performance to a metric was assessed

The flow chart in Figure 2 illustrates the E^3 process methodology.

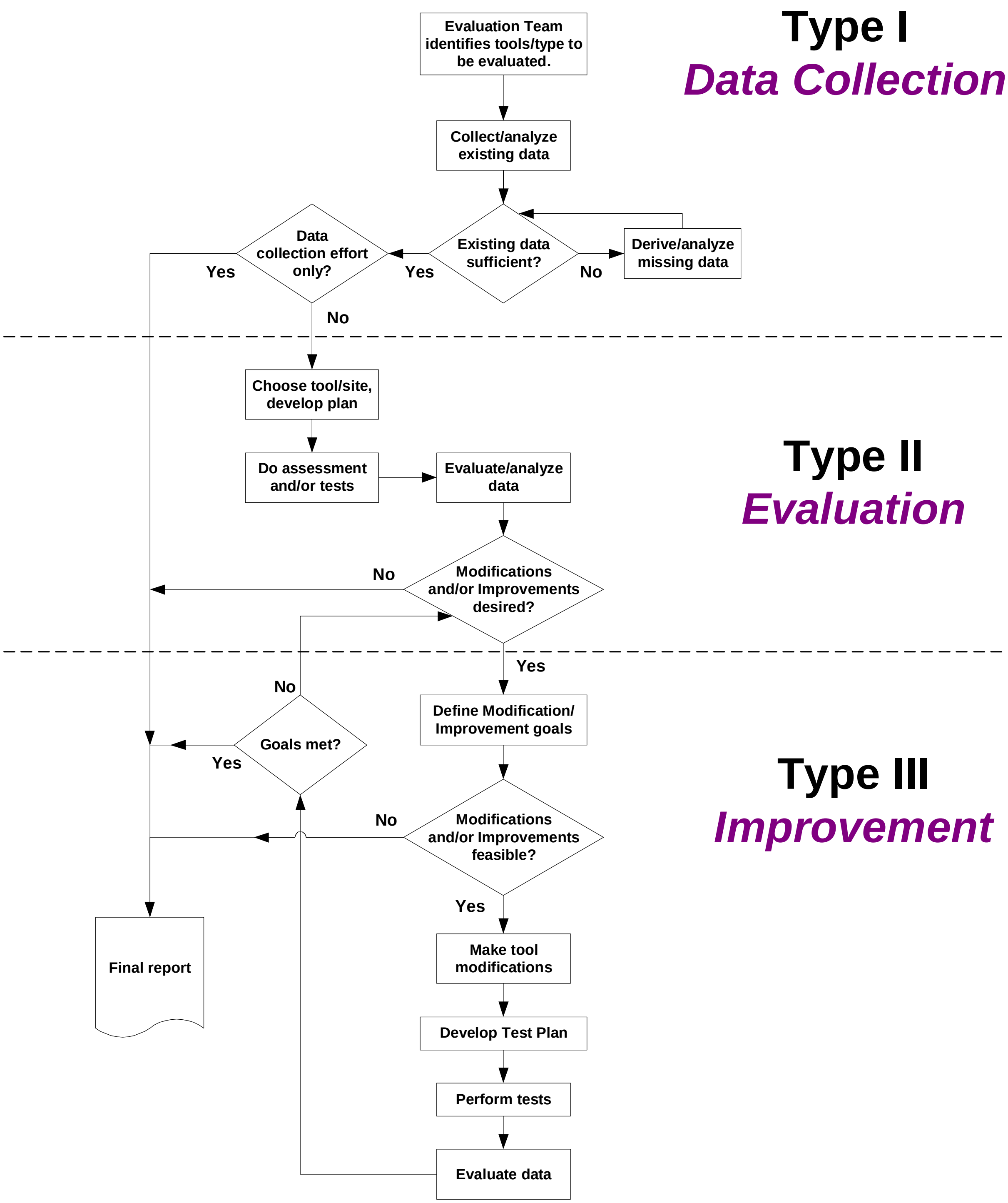

Figure 2 Flowchart of the E^3 Methodology

4.2 E^3 Prerequisites

To effectively implement an E^3 project, certain infrastructure requirements must be met. At a minimum, these include the appropriate skill set, customer and industry information sources, test resources, and the identification of and conformance to relevant standards and guidelines.

4.2.1 Technical Skill Set

Equipment evaluation requires a broad set of skills in a wide variety of disciplines. In many cases, team members will have expertise in several areas, providing a resource pool from which to draw on during an evaluation project. A well staffed team for performing equipment evaluation would have knowledge in the following categories:

- Process technology and development
- Project management
- Equipment development and reliability
- Manufacturing operations
- Statistics
- Technology transfer
- Environment, safety, and health
- Facilities operations and management
- Software/automation technology

These skills may not be required at all times during the evaluation; however, they should be available as needed.

4.2.2 Preparation and Execution

In preparation for an E^3 project, certain preconditions should be met. There must be a reasonable expectation that the equipment is ready for evaluation and that performance results will meet the expectations of the 300 mm tool set. The evaluation team members should be identified and possess all the requisite skills described above.

The evaluation process is a cooperative effort among representatives of the evaluation team and the supplier, who will work together to populate the areas of equipment performance to be tracked. An E^3 evaluation team must include (or have access to) the following skill sets as a minimum:

- Process technology and development engineering
- Equipment reliability
- Statistics
- Safety
- Facilities engineering

During an equipment evaluation, significant factors may be outside the direct control of the evaluation team that could materially or detrimentally affect the evaluation process. If such factors are encountered, the evaluation team will need to determine the course of the project. If a decision is made to prematurely terminate an evaluation, all factors contributing to the decision should be identified, captured, and reported in the final report.

4.2.3 Assessment and Test Resources

A Type 1 equipment evaluation is limited to data collection and analysis; therefore, no test resources are required although certain data analysis resources may be needed. An exception to a Type 1 evaluation is the identified existence of a severe disparity between expectations and performance. In such a case, the evaluation team may decide to immediately begin a Type 3 evaluation.

For a Type 2 or Type 3 E^3 evaluation, the necessary resources for support and execution of the evaluation and/or test must be identified. Key areas to evaluate include personnel allocation, wafers, process materials, equipment test time, equipment support, and the evaluation/test site facility. The availability of these resources will fundamentally affect the project and its schedule. A lack of adequate staff and physical resources can lead to the failure of an equipment evaluation.

The suitability of the evaluation/test site and the facilities that will support the tool should be emphasized. The tool, test site, and facilities should be evaluated independently and as a unit to identify potential problems. Most importantly, any ESH-related issues are of special concern. The evaluation, at a minimum, must consider industrial hygiene, equipment safety, and environmental impact.

4.2.4 Customer and Industry Requirements

Goal review and evaluation planning should involve the end users, as they determine whether the outcome of the test was a success compared to their expectations. Industry requirements and customers' needs must be understood before the test is defined for a Type 2 evaluation. As a precursor to any equipment evaluation, reliable sources of customer and industry information need to be identified. Therefore, the customers and supplier must agree on realistic goals and objectives before the test plan is developed, defining what constitutes a test's success before the execution of a Type 2 test begins. A well documented and understood definition of what constitutes a "failure" is critical to setting and meeting evaluation and/or test success criteria.

4.2.4.1 Relevant Standards

Standards that will affect the equipment evaluation must be identified before the project is defined. The supplier will generally be aware of the applicable standards requirements for the technology of the test tool. All equipment evaluations will report conformance to specific 300 mm standards of interest and generic industry standard requirements, such as the SEMI S2 safety standard; SEMI S8 ergonomic standard; and SEMI E10 reliability, availability, and maintainability standard. Other standards relevant to the expectations of the 300 mm tool set may be evaluated as required by the evaluation team. Many are listed in Table 1. Conformance to all or specific aspects of the expectations, as determined by the team, may be assessed during an evaluation and the results presented in the final report.

5 EARLY EQUIPMENT EVALUATION (E^3)

ISMT and its member companies have determined the need for a method to evaluate equipment that potentially may become productive components of new or retooled fabrication plants and/or the ISMT ATDF. Therefore, one could describe the E^3 methodology as a “needs”-driven process.

5.1 E^3 Process

The E^3 provides evaluation teams with key equipment performance results derived through a systematic process along with supporting evidentiary materials. When process or reliability performance results are provided, it is imperative that those results be statistically valid. The E^3 process can be performed on any tool or process, preferably before extensive field deployment of a model or system design. The three major activity groups in an equipment evaluation are described below.

5.1.1 Evaluation Types

The E^3 methodology establishes three thresholds that define significantly different evaluation types. The three types of evaluation represent differences in the scope, extent, and rigor of an evaluation in terms of performance and comparison of results to the expectations to the 300 mm tool set. The three evaluation types are as follows:

- ***Type 1*** entails obtaining a baseline of tool performance results measured against criteria relating to process, productivity, and standards and guidelines endorsed and/or established by the ISMT member companies or the semiconductor industry. This portion of the process uses existing data or benchmarking. No specific equipment tests are performed except when there is a known severe disparity between expectations and performance or absence of any data. Some of those items are referenced (but not limited to) in the E^3 Toolbox in Table 1. The evaluation team will review the results of this phase and determine whether to request additional evaluation activity under a Type 2 evaluation.
- ***Type 2*** requires additional and possibly more extensive testing (a specific tool) against one or more criteria in the E^3 Toolbox and will be performed after Type 1, if requested by the evaluation team. If a Type 2 project is pursued, the supplier will perform additional testing and provide the deliverables similar to those in Appendix A and Appendix B. The evaluation team will review the results of Type 2 and determine whether to request additional work under a Type 3 evaluation.
- ***Type 3*** is the improvement phase requiring additional testing to optimize tool performance against certain criteria referenced in the E^3 Toolbox and will be performed after a Type 2 evaluation, if requested by the evaluation team. If a Type 3 evaluation is pursued, the supplier will perform the improvements and testing requested by the evaluation team. The evaluation team will review the results of a Type 3 evaluation.

5.1.2 Equipment Evaluation Identification

The first stage of the E^3 process is to identify the tools to be evaluated. During this step, the evaluation team will decide what tool(s) models should be evaluated to achieve the next technology milestone or the tool(s) that have potential to provide the best return on investment (ROI).

5.1.2.1 Evaluation Team

During this portion of the process, the evaluation team should be identified. The evaluation team is a combination of company representatives who provide technical assistance and direction for the E^3 activities on the selected tool models.

All evaluation teams will define all aspects of the evaluation including what aspect of the tool is to be evaluated, what method may be used, and whether the project will focus on performance improvement or simple assessment to determine current levels of performance.

5.1.2.2 E^3 Planning

Early equipment evaluations must include a planning step that will set the goals and procedures to be used for the evaluation, help predict potential problems, and provide a framework for decision-making if problems occur. Failure to thoroughly plan before the evaluation begins will allow problems during the evaluation to affect the results and timeline. The review process may require that the plan be updated, but its basic framework is created here.

5.1.3 Data Gathering

A review of all existing data is a necessary precursor to any activities that may occur during the evaluation. The first step is to gather all of the available data related to the equipment chosen for evaluation. All of the relevant data and supporting evidentiary materials should be collected on the selected tool model from the team members and suppliers. If data exist outside of these resources, it should be included as well. To support the analysis of the information provided to an evaluation, all results should be submitted and reviewed with corresponding evidentiary materials to understand the method by which performance results were collected. The lack of these evidentiary sources may render results insufficient. Table 1 lists known and accepted methodologies by which data can be submitted to an E^3 project. Another useful resource is the *Equipment Maturity Assessment (EMA) Handbook.*

Table 1 E³ Toolkit Matrix

Description	Expected Results: Specification, Guideline, or Metric along with Document Reference	Means of Providing Measurable Results: Test/Assessment/Calculation Method or Procedure and Reference
A. Process		
1. Integrated Circuit Manufacturing	• Unified Equip. Performance Metrics for 0.25 µm Tech. • EPM 180 nm, 99093826A-TR • EPM 130 nm, 99123857B-ENG • International Technology Roadmap for Semiconductors (ITRS)	• Engineering Statistics Internet (ESI) Handbook • PDC, 97063297B-XFR • Gauge Study, SEMI E89 • Sensitivity Analysis, 97063297B-XFR
2. Automated Material Transfer	• Metrics for 300 mm Automated Material Handling Systems (AMHS) & Production Equipment Interfaces (Rev 1.0), 97123416B-TR • ITRS	• ESI Handbook • Gauge Study, SEMI E89 • Sensitivity Analysis, 97063297B-XFR • OHT Assessment Checklist
B. Reliability		
1. Mech. MTBF Demonstration 2. System MTBF Demonstration 3. Reliability Growth	• Unified Equip. Performance Metrics for 0.25 µm Tech. • EPM 180 nm, 99093826A-TR • EPM 130 nm, 99123857B-ENG • ITRS • Metrics for 300 mm AMHS, 97123416B-TR	• Mechanical Dry Cycle (MDC), 97063297B-XFR, and the ESI Handbook • Marathon, SEMI E10, 97063297B-XFR, and the ESI Handbook • IRONMAN, 95113028A-GEN, and the ESI Handbook
C. Throughput/COO		
1. Throughput 2. COO	• Unified Equip. Performance Metrics for 0.25 µm Tech. • EPM 180 nm, 99093826A-TR • EPM 130 nm, 99123857B-ENG • ITRS • Metrics for 300 mm AMHS, 97123416B-TR • I300I Factory Guidelines: Ver 5.0, 97063311G-ENG	• Throughput, SEMI E79 • COO, SEMI E35

Description	Expected Results Specification, Guideline, or Metric along with Document Reference	Means of Providing Measurable Results Test/Assessment/Calculation Method or Procedure and Reference
D. Facilities		
1. Facilitization	• SEMI E6 • I300I Factory Guidelines: Ver 5.0, 97063311G-ENG	• SEMI E6
E. Environment, Safety, & Health (ESH)		
1. Safety	• SEMI S2 • ISMT Equip. ESH Purchase Spec., 01064135BENG • Overhead Hoist Safety Guidelines (Version 2.0A) • I300I Factory Guidelines: Ver 5.0, 97063311G-ENG	• SEMI S2 • ISMT Equip. ESH Purchase Spec., 01064135BENG
2. Ergonomics	• SEMI S8	• SEMI S8
F. Physical Interfaces & Carriers (PIC)		
1. Physical Interfaces	• SEMI E15.1, 47.1, 57, 62, 84 • I300I Factory Guidelines: Ver 5.0, 97063311G-ENG	• 300 mm Best-Known Practices (300 BKP), 00124063B-ENG • 300 mm FOUP/Load Port Interoperability Report, SEMI AUX003-1200
G. Information and Control (I&C)		
1. Communication Interfaces	• SEMI E30, 37.1, & 84 • I300I Factory Guidelines: Ver 5.0, 97063311G-ENG	• 300 mm BKP, 00124063B-ENG, §4.2.1.1
2. Automation	• SEMI E87, 94, 40, & 90 • I300I Factory Guidelines: Ver 5.0, 97063311G-ENG	
3. e-Manufacturing	• EEC Guidebook - Phase 2.0 • e-Diagnostics Guidebook (update) V1.1b	• e-Diagnostics Guidebook (update) V1.1b, Chapter 11

5.1.3.1 Existing Data Sufficient

This step determines if the accumulated data is sufficient (statistically valid, supporting evidence provided, etc.) to make informed decisions on tool performance and/or needed modifications/improvements. Verifiable evidence of performance results is necessary to demonstrate equipment capability against end user expectations. If data or evidence is insufficient, the evaluation team must exhaust every available venue to ensure that all information is provided. Data gathered in this step are necessary for comparing expectations to performance results. The significance of this need should not be understated. An evaluation team may agree to terminate a project if insufficient data continue to be an issue.

5.1.3.1.1 Quantifiable Results Entry Criteria

Table 2 provides guidance on the type of quantifiable information that will be considered "sufficient" for an evaluation. To be considered sufficient, a supplier's submission of quantifiable data to populate the *Quantifiable Result* field must be statistically valid. An example of this requirement is process data, in which a sampling plan is used to estimate all relevant sources of variability. To meet a stated goal or specification, it is assumed that the distribution of all measurements meets a goal or specification. In the case of equipment performance parameters with known associated metrics and unit designators, any information provided to the E^3 project must include those values and units. Appendix A and Appendix B show examples of a supplier's submitted metric profile on an etch tool and an overhead delivery system, respectively.

The first section of Table 2 (A. Process) lists both integrated circuit manufacturing and material transfer systems. After the initial data have been accumulated and the analysis completed, an evaluation may limit focus to only one of these items, as they are almost mutually exclusive domains of the semiconductor manufacturing processing facility.

5.1.3.1.2 Qualitative Results Entry Criteria

Table 2 also provides guidance on the type of qualitative information that will be considered "sufficient" for an evaluation. Typical entries into the *Qualitative Result Available* field are "Yes" or "No." If equipment performance parameters have no associated metrics, any information provided to the E^3 project must be submitted with evidentiary material. Typical entries into the *Evidence Provided* field are also a "Yes" or "No." Examples of this are shown in Appendices I and II.

5.1.4 Derive Missing Data

If the data are insufficient to make an informed decision, the team must develop a method to procure alternative information sources. This may include an abbreviated test to complete deficient areas where necessary or engaging a source of information not before considered. If a short test must be run, then it must be as statistically rigorous and supply evidentiary materials as required in the previous step. Note: this is the end of a Type 1 evaluation.

5.1.5 Gap Determination

When the information and supporting evidence are sufficient and a gap determination has been made**,** the E^3 project team may then develop a test plan. At that point, the project team will use the information gathered in the previous step to develop a comprehensive plan with minimal test time and costs against defined metrics. The team members must solidify the goals and procedures for the test. One test can have many goals. These goals should specifically state the metrics targets and the basis for evaluation. Proper planning clearly defines specification metrics, establishes the methods of data collection, and defines the method of data reporting. Baseline metrics may be developed by the evaluation team, if necessary, to determine the success of the equipment evaluation.

Table 2 E^3 Focus Areas Showing More Detail Related to the Comparison of Expectations to Performance Results

Description	Quantifiable Result	Qualitative Result Available (Yes/No)	Expected Result or Goal	Evidence Provided (Yes/No)	Meets Expected Result (Yes/No)
A. Process					
1. Integrated Circuit Manufacturing					
2. Material Transfer System					
B. Reliability					
1. Mech. MTBF Demonstration					
2. System MTBF Demonstration					
3. Reliability Growth					
C. Throughput/COO					
1. Throughput					
2. COO					
D. Facilities					
1. Facilitization					
E. Environment, Safety, & Health (ESH)					
1. Safety					
2. Ergonomics					
F. Physical Interfaces & Carriers (PIC)					
1. Physical Interfaces					
G. Information and Control (I&C)					
1. Communication Interfaces					
2. Automation					
3. e-Manufacturing					

5.1.6 Engineering Modifications/Improvements

Once all the data have been obtained, a decision must be made about whether the project will proceed to an improvement phase (Type 3). At this point, the project team reviews the gap determination and possible improvement activities. If this is to be a Type 2 evaluation only, publishing a final report should terminate all E^3 activities.

5.1.6.1 Gap Review

A special meeting with the supplier may be required to review the gap determination, possible areas of evaluation, or desired modification/improvements.

5.1.6.2 Define Modification/Improvement Goals

If the evaluation team suggests design modifications or improvements, a modification/improvement plan must be generated. These improvements or goals must be clearly outlined and defined such that all parties (device manufacturers, suppliers, etc.) understand when the documented goals are achieved. These goals should map to the specific ISMT/Selete equipment performance metrics or *International Technology Roadmap for Semiconductors* (ITRS) technology nodes. The goals should also consider the development maturity of the tool under evaluation. The development maturity level of the tool could hinder the equipment's ability to meet production-level expectations.

5.1.6.3 Modifications/Improvements Feasible

After defining the desired modifications and/or improvements, the supplier must provide a written response that addresses the feasibility of the requested modifications. In some cases, the desired modifications/improvements may require more time, money, resources, etc. than the supplier deems reasonable. In other instances, the improvements may be too advanced for the equipment generation and, therefore, may need to be incorporated into future generations. At this point, the project may be terminated as a Type 2 evaluation. If the supplier agrees to the modifications, their internal mechanisms for product development must be engaged along with consistent and scheduled communication to the evaluation team.

5.1.7 E^3 Test Plan Development

For the evaluation, several types of testing or assessment activities may occur, depending upon the equipment under evaluation. Any type of evaluation will address semiconductor equipment in terms of its performance against predefined expectations. Those expectations, along with methods for providing measurable results, are in Table 1. Interpretative documents, such as the *Equipment Class Application Guideline* (Technology Transfer # 97033270B-ENG) and *Overhead Transfer System Test Methodology* (Technology Transfer # 01064132A-ENG), may be referenced for test guidance specific to the equipment class under evaluation.

5.1.7.1 Generate E^3 Equipment Evaluation Plan

The evaluation plan is the formal documentation of the equipment evaluation goals and procedures. The evaluation plan should not only establish and quantify the test parameters and resources, but also include the documentation of decisions and background information that will validate the goals, operational parameters, and test level to be executed.

The completed evaluation plan is reviewed for conformance to industry and customer requirements to ensure that the equipment evaluation will produce adequate value for the invested resources. If the evaluation plan does not adequately meet industry needs and requirements, the planning process should be repeated until an acceptable plan has been defined. The project team should review the evaluation plan as the project progresses to reflect changes to product development, goals, procedures, or other external factors.

The subject matter experts in the evaluation team may identify important metrics in addition to those presented in the E^3 Toolkit Matrix. These additional metrics will be communicated to the supplier in the method agreed to as early as possible. The test team is responsible for establishing an estimate of the targets for any additional metrics used in testing.

5.1.7.1.1 Establish Goals and Procedures

In establishing goals for an evaluation, significant effort should be made to produce goals specific to the gap identified for improvement. Since the goals will influence the extent and rigor of testing as well as the procedures to be used, all requirements and outputs must be reflected in these goals. Sources such as the ITRS and *ISMT/Selete Unified Equipment Performance Metrics* documents are valid references and guides for determining evaluation goals.

If certain equipment performance metrics do not exist, the evaluation team (in conjunction with the equipment supplier) may establish a goal to facilitate a determination of success with respect to expectations. In some instances, a goal may not be attainable. If so, the user's group may rely on qualitative results or interim goals for the equipment evaluation.

Goals should include (but not be limited to) the following:

- Equipment performance metrics
- Process parameters
- Identification of key process or automated material handling input factors
- Manufacturing and reliability
- Cost of ownership
- No critical S2/S8 ESH deficiencies

The test procedures/plans define the way the test will be executed, the way resource requirements will be met, and any logistical requirements. The procedures should also include any contingency plans that can be executed as necessary because of special circumstances. Some of the items to be considered in generating the procedures are as follows:

- Test location
- Facilities requirements
- Environmental factors
- Metrology and support equipment requirements
- Manpower availability
- Data collection methodology
- Logistics
- Cost constraints
- Pre-processed wafer requirements
- Joint development with another supplier or IC company

5.1.7.1.2 Analyze Pre-knowledge

Pre-knowledge refers to the amalgam of all available data from the tool and process development activities and any testing that may have previously been done. This could consist of unit-level test results, process characterization runs, and any other data. Performance data on the previous generation of the tool can be used where there is a high degree of commonality, especially where the same subsystems are used. In the absence of data on the test tool, the best and worst-case estimates derived from the experience of knowledgeable engineers can be used as pre-knowledge.

By applying a Bayesian statistical design technique to the pre-knowledge, valid testing can be performed in a shorter time or with higher statistical confidence while lowering resource requirements. This technique is applied by the following:

1. Using past data or experience, construct a previous distribution (probability density function) of the failure rates from which to derive the failure rate of the upcoming test.
2. Select a test time (*T*) and use the previous distribution to compose a list of the most likely test results.
3. Combine the previous distribution and likely results to construct confidence intervals for each likely result. Compare with the goals of the test.
4. The design technique is complete if each likely result produces approximately the required confidence. If the likely confidence intervals are well above or below the test goal, select another test time (*T*) and repeat the process.

5.1.7.1.3 Test Scaling

Test scaling is the process of reducing the scope, extent, and rigor of an equipment evaluation based upon tool maturity, test level, and other factors. This allows tools at any development stage to be tested and ensures that only meaningful testing is performed. Well executed test scaling will produce the most valuable test results for the least investment of resources. Scaling the test goals and statistical confidence levels within the test elements ensures that the appropriate extent and rigor of testing is done. Developmental maturity of the tool model should also be considered when making scaling adjustments.

Some tests may be combined with others to provide data on both. Care should be taken when concurrently performing tests to avoid increased variability and to preserve the integrity of a decision-making capability based on data analysis.

5.1.7.1.4 Test Goal and Statistical Confidence Level Scaling

Scaling the test goals and statistical confidence levels ensures that the appropriate extent and rigor of testing are performed. A specific test goal and its corresponding statistical confidence may be scaled by the evaluation team to facilitate accelerated equipment improvement activities. It is important that a systematic method be used to scale the test goals and statistical confidence levels to provide consistency from test to test. This method will be based on the current measured performance of the test tool.

The test goal and statistical confidence level scaling procedure has four steps:

1. The supplier provides the current performance against the specific parameter of the equipment under evaluation. The parameter should be appropriate with relation to the *ISMT/Selete Equipment Performance Metrics* (see Table 1) or the ITRS. As stated

above, the test team may define other test metrics in advance. The suppler will also provide as much test and raw data as possible (evidentiary materials) to validate the submitted performance result. Note that "no metric" or "no data" can be an acceptable input in some instances, depending upon the development stage.

2. The evidence provided by the supplier is reviewed to validate the performance result. The team uses the validated results to create a derating factor insofar as the evidence substantiates the submitted performance result.
3. A submitted performance result is reconciled with its associated requirement. The level to which the submitted performance result fails to meet its goal should be the basis for the generation of a specific derating factor for that metric.
4. The derating factor is applied to establish the initial test goal and statistical confidence level for the improvement activity.

The output of this scaling process establishes the initial test goals and statistical confidence levels for equipment evaluation. The evaluation team may modify these goals as other factors such as resource limitations and equipment maturity are considered.

5.1.7.1.5 Equipment Maturity Recommendations

Equipment maturity should be considered while planning a test or improvement activity. The *I300I Demonstration Test Method* (Technology Transfer # 97023297B-ENG) provides a process by which equipment maturity may be assessed (i.e., Equipment Maturity Assessment [EMA]). Modifying the test plan as a result of a maturity recommendation is a form of test scaling. For more information, see the *International SEMATECH Equipment Maturity Assessment (EMA) Handbook*, Technology Transfer # 01044107A-ENG.

5.1.7.2 Test Plan Review

The role of the test plan review is to ratify the test goals, procedures, and resources as well as provide a formal venue for customer input and validation. Once the formal test plan has been completed, a meeting should be scheduled with key customers, engineering, and any other appropriate participants. Each of the goals, procedures, constraints, and resources should be reviewed.

The test plan review is used to solicit wide support and acceptance of the test plan and to avoid unforeseen or unnecessary changes during test execution that would result from oversights with the resultant increases in cost and duration of the test.

5.1.8 Make Equipment Modifications

During this portion of the process, the supplier performs the tool engineering changes. The supplier's internal procedure for changes and/or modifications to their design is the vehicle by which these changes are made.

5.1.9 Perform Tests

Any modifications introduced by the supplier to improve the equipment are to be tested at this time. This step requires the evaluation team's oversight. The evaluation team will help work logistical issues and, if necessary, terminate the test before the original completion date(s) because of complications or impediments to the test completion or success.

5.1.10 Evaluate Data

Once the tool modifications have been completed and the tests to assess tool improvement are finished, the data must be analyzed. This analysis must be thorough and measured against the project test goals established in Section 5.1.7.1.1.

5.1.10.1 Goals Met

This step determines if the goals established for the improvement activity were met. If the answer is yes, then it is appropriate to terminate the project and publish a final report. If the answer is no or the goals were modified during the test, the project must revert to the point at which modifications or improvements are desired (Section 5.1.8).

5.1.11 Evaluation Termination and Close-Out

An equipment evaluation can be terminated for a number of reasons, such as inconsistent process performance, poor reliability, or the equipment's inability to meet the necessary level of test requirements, which renders further testing invalid. To that end, a review should be held for any type of evaluation (I, II, or III) at any time or at regular times if the test length is sufficient. This review discusses the current results of the evaluation activity. During this review, future activities may be discussed or the evaluation may be terminated. If the evaluation is to be closed out, emphasis moves to the documentation stage and all other levels of the test are terminated. Equipment and materials must be dispositioned, results and data sources consolidated, and artifact materials (wafers) archived if appropriate. If the test is terminated, the test team focuses on documenting the achievements and failures of the activities completed to that point.

5.1.11.1 Final Report

All aspects of the work are documented in a precise and prepared format (see Section 4) for publication and distribution.

6 EARLY EQUIPMENT EVALUATION (E^3) REPORTS

Any equipment evaluation that compares performance results to end user expectations must be formally documented. This section provides guidelines for the content, structure, and documentation of equipment evaluation results. It also provides a high level outline of a final report summarizing the evaluation's activities.

An E^3 evaluation produces a singular report for an equipment evaluation. The final E^3 report summarizes performance results of the evaluation process. Supplier comments and inputs on the results or improvement plans and roadmaps will be included in the final report. The final report will reference detailed data gathered during the process, and an evaluation team may provide raw data on a request-only basis.

6.1 E^3 Project Final Report

The purpose of the equipment evaluation is to produce valid, objective results that are representative of the equipment at its current stage of development. An E^3 Project Final Report is a comprehensive summary of all the test results from activities and information gathered at any of the three E^3 types. It provides a high level overview of the tool performance, including a minimum level of detailed data.

6.1.1 E^3 Project Final Report Outline

An outline of the content and structure to be used for an E^3 report is as follows:

- Executive Summary
- Introduction
- Purpose and Scope
- User Group Information
- Assessment Information
- Description of the Equipment
- Summary of Findings
- Gap Determination Description (if required)
- Improvement Activities (if required)
- Summary and Conclusions
- Supplier Inputs

6.1.2 Documentation

The following information should be included in reporting an equipment evaluation:

- Equipment model number, serial number(s), options, configuration, and software release number or identifier
- Process performance
- Reliability data
- Throughput and cost of ownership (COO)
- Environment, safety, and health (ESH)
- Facilities requirements
- Software/hardware standards and guidelines conformance

Table 2 in Section 5.1.3.1.1 lists the subject matter areas. The equipment performance parameters are shown along with a more detailed presentation of the underlying aspects of each key parameter.

7 SUMMARY

The ISMT E^3 process is a method of early and efficient determination of equipment performance against the expectations of the 300 mm tool set. The purpose of the E^3 process is to enable accelerated performance evaluation, selection, and delivery of manufacturing worthy 300 mm semiconductor manufacturing equipment. The value of a consistent, standardized approach that meets the customers' needs, which reduces the cost of redundant assessment or testing resources, cannot be overstated.

The E^3 process includes several iterations of end user expectations and methods for measuring a supplier's performance against those expectations. The development of an effective method for collecting and analyzing early equipment performance measured against quantifiable and agreed to metrics or goals should accelerate deployment of high quality equipment to the customer or end user.

APPENDIX A – EXAMPLE A SUPPLIER'S METRIC PROFILE OF A METAL ETCH TOOL MODEL
(Note: other attributes may apply, this is an example only)

Description	Quantifiable Result	Qualitative Result Provided (Yes/No)	Expected Result or Goal	Evidence Provided (Yes/No)	Meets Expected Result (Yes/No)
A. Process					
1. Integrated Circuit Manufacturing	–	Yes	Yes	Yes	Yes
a. Electrostatic chuck	–	Yes	Yes	Yes	Yes
b. Polymer free after strip	–	Yes	Yes	Yes	Yes
c. Auto endpoint	–	Yes	Yes	Yes	Yes
d. Quick changeable assembly	–	Yes	Yes	Yes	Yes
e. Process CD (L/S)	0.24 µm	–	150 nm	Yes	Yes
f. CD control (3 σ)	6%	–	< 7%	Yes	Yes
g. CD bias	0.009 µm	–	< 10 nm	Yes	Yes
h. Select to resist	4:1	–	> 3:1	Yes	Yes
i. Side wall profile	90°	–	> 89°	Yes	Yes
j. Select to oxide	11:1	–	> 15:1	Yes	Yes
k. Select to oxide (over-reach)	22:1	–	>20:1	Yes	Yes
l. Oxide Loss	22 nm	–	< 30 nm	Yes	Yes
m. Micro-loading	7%	–	< 8%	Yes	Yes
n. AlCu etch uniformity tool variability (3 σ)	3%	–	< 4%	Yes	Yes
o. AlCu etch uniformity within wafer (3 σ)	7%	–	< 7%	Yes	Yes
p. Oxide damage parameters	–	–	TBM	Yes	Yes
q. Metallic contamination	–	–	< 1.00E+11 atm/cm^2	Yes	Yes
r. Corrosion parameters	27 hours	–	> 24 hrs	Yes	Yes
s. Charge up parameters (Antenna > 100K)	–	–	TBM	Yes	Yes
t. Residue under etch	None	–	None	Yes	Yes
u. In-film @ 0.20 µm	1.5/wafer	–	< 2.6/wfr	Yes	Yes
v. On bare Si @ 0.09 µm	14.2/wafer	–	< 12.9/wfr	Yes	Yes
2. Material Transfer System	N/A	N/A	N/A	N/A	N/A
B. Reliability					
1. Mech. MTBF Demonstration	9000 wafers	–	> 5000	No	No
2. System MTBF Demonstration	400 hrs	–	> 350 hrs	Yes	Yes
3. Reliability Growth	–	–	–	N/A	N/A

Description	Quantifiable Result	Qualitative Result Provided (Yes/No)	Expected Result or Goal	Evidence Provided (Yes/No)	Meets Expected Result (Yes/No)
C. Throughput/COO					
1. Throughput	35	–	> 30 wfr/hr	Yes	Yes
2. COO	$4.00/wfr pass	–	< $5.83/wfr pass	Yes	Yes
D. Facilities					
1. Facilitization	–	Yes	Compliance	Yes	Yes
a. E6	–	Yes	Compliance	Yes	Yes
b. E47	–	Yes	Compliance	Yes	Yes
c. E49	–	Yes	Compliance	Yes	Yes
d. E72	–	Yes	Compliance	Yes	Yes
E. Environment, Safety, & Health (ESH)					
1. Safety	–	Yes	Compliance	Yes	Yes
a. S2	–	Yes	Compliance	Yes	Yes
b. S7	–	Yes	Compliance	Yes	Yes
c. S11	–	Yes	Compliance	Yes	Yes
d. S17	–	Yes	Compliance	Yes	Yes
2. Ergonomics	–	Yes	Compliance	Yes	Yes
a. S8	–	Yes	Compliance	Yes	Yes
F. Physical Interfaces & Carriers (PIC)					
1. Physical Interfaces	–	Yes	Compliance	Yes	Yes
a. E15.1	–	Yes	Compliance	Yes	Yes
b. E47.1	–	Yes	Compliance	Yes	Yes
c. E57	–	Yes	Compliance	Yes	Yes
d. E62	–	Yes	Compliance	Yes	Yes
e. E84	–	Yes	Compliance	Yes	Yes
G. Information and Control (I&C)					
1. Communication Interfaces	–	Yes	Compliance	Yes	Yes
a. E37	–	Yes	Compliance	Yes	Yes
b. E84	–	Yes	Compliance	Yes	Yes
2. Automation	–	Yes	Compliance	Yes	Yes
a. E30	–	Yes	Compliance	Yes	Yes
b. E40	–	Yes	Compliance	Yes	Yes
c. E87	–	Yes	Compliance	Yes	Yes
d. E90	–	Yes	Compliance	Yes	Yes
e. E94	–	Yes	Compliance	Yes	Yes
3. e-Manufacturing	–	Yes	Compliance	Yes	Yes

APPENDIX B – EXAMPLE A SUPPLIER'S METRIC PROFILE OF AN OVERHEAD WAFER TRANSPORT SYSTEM

(Note: Other attributes may apply, this is an example only)

Description	Quantifiable Result	Qualitative Result Provided (Yes/No)	Expected Result or Goal	Evidence Provided (Yes/No)	Meets Expected Result (Yes/No)
A. Process					
1. Integrated Circuit Manufacturing	N/A	N/A	N/A	N/A	N/A
2. Material Transfer System	–	Yes	Yes	Yes	Yes
a. Verification of basic unit functionality	N/A	Yes	• Power (on/off) switches • Equip. status light	Yes	Yes
b. Collision avoidance (other vehicles, miscellaneous track obstructions)	N/A	Yes	• Sensor must slow or stop the vehicle	Yes	Yes
c. Verification of track/hoist speed (Empty, Full, around curves)	1.5%	N/A	• Within 2% of avg. design speed	Yes	Yes
d. FOUP vibration Verification	• Avg. = 0.08 g • Peak =0.24 g	N/A	• Avg. < 0.1 g • Peak < 0.25 g	Yes	Yes
e. Pick and place accuracy, repeatability and robustness of pick	• Accuracy = 6.1mm • Repeatability = 4.3 mm • Pick robustness: ± 10 mm	N/A	• Accuracy > 5 mm • Repeatability > 5 mm • Pick robustness: ± 10 mm	Yes	Yes
f. Wall clearance verification	• Straight runs: 24 cm • Around curves: 33 cm	N/A	• Straight runs < 50 cm • Around curves < 85 cm	Yes	Yes
g. Verifications of audible and visual alarms	N/A	Yes	• Full conformance to design and specifications	Yes	Yes
h. Airborne particle testing	• On bare: 2.1 • Backside: 119	N/A	• On bare: < 2.3 • Backside: < 200	Yes	Yes
i. ESD emissions	• 0.9 Ohm • 30 V	N/A	• < 1 Ohm • < 50 V	Yes	Yes
B. Reliability					
1. Mech. MTBF Demonstration	N/A	N/A	N/A	N/A	N/A
2. System MTBF	600 hours	N/A	> 500 hours/vehicle	Yes	Yes
3. Reliability Growth	N/A	N/A	N/A	N/A	N/A

Description	Quantifiable Result	Qualitative Result Provided (Yes/No)	Expected Result or Goal	Evidence Provided (Yes/No)	Meets Expected Result (Yes/No)
C. Throughput/COO					
1. Throughput	–	Yes	$> 1.25 \times 200$ mm	No	No
2. COO	–	Yes	$\leq 1.3 \times 200$ mm	No	No
D. Facilities					
1. Facilitization	–	Yes	Compliance	Yes	Yes
E. Environment, Safety and Health (ESH)					
1. Safety	–	No	Compliance	No	No
2. Ergonomics	–	Yes	Compliance	Yes	Yes
F. Physical Interfaces and Carriers (PIC)					
1. Physical Interfaces	–	Yes	Compliance	Yes	Yes
a. E84	–	Yes	Compliance	Yes	Yes
G. Information and Control (I&C)					
1. Communication Interfaces	–	Yes	Compliance	Yes	Yes
2. Automation	–	Yes	Compliance	Yes	Yes
3. e-Manufacturing	–	Yes	Compliance	Yes	Yes

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