



Overhead Wafer Carrier Transport System Test Methodology

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Overhead Wafer Carrier Transport System Test Methodology
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Abstract: This document from the 304-501 project is a high level test methodology (not a test plan) for overhead wafer carrier transport systems, both monorail/hoist vehicle and overhead conveyor designs. The methodology addresses overhead transport systems (OTS) for wafer carriers from more of a performance-based testing standpoint than the existing Overhead Hoist Transport Test Plan developed by the International 300 mm Initiative (I300I).

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Acronyms and Abbreviations

AGV – Automated guided vehicle.

AMC – Airborne molecular contaminants.

AMHS – Automated material handling system.

DTM – Demonstration Test Method.

ECAG – Equipment Class Application Guideline.

EMA – Equipment Maturity Assessment.

EPM – Equipment Performance Metrics.

FOUP – Front opening unified pod wafer carrier.

FOSB – Front opening shipping box.

FOUP for 1 – Front opening unified pod for a single wafer.

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.

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.

LPC – Liquid particle counter.

MCS – Material control system.

MDC – Mechanical dry cycle.

MTBF_p – Mean “productive” time between failures.

MTBI_p – Mean “productive” time between interrupts.

MTTR – Mean time to repair.

MWBF – Mean wafers between failures.

MWBI – Mean wafers between interrupts.

NIST – National Institute of Standards and Technology.

Output parameter – The result (typically measured on product) of the equipment process.

PDC – Passive data collection.

PGV – Person guided vehicle.

PSG – Phosphorus doped silicon glass.

PWP – Particles per wafer pass.

P/T ratio – The ratio of precision to tolerance of a metrology tool. Reference SEMI M27.

RAM – Reliability, availability, and maintainability.

RGV – Rail guided vehicle.

SA – Sensitivity analysis.

SAW – Surface acoustical wave.

SPC – Statistical process control.

WIP – Work in progress. This term is used to describe the inventory in an IC manufacturing environment.

1 EXECUTIVE SUMMARY

International SEMATECH (ISMT) has an established test method, the *I300I Demonstration Test Method – Revision 1* (DTM), which provides a standardized objective approach for characterizing the process performance and reliability of semiconductor IC process, metrology, and automated material handling (AMH) equipment at any phase of the development cycle. In addition to the DTM, International SEMATECH provides further test method guidance by categorizing the tools into equipment classes and providing detailed interpretation and technical direction for testing tools within each class. Tools within an equipment class share the following basic characteristics:

- They perform a very similar function within the IC fabrication process.
- They have similar process capabilities.
- They require common testing approaches and requirements.

At the same time, tools within an equipment class may employ different technological approaches to perform a process, and they may have very different operating characteristics and configurations. By categorizing the equipment into a specific class, it becomes possible to provide detailed technical direction and information about performing demonstration tests on tools belonging to that class, the type of gauges and metrology required for the test, as well as guidance for equipment performance tests such as a Mechanical Dry Cycle (MDC) or Marathon tests.

The classification of equipment into classes should also enable suppliers to independently perform demonstration testing based upon a common direction and common expectations, which should enable a test team to plan and perform a test based on the *I300I Demonstration Test Method – Revision 1* consistently and effectively.

This document, the *Overhead Wafer Carrier Transport System Test Methodology*, presents a high level test methodology (not a test plan) for both monorail/hoist vehicle and overhead conveyor designs. Since it is important to understand how wafers are affected during transport, this document presents ideas and methods for wafer-level issues with respect to transport-induced failure mechanisms. The methodology addresses overhead transport systems (OTS) for wafer carriers from more of a performance-based testing standpoint than the existing Overhead Hoist Transport Test Plan available on the ISMT website, which was generated as part of the International 300 mm Initiative (I300I).

2 INTRODUCTION

The *Overhead Wafer Carrier Transport Test Methodology* is a reference guide designed to be used with the *I300I Demonstration Test Method – Revision 1* and the *Metrics for 300 mm Automated Material Handling Systems (AMHS) and Production Equipment Interfaces: Revision 1* documents. It provides interpretation, guidance, and additional information for applying the test methodology during demonstration tests on wafer handling equipment. The guide provides test engineers, process engineers, development engineers, and their managers with generic direction for planning and executing demonstration tests at any phase of the equipment development cycle.

2.1 About This Document

This document includes several sections, most of which contain parameters and guidelines for performing a demonstration test. The sources of this information include the *Metrics for 300 mm Automated Material Handling Systems (AMHS) and Production Equipment Interfaces: Revision 1*, the expertise and judgment of ISMT technical staff, and other appropriate technical sources. The listings of test parameters are not exhaustive. Rather, they should be considered the minimum set of requirements for performing a test element. At times, it may be appropriate for test teams to seek additional direction from other knowledgeable sources when developing test plans.

Each section contains subsections that provide the following information:

- A brief *description of the tool*, which includes its role within the IC manufacturing process and other key characteristics and capabilities. This description should be broad enough to include a variety of technological approaches and configurations, yet specific enough to facilitate classification of a tool into an equipment category.
- Detailed *interpretations of the requirements* for implementing the elements of DTM testing for tools within the classification. This includes the requirements for performing gauge studies, the MDC, passive data collection (PDC), and sensitivity analysis (SA) test elements. In addition, each section provides guidance for applying test metrics, collecting additional data, and working with technology- and process-dependent considerations for tools within the particular equipment class.

The following section briefly discusses the material covered in each of the sub-sections of the *Overhead Wafer Carrier Transport System Test Methodology*.

2.2 Implementing the Demonstration Test Method (DTM)

This subsection provides detailed interpretations of the specific element requirements for DTM testing of tools within a particular equipment class.

2.2.1 Equipment Maturity Assessment (EMA)

This sub-section provides general direction on the EMA and its outputs, which must be comprehended before demonstration test planning occurs.

2.2.2 Gauge Studies

This sub-section provides specific direction on the types of gauges required for demonstration testing. It also provides the corresponding measurements and establishes targets for the tolerance requirements on the gauges where applicable. It is important to note that it may not be necessary to perform a gauge study on a metrology tool that has previously been studied and found to be under statistical process control (SPC).

Ongoing monitoring and control of gauge performance parameters is required to ensure stability following the gauge study. At a minimum, repeatability, reproducibility, and accuracy must be under valid SPC.¹ SEMI Standard E89, *Guide for Measurement System Capability Analysis*, should be used as a reference for all gauge studies to be performed.

¹ Douglas Montgomery, *Introduction to Statistical Quality Control* (Second Edition) John Wiley (1991).

Internal control systems, including those calibrated with external references, cannot be considered gauges for measuring the process output parameters for a test. Gauges refer to the traceable metrology equipment used to measure and assess the output results of the equipment or process being tested. At a minimum, the gauges should be traceable to a transfer standard, to an artifact of a product type, or to a reference product.

2.2.3 Mechanical Dry Cycle (MDC)

The intent of the MDC test element is to exercise every mechanical function possible without the complexity of processing. This sub-section establishes expectations and provides guidance on the functional definition of a machine cycle for the equipment class. Where appropriate, alternative or additional goals are established and special-case considerations are explored.

2.2.4 Passive Data Collection (PDC) and Sensitivity Analysis (SA)

The section on PDC and SA identifies the recommended input parameters to monitor and output parameters to measure for tools in the equipment classification. No distinction is made between the PDC and SA test elements, since the factors to be investigated during the designed experiments of the SA are generally a subset of the PDC parameters of interest.

During the PDC, the inputs are monitored and the process outputs are measured without adjustment or alteration, specifically to establish the stability and repeatability of the process. This stability provides the statistical foundation for the designed experiments that will be used during the SA to investigate the relationship and extent of input interactions as measured in the quality of output results.

2.2.5 Marathon Test

The intent of the Marathon test element is to simulate typical manufacturing as closely as possible. This sub-section establishes expectations and provides guidance on the functional definition of a machine cycle for the equipment class. Where appropriate, alternative or additional goals are established and special-case considerations are explored.

2.3 Applying Test Metrics

This section summarizes the test metrics and parameters to be measured and reported for a demonstration test for tools within the equipment class. Results should be reported for all test metrics except those specifically removed from the test plan during test scaling and planning.

The test metrics section is generally modeled after the AMHS performance metrics definitions; the same units and guidelines should be considered to apply to the equipment class as a whole.

2.4 Collecting Additional Metrics and Data

This section provides direction on parameters for which additional data (not stated in the metrics) should be collected during the test. This additional data may be related to a parameter whose effect or impact on processing is not well understood and has not been quantified or to a case where a robust measurement tool, method, or technique has not been generally accepted. It could also include data of special interest to one member of the test team or to the supplier.

The additional data required for an equipment class must be collected during a test, if possible, to ensure consistent standardized performance of demonstration tests among different tools within the same classification. This data is then analyzed statistically by the same methods that are used to analyze the test metric data, and the results are published in the final test report.

2.5 Working with Technology- and Process-Dependent Considerations

Within an equipment class, certain processes may have specific testing requirements, additional metrics, technological challenges, or other considerations that are particular to them. This section summarizes and provides guidelines for working with these technology- and process-dependent considerations.

3 OVERHEAD TRANSPORT TEST METHODOLOGY (WAFER CARRIERS)

Overhead transport systems for wafer carriers may be comprised of integrated interbay/intrabay transport designs for moving, storing, and tracking work in progress (WIP) materials. The individual components of these systems can be broadly grouped into two functional categories, as summarized in Table 1.

Table 1 Overhead Transport Categories for Wafer Carriers

Transport	Storage	Control and Data Systems	Transfer Mechanism to/from Load Port	Carriers
Overhead Monorail/Hoist Vehicle	Stocker	Host Control System, E84	Overhead Hoist (vehicle mounted)	25-wafer FOUN
Overhead Conveyor	Stocker and/or Conveyor based storage position	Host Control System, E84	Robot (delivery point)	25-wafer FOUN

Of the two functional categories described in Table 1, only the transport, storage, and transfer categories are candidates for the application of the I300I *Demonstration Test Method – Revision 1*. Valid testing can be performed on an integrated overhead wafer carrier transport configuration using the methodology, but it will be valid for that configuration only. The distributed nature of overhead transport systems suggests that statistical analysis and modeling of the systems be module- or unit-based to allow for visibility into various implementation schemes. A method for projecting and determining system performance from the performance results of the individual components should follow SEMI E10, *Specification for Definition and Measurement of Equipment Reliability, Availability, and Maintainability (RAM)* and SEMI E79, *Standard for Definition and Measurement of Equipment Productivity*. Control systems (i.e., E84 parallel I/O), software, and individual components have testing requirements different from electromechanical machine tools are, therefore, considered outside the scope of this document.

3.1 Implementing the Demonstration Test Method (DTM)

Below is guidance for applying the I300I *Demonstration Test Method – Revision 1* when testing tools in the overhead wafer carrier transport equipment class.

3.2 Equipment Maturity Assessment (EMA)

The I300I *Demonstration Test Method – Revision 1* (DTM Section 6.1) requires that EMA be performed to understand the developmental maturity of the system that is a candidate for demonstration testing. The purpose of the EMA is to determine the candidate system’s capability to perform different levels or phases of testing. Demonstration testing can be performed at any stage in the development cycle to produce valuable characterization data so that data-driven management and engineering can be applied to decision-making and further development. In the DTM process, each level or phase of testing has different requirements relating to the type, extent, and rigor of the testing to be performed. Four incremental levels of increasingly rigorous testing encompass the ongoing development of equipment throughout the development cycle from a testing perspective. Each phase of testing requires additional capabilities from the equipment to meet the testing requirements. A principle of sound engineering is to perform only that testing that is valid and useful at the development maturity of the test equipment or process.

A critical EMA characteristic with respect to overhead wafer carrier transport systems is conformance to standards. It is during the EMA that baseline measurements of the system’s standards conformance are physically measured. Using approved test fixtures and gauges, the dimensions and attributes of the candidate system are recorded as a baseline for any future tests that may be performed. Again, the distributed nature of an overhead transport system suggests that some aspects of the EMA be module- or unit-based to comprehend various implementation schemes.

The ISMT *Equipment Maturity Assessment Handbook* can be used as a guide to assist those preparing for or performing equipment maturity assessments.

3.3 Gauge Studies

The I300I *Demonstration Test Method – Revision 1* (DTM Section 6.1) requires that a gauge study be conducted where applicable on the metrology tools that will be used for demonstration testing. Table 2 identifies the measurements and gauges required for performing a demonstration test on an overhead wafer carrier transport. It also provides guidance about the expected range of measurements to be supported for each gauge. SEMI E89, *Guide for Measurement System Capability Analysis*, should be used as a reference for all gauge studies to be performed.

Table 2 Gauges and Measures for the Testing of Overhead Wafer Carrier Transport Systems

Measurement	Gauge	Range	Unit
Defect detection (unpatterned)	Laser scattering	≥ 0.09	count/cm ² size in μm
Velocity	Stopwatch and tape measure	TBD	TBD
Shock/vibration	Accelerometer	< 1 g	g
Particles	Liquid particle counter (LPC)	≥ 0.09	#/ml
Particles	Sniffer	≥ 0.09	count/cm ² size in μm
ESD	Electrostatic Discharge Meter	1-1000	Volts
Electrical Field	Electrical Field Meter	10-100,000	Volts

3.4 Mechanical Dry Cycle (MDC)

The I300I *Demonstration Test Method – Revision 1* (DTM §6.2) requires that an MDC (otherwise known as “dry run”) test be performed to quantify the mechanical performance of the tool without the complexity of wafer processing or transport.

In general, the requirement to exercise every mechanical function within the normal operational flow of a functional tool without the complexity of actual wafers being transported should be maintained. At each intermediate station, as many mechanical functions as possible should be activated or cycled. The goal for the number of cycles to be tested should be based on the goal and statistical confidence level selected for the number of machine cycles needed in the demonstration test.

It is important to note that a key difference between the Mechanical Dry Cycle (also known as “dry run”) and a Marathon demonstration test is that the Marathon test should be constructed to exercise a transport system in its entirety, with the added complexity of transporting mechanical or prime grade wafers.

3.5 Passive Data Collection (PDC) and Sensitivity Analysis (SA)

The I300I *Demonstration Test Method – Revision 1* (DTM Section 6.3 through Section 7.1.2) requires monitoring of specific input and output data sets during the PDC and SA test elements.

Unless otherwise indicated, testers should assume that the parameters are the same for both the PDC and SA since the designed experiments will investigate factors that were identified as significant during the PDC. During the PDC, monitoring inputs and measuring process outputs specifically establish the stability and repeatability of the process. The objective of the SA is to investigate the interaction between the inputs and outputs as measured in the quality of the outputs.

The following inputs should be monitored for overhead wafer carrier transport systems, regardless of process configuration:

- Number of wafers in the carrier
- Mass of the carrier
- Carrier manufacturer
- Carrier environment
- Travel distance (both in the x and z planes)
- Programmed parameter setpoints (i.e., speed, etc.)

The following outputs should be monitored for overhead wafer carrier transport systems, regardless of process configuration:

- Wafer particulate level (per wafer pass [PWP])
- Vibration (attenuated and maximum)
- Velocity (average, peak)
- Delivery time (average, peak)
- Response time (average, peak)
- Throughput
- Mean time between failures (MTBFp)

- Mean time to repair (MTTR)
- Availability
- Placement precision (reproducibility and repeatability)
- Placement accuracy
- Pick precision (reproducibility and repeatability)
- Pick accuracy
- Stability

3.6 Marathon Test

The I300I *Demonstration Test Method – Revision 1* (DTM Section 7.2) requires that a Marathon test be performed, if appropriate, depending on the maturity of the tool. This document does not provide detailed guidance for planning or performing the Marathon test element since sufficient detail is included within the DTM and the methodology for Marathon testing is the same for all equipment classes.

As mentioned previously, the distributed nature of overhead transport systems suggests that statistical analysis and modeling of the systems be module- or unit-based to allow for visibility into various implementation schemes. Care should be taken when such analyses are performed.

4 APPLYING TEST METRICS

For overhead wafer carrier transport equipment, two test metrics characterize performance results: *process performance parameters* and *cost performance parameters*.

4.1 Process Performance Parameters

Process performance parameters are the parametric results of wafer carrier handling. The following metrics should be collected, evaluated, and published as results of a Marathon demonstration test.

Metric	Units
“On bare Si” defects per-wafer-pass @ 0.09 μm	$\#/\text{cm}^2$
“Backside on Si” defects per-wafer-pass @ 0.20 μm	$\#/\text{cm}^2$

4.2 Cost Performance Parameters

Cost performance parameters represent the summary analysis of equipment manufacturing performance and reliability measured during the Marathon demonstration test. The following metrics should be collected, evaluated, and published as results of the demonstration test.

Metric	Units
Throughput	Wafer starts/month (WSPM)
Tool capital cost assumption	\$M
Mean time between failures (MTBFp)	hours
Mean time to repair (MTTR)	hours
Preventative maintenance	hours/week
Consumables	\$/WSPM
Area per tool	m ²
Support area per tool	m ²
Production utilization	%
Cost of Ownership (COO)	\$/WSPM

5 COLLECTING ADDITIONAL METRICS AND DATA

In addition to the metrics routinely collected during the MDC, PDC, SA, and Marathon tests, members of the test team may wish to collect additional metrics. For example, they may wish to obtain data about a parameter whose effect on processing is not well understood or has not previously been quantified, or they may wish to obtain data to promote the acceptance of a measurement tool that although robust has not previously been accepted by all team members. Any additional data must be collected during demonstration testing. The data should be statistically analyzed by the same methods as those used with the standard test elements, and all results should be published in the final test report.

6 WORKING WITH TECHNOLOGY- AND PROCESS-DEPENDENT CONSIDERATIONS

For certain classes of equipment, additional guidance is required for particular processes or technological challenges that are unique to those classes. Since there are no unique processes or technology attributes within the overhead wafer carrier transport equipment class, this is not applicable.

7 REFERENCES

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7.1 Process-Specific Test Metrics

The complete set of test metrics and recommended goals can be found in the *ISMT Metrics for 300 mm Automated Material Handling Systems (AMHS) and Production Equipment Interfaces* document.

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