



**ISMI Consensus Preventive and Predictive Maintenance Vision  
Guideline: Version 1.1**

**International SEMATECH Manufacturing Initiative  
Technology Transfer #06114819C-ENG**

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November 20, 2007**

**Abstract:** This report from the MFGM032M project represents the consensus of the International SEMATECH Manufacturing Initiative (ISMI) member companies on their vision of the future and direction for preventive and predictive maintenance (PPM). It presents concepts and values, rather than specific methods or procedures, to be used by equipment suppliers and others in the industry to understand the direction and requirements for PPM, to allow for strategic planning and participation in the ISMI PPM Project, and to begin discussions on the capabilities needed to realize PPM as a source of improved factory productivity. This revision adds a section on implementation considerations.

**Keywords:** Automated Data Collection, Business Trends, Maintenance, Predictive Maintenance, Preventive Maintenance

**Authors:** Steve Fulton, Myungkill Kim

**Approvals:** Steve Fulton, Project Manager  
Brad Van Eck, Program Manager  
Scott Kramer, Director  
Laurie Modrey, Technology Transfer Team Leader



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# 1 INTRODUCTION

## 1.1 Background

Benchmarking metrics collected from International SEMATECH Manufacturing Initiative (ISMI) member companies representing a good cross-section of the semiconductor industry estimate that overall equipment effectiveness (OEE) generally lies in the 40% to 60% range, which is low, considering the capital cost of fab process and metrology tools. Improving equipment utilization therefore represents a huge potential opportunity for improving fab productivity.

According to the latest ISMI data, there are four drivers for productivity improvements:

1. Continual shrinking of the transistor size
2. Productivity increase (e.g., equipment)
3. Wafer size
4. Yield improvement

This shows that the potential improvement available from the equipment and fab automation/integration opportunity space must be actively addressed.

Improving OEE through better availability, predictability, and cost contributes directly to the productivity bottom line. While there is no realistic expectation that OEE can closely approach 100% in any cost-effective way, it remains a huge opportunity for potentially improving the value from equipment and fabs. Asset management is therefore seen as an enabler to gain this potential benefit, which can be realized in production planning and maintenance. While tool-level sensor data are currently available, the high engineering costs for the combination of process and equipment data are one of the main reasons that asset management systems have not yet been established.

Current predictive maintenance (PdM) practices to prevent unscheduled failures are rudimentary where they exist at all and limited by the data that the equipment can provide. Preventive maintenance (PM) activity is predominantly based on elapsed calendar time and not on data. Factors such as part lifetime, wear profiles, or service history analysis are not extensively used. Today's fab equipment does not even use predictive or preventive methods internally, such as model-based performance tracking (monitoring performance and comparing its component variables to a baseline model) or health monitoring. Many of the components selected and used cannot supply the needed data and information to allow predictive/preventive maintenance (PPM). Suppliers generally do not make good use of failure rate data or large performance databases to establish performance expectations or determine corrective action.

Factory systems for predictive and preventive maintenance are not well developed, largely because data are unavailable. It is not well understood what a factory application for this purpose should be, or look like, or what its performance attributes should be.

Predictive maintenance is emerging in other industries as a compelling value. The automotive industry, for example, has been investing with proven value results for several years and their maintenance strategy has now matured beyond the development phase. With the addition of the ISO TS-16949 Quality Management Systems extension of ISO 9001:2000 making the use of predictive maintenance a requirement for automotive design and service organizations, it has

become a mainstream requirement and technology. The semiconductor industry can benefit directly from the use of advanced manufacturing technologies.

This provides a high level view of the data needed from the equipment, and the expected results of such efforts. It additionally provides guidance for suppliers to incorporate improved internal equipment capabilities to enhance onboard performance and support factory system applications to use advanced techniques for near real-time monitoring and intervention. Suppliers should incorporate knowledge management and decision support tools into their equipment to maximize the value of the data.

IC makers will merge this information with other data sources and put the common result into their own PPM planning system. The goal of PPM is to identify the criticality of certain deviations or error conditions in a real-time manner and to identify the required actions. Such interpretations are seen as a critical enabling capability to enhance OEE.

## **1.2 Purpose**

This document represents the consensus of the ISMI member companies on their vision of the future and the direction desired for PPM. The concepts and values, rather than specific methods or procedures, enable a comprehensive high level view of the vision. The document is intended to be used by equipment suppliers and others in the industry to understand the direction and upcoming requirements, to allow for strategic planning and participation in the ISMI PPM Project, and generally to begin discussions and alignment on the capabilities and needs to realize PPM as a source of improved factory productivity.

As yet there is no widespread agreement on the language, elements, or direction for development and implementation of PPM. Opening discussion is one of the purposes of this document, with a focus on the following goals:

- Define and investigate PPM systems that will support improved and stable equipment availability, productivity, and OEE. Repeatable availability is a basic requirement for PPM.
- Establish consensus equipment behavior and data requirements for predictive maintenance and condition-based preventive maintenance methods to improve equipment productivity as measured by uptime, availability, cost, and OEE.

To be successful, all stakeholders, including IC makes, equipment suppliers, OEMs, third-party providers, and every member of the supply chain, must participate in the development of PPM capabilities. This guideline provides a starting point for developing these capabilities, with these objectives:

- Present the IC maker consensus vision and guidelines
- Describe some of the equipment and system requirements that would support these critical capabilities
- Consider areas in which standards would be beneficial or needed
- Consider what investigation, research, and prototyping of data capabilities and implementations could assess feasibility and requirements for robust manufacturable systems

- Determine how to drive the commercial availability of predictive and condition-based preventive maintenance capabilities for both software and equipment suppliers

## **1.3 Terminology**

### **1.3.1 Definitions**

For this document, the following definitions will be used.

- Preventive Maintenance – A schedule of planned maintenance actions aimed at preventing unscheduled equipment down time. It is traditionally based on elapsed calendar time or fixed unit count usage.
  - Predominantly time and usage based
  - Daily, weekly, monthly
  - Wafer count- or RF count-driven
- Condition-based Preventive Maintenance – An enhanced method that applies advanced analysis techniques to data from equipment components, modules, or other sources to identify performance indicators, such as thresholds, control limits, voltage, etc., requiring preventive maintenance. Condition-based PMs are intended to maximize the availability and productivity of the equipment while optimizing maintenance costs.
  - Optimizes the availability of the equipment
  - Includes conditional and time-based preventive maintenance
    - Uses real data to determine when PMs should be done
    - Uses data from all possible data sources that can be obtained as input (equipment data, maintenance data, warning frequency and etc.)
  - Applies advanced analysis and scheduling techniques
  - Aims to reduce scheduled downtime, usage of consumables/parts, and optimization of maintenance effort and costs
  - Acknowledges that “optimum” may vary among users or equipment type and related costs for implementation, as may the important input parameters to analytical algorithms
- Predictive Maintenance – A maintenance technique that uses data from equipment and other relevant sources (i.e., FDC, APC, Yield learning, PM history, etc.). These data allow events and trends in performance and equipment settings to be monitored through advanced analysis techniques and failure behavior profile matching. Analysis of component performance data and other indicators enable the identification, give warning, and prioritize impending or imminent unscheduled failures in advance. Predictive maintenance is complementary to condition-based preventive maintenance.
  - Predictive maintenance is supported by high performance equipment data availability and well developed factory systems

### 1.3.2 Acronyms

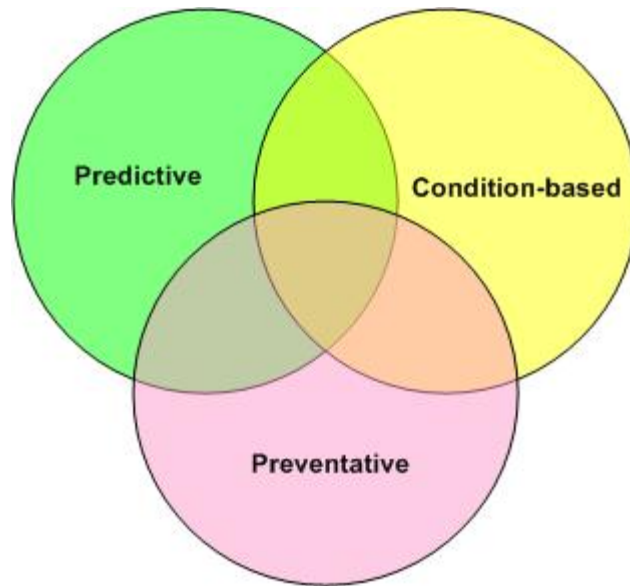
AO	Availability
APC	Advanced Process Control
CEM	Common Equipment Model
COO	Cost of Ownership
EDA	Equipment Data Acquisition
EPT	Equipment Performance Tracking
FDC	Fault Detection and Classification
ISMI	International SEMATECH Manufacturing Initiative
M-Ratio	Maintenance ratio between scheduled/unscheduled maintenance
MTBF	Mean Time Between Failure
MTTR	Mean Time to Repair
OEE	Overall Equipment Effectiveness
PdM	Predictive Maintenance
PM	Preventive Maintenance
PPM	Predictive and Preventive Maintenance
PTTF	Predictive Time to Failure
RF	Radio Frequency
SMC	Statistical Machine Control
SPC	Statistical Process Control
SVID	Status Variable ID
TBM	Time-based Preventive Maintenance
UBM	Usage-based Preventive Maintenance
WIP	Work-in-Process

### 1.3.3 References

Equipment Engineering Capabilities (EEC) Guidebook, International SEMATECH and JEITA/Selete Collaboration, Version 2.5, July 2002

## 2 FUNDAMENTAL PPM EXPECTATIONS

Predictive/preventive maintenance capabilities (see Figure 1) make use of available equipment operational and performance data to reduce scheduled and unscheduled downtime and optimize equipment productivity, availability, and operational maintenance cost.



**Figure 1 Components of Maintenance**

The goal of a successful maintenance strategy is to incorporate all aspects of equipment data and develop a program to limit non-planned maintenance to a minimum by reacting to this data through various predictive and planned activities.

### **2.1 Improving Equipment Uptime and Availability**

As the cost of semiconductor equipment rises, it is imperative that assets are used at high levels. This can be achieved by eliminating or reducing the occurrence of unplanned failures. Scheduled maintenance events can be optimized by basing these activities on tool data that indicate specific areas of the equipment that require attention and the optimum frequency for this maintenance. Efforts to reduce tool variability, mean time to repair (MTTR), and improvements to mean time between failures (MTBF) are crucial to the flow of production of a semiconductor fabricator.

### **2.2 Reduce Operational Cost**

The cost of consumables is becoming a larger component of tool ownership. Through data analysis, tool owners have better insight into consumable lifetimes, enabling them to run these components to full life while minimizing any unexpected downtimes to equipment due to consumable failure.

Toolset data can enhance the efficiency of service personnel. Reductions in toolset variability will decrease staffing requirements to maintain the tools. For example, troubleshooting time can be reduced with the additional information that is at the technician's disposal. Through improvements to toolset MTBF, requalification frequencies are also reduced.

### **2.3 Improve Product Quality**

Product quality is always a concern when tool owners recognize that a tool has been performing at a sub-standard level. Semiconductor equipment can ensure product quality and eliminate rework when a real-time detection system provides feedback if tool parameters start to run out of specifications.

Another benefit to toolset data is that product performance can be trended against toolset parameters as a learning tool that promotes optimization to process recipes.

## **2.4 Factory System**

Equipment suppliers can provide safeguards to protect tool performance quality by monitoring and reacting to key parameters based on tool parameters while equipment users will need to provide systems with decision making based on all data available to them. The factory system should take into account tool data provided by the equipment supplier's system in addition to data sources available in the fabricator (e.g., SPC, in-line monitoring, etc.).

While the factory system can use more data inputs in its decision making, including product and process factors, the equipment system should provide the first line of defense in reacting to changes in tool performance.

The framework of the factory system must be able to accept different algorithms from different sources or equipment.

## **2.5 Equipment System**

Auxiliary equipment data that are part of the tool should be integrated into the main tool and available through it to the factory system. In some cases, this auxiliary equipment data are not fed to the main equipment, but the goal should be to allow the main tool to contain algorithms to monitor and react to these data at a local level before supplying the data together with its own data to the factory system for more complex analysis (i.e., multiple tools, multivariate SPC).

An important component of the equipment system is determining the polling frequency for individual parameters. Unnecessary excess data could impact tool performance; this is unacceptable for equipment users. The volume of the data stored will depend on tool type.

## **2.6 Data**

Access to extensive high fidelity data is a requirement for predictive and preventive maintenance. The type, volume, and handling of such data can present significant challenges.

- **Transfer**

Data transfer from the equipment should be provided through standardized interfaces such as equipment data acquisition (EDA) or Interface C (e-diagnostics). To provide an effective predictive maintenance program, data must be obtained from all available sources (not just equipment). In some cases, new data sources may require development.

The collection and storage of data must not impact tool performance in terms of quality or rate of production.

- **Application**

The predictive maintenance application provided through the equipment supplier should allow remote access (monitor from off-line locations) and portability (information can be transferred to a server database for additional analysis).

Analysis techniques for both factory and equipment systems may include, but are not limited to, modeling parameter performance and predicting future behavior to reduce performance variability.

The application must be able to discontinue the tool based on changes in tool parameters that indicate a need to stop production.

- **Storage**

Equipment users should be able to define the sample rate and amount of data to be stored. Individual parameters may require highly variable sample rates. The equipment should have sufficient data storage to make initial decisions on the tool data. The system should automatically transfer data that are collected to a customer database for more in-depth analysis in combination with external data sources.

## 2.7 Other Considerations

Suppliers should give consideration to companies that have older tool sets. When it makes sense from a practical and monetary standpoint, solutions should be provided that can be retrofit to these older systems to provide value to companies that have a fixed tool base.

Equipment suppliers should consider a phasing strategy that allows customers to realize some PPM benefits in the short term before an application is fully developed.

## 3 PHASING STRATEGY

Certainly a paradigm shift will be required to reassess some of the basic assumptions underlying the maintenance strategies in use today, as well as to access additional data and analytical tools.

PPM will not happen immediately or as a single event. The expectation is that the development and implementation of the PPM vision will occur as a smooth transition over time, most likely following the logical implementation sequence of improving current PM practices, concurrently developing new data sources and handling that will enable effective implementation of condition-based preventive maintenance, and culminating in the addition of PM capabilities.



### 3.1 Challenges for the PPM Vision

This section highlights the challenges involved in enabling PPM solutions to help suppliers and others in the industry gain greater understanding. This is not an inclusive list of all challenges, but outlines the high level challenges for PPM development.

In developing a strategy for the systematic development and deployment of PPM capabilities, several key areas should be considered. Understanding the technical difficulty, solution

technology, available resources, and schedule will help prioritize these challenges to deliver robust value.

- **Sensing and Data Acquisition**
  - The first phase in delivering integrated PPM solutions is ensuring accurate data signals are available from the equipment. These signals are then captured using specific sensors. The correct data signals and sensors are the foundation of PPM solutions.
  - Sensors are categorized into three groups to support semiconductor equipment. Examples of sensor families are shown below. In the drive to enable a full PPM solution, extensive instrumentation of sensors is required to deliver accurate equipment and product status.
    - Equipment state sensors: Monitor equipment parameters
    - Process state sensors: Monitor process condition
    - Product state sensors: Monitor product status
- **Condition Monitoring and Health Assessment**
  - Establishing a baseline for equipment performance is a critical step in enabling predictive maintenance solutions. Standard condition monitoring techniques (e.g., SPC, APC) are employed primarily in process monitoring. Going forward, “condition monitoring algorithms” should be developed that include equipment signals integrated with statistical process control (SPC)/advanced process control (APC) delivering a “health assessment” metric for the equipment.
  - Ideally, equipment providers should provide standard health assessment metric for each critical equipment module through Interface A.
- **Health Assessment and Prognostics**
  - Prognostics (predicting impending equipment failure) is one of the key challenges in enabling PPM solutions. The complexity of the mathematical algorithms to infer impending failure will require AI/machine learning solutions. Due to the complexity and uniqueness of each tool family, prognostic algorithms may need to be developed with each equipment supplier.
- **Data Integration and Automation Architectures**
  - Data fragmentation and organization in high volume manufacturing sites must create challenges for integrated PPM solutions.
  - Integration of data from multiple sources should be included in the final PPM decision; this integration of multiple data sources with potentially different data structures (text vs. numerical) provides a major challenge for semiconductor companies.
  - Sample examples of PPM data sets are as follows:
    - Equipment health assessment sensor data
    - Process health (in-line metrology + end-of-line yield)

- Historical parts performance
- Maintenance headcount
- Area equipment availability
- Area WIP status
- The sheer volume of data can be overwhelming, particularly if integrated data sets are required. This must drive innovative approaches to equipment data collection and treatment.
- **Cross Technology Challenges**
  - Delivering a PPM solution that works across each wafer size technology presents a major challenge, due to differences in data sets, quality of data, and automation architectures, particularly on older technologies.
- **PPM Decision Making**
  - The PPM decision on when to take equipment down for maintenance should be integrated with overall manufacturing operations decision making and not viewed as an equipment-only decision.

### 3.2 Implementation Challenges

- **Equipment Considerations**
  - Suppliers need to integrate some of the solutions and recommendations into their tools. The overall expectation is that equipment owners will have the ability to know when the tool is about to fail.
  - SECS ports are the current standard for extracting data from the tool, with EDA becoming dominant. Data identifiers, such as SVIDs, Common Equipment Model (CEM) descriptors, or EDA metadata, should include a reference to the specific parts of the tool that are about to break.
  - The goal is to have 100% confidence in the information from the tool about current and predicted performance, which will reduce the variability of equipment availability.
  - With the large volume of data requiring analysis, reliable data transfer is critical to enable intelligent failure prediction. Interface A can play a key role in ensuring the quality of data.
  - Predictive Time to Failure (PTTF) (time/wafer, etc.) is recommended and should be based on sensor data and equipment/process parameters extracted from the tool during processing.
- **Factory Considerations**
  - Factory Systems
    - Novel solutions must be required to integrate equipment data and overall factory operations into valid data sets for PPM decision making.

- Models and algorithms such as machine learning algorithms, predictive failure models, Weibull analysis, etc., must be developed.
- Failure models for each key component of the tool should be standardized. Model-based-predictions will use both historical and real-time data from the tool to generate an imminent failure warning.
  - While the component is running, the model should compare current performance to the result that is expected.
  - The model should have the ability to predict the near future performance; monitors should be implemented that validate the prediction on a continuous basis.
- Device performance should be integrated with predictive maintenance.
- A common industry message is needed, including user requirements for PPM systems and the equipment data to effectively implement them.

### **3.3 Phased Approach to Implementation**

The development and implementation of the elements and capabilities for PPM are expected to be gradually integrated and deployed in equipment and to fabs, as a natural progression of continuous improvement. Each of the maintenance types—preventive, condition-based preventive, and predictive—target and best support different types of service and failure regimes. They should be viewed as working together synergistically to provide a comprehensive approach to equipment support for maximizing cost-effective equipment productivity.

Most IC makers have an ongoing equipment engineering effort to monitor and improve the performance and cost effectiveness of the PM in production fabs. Ongoing continuous improvement is the first phase of the effort to realize the PPM vision.

The second phase for PPM most likely contains two concurrent focus areas. Systematic efforts to improve the available data and to incorporate effective health monitoring, which includes advanced analytical methods, model-based controls, and predictive elements in the equipment, constitute one focus area. IC makers are expected to be concurrently working to develop and implement condition-based preventive maintenance that will be most effective for their specific process and product environment.

Finally, PdM capability that uses advanced trending and analytical tools to identify and proactively avoid potential and impending failures will be added. It is likely that predictive systems that do not consider the upstream material and workflows will be implemented first, adding complexity to factory logistics, including spare parts management, as confidence and performance grow. Implementation of PdM adds to the capabilities of the preventive systems, in which each component contributes to the holistic approach to equipment productivity and optimized operating costs.

### **3.4 ISMI Predictive and Preventive Maintenance Project**

ISMI is funding a limited term technical project for PPM. This project is intended to provide coordination and shared-cost development for the member companies while accelerating the development and implementation of solutions described in this document.

The ISMI project will be comprised of several activities, each aligned with a particular need or focus area within the PPM vision. Like the majority of the IC industry, the particular focus will be determined based on need and delivered performance. The focus areas are expected to include the following:

- Industry education
- Supplier interaction
- Benchmarking
- Investigation and research
  - The current state of the practice
  - Resources from other industries that can be leveraged
  - Knowledge and resources to incorporate into a PPM philosophy
- Conceptual prototypes
- Prototype and pilot implementation cases
- Collaboration with academia
- Standards development where appropriate
- Work with suppliers to develop and demonstrate solutions
- Factory system requirements
- Socialization and commercialization

This partial list suggests the scope and boundaries of the ISMI PPM project.

## **4 GENERAL GUIDELINES**

### **4.1 PPM Data Sharing**

PPM should use data from all available sources to provide the best performance monitoring and predictions. When determining what sources of data are available and relevant, the entire environment that the equipment operates in should be considered (see Figure 2).

Implementations should evaluate the usefulness of the data in improving equipment availability, maintenance cost, and OEE and make that data available to the PPM systems.

### **4.2 Determination of PPM Data**

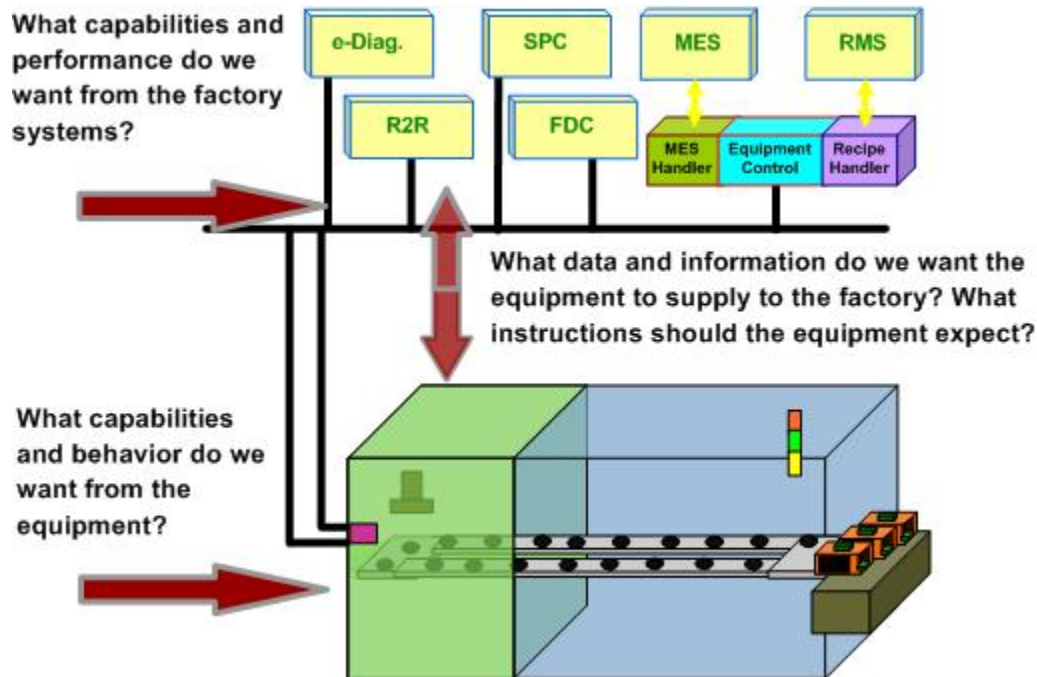
The type and extent of data for each of the components of comprehensive PPM solutions will vary depending upon their role. Preventive maintenance requires the simplest data set, whereas predictive methodologies require much more data in both amount and type.

#### **4.2.1 Preventive Maintenance**

Preventive maintenance is traditionally based on elapsed calendar time or fixed unit count usage.

- Usage Based Preventive Maintenance (UBM)
  - Maintenance activities carried out at predetermined intervals of usage

- The determination of usage is based on wafers counted since the last exchange, on cumulated hours of usage (e.g., RF hours) or consumption of consumables



**Figure 2 Predictive and Preventive Maintenance Data and Implementation Environment**

- Time-Based Preventive Maintenance (TBM)
  - Parts that have to be exchanged/repared at predetermined intervals of time
  - Intervals of time are fixed and independent of usage (e.g., weekly, monthly, or quarterly exchange)

Traditional PM will continue to be a component of comprehensive PPM systems, as it is suitable for some types of maintenance. PM should be based on data, such as the expected life of consumable parts or historical data on the useful life on the equipment.

#### 4.2.2 Condition-Based Preventive Maintenance

Condition-based preventive maintenance is an enhanced method based on equipment or other possible data collection and analysis. Various advanced analysis techniques and data collection methods are currently being used to achieve more competitive equipment availability and productivity.

- Condition-based PMs are intended to maximize the availability and productivity of the equipment while optimizing maintenance costs. PM actions must be done at the time needed to do them to avoid unscheduled failure while not wasting any usable time for the part, component, etc. Costs are reduced as parts are used as long as maintenance effort is spent only as often as required. This also reduces planned downtime and thus increases availability.

- Data sources are internal machine sensors, equipment performance and process data from the machine, and external systems (e.g., SPC). They can be any data that indicate the condition of a consumable, component, unit etc. Once a defined level is reached, it triggers a maintenance action.
- Necessary data to determine the condition of a part or machine may be collected in real time or in defined intervals, which need to be short enough to give an indication early enough to avoid unscheduled failure.
- Analysis of the collected data is possible either in real time or from offline databases.
- Application of advanced analysis and scheduling techniques is needed.

#### **4.2.3 Predictive Maintenance (PdM)**

Predictive maintenance identifies impending or imminent unscheduled failures and generates advanced warning and prioritization, which is not easy because of their natural uncertainty. To make predictions that are useable in a real factory, there are four essential components (input, methodology, output, and use) as described below. In any case, predictive maintenance is complementary to condition-based preventive maintenance.

##### **4.2.3.1 Input**

- Input includes data about the condition of equipment and facilities, fab performance indicators, and maintenance management data to schedule the most convenient time for maintenance.
- All available data such as the following are considered input:
  - Internal data about performance and condition of equipment, equipment components and other sources e.g. additional sensors within the equipment
  - External data and events including FDC, EPT, PM history, SPC, SMC, etc.

##### **4.2.3.2 Methodology**

- The methodology should monitor single parameters, trends, and performance of equipment and additional data sources:
  - Equipment parameters (electric, mechanic, pressure, chemical, etc.)
  - Fab performance indicators (number of processed wafer, used recipes, WIP, etc.)
  - Facility data
  - Availability of equipment
  - M-Ratio: Scheduled/unscheduled downtime
  - MTBF
  - Cost of ownership
- Statistical and other analysis and failure behavior profile matching should be included.
- Information that identifies the possibility of concurrent failures or that allows for prioritization of maintenance on imminent required maintenance is important.

- Event-driven failures that do not need trend data (FDC data may be an input source for fault prediction) should be included.
- The PdM system must analyze the input data according to rules and models defined. It then calculates the optimum time to do maintenance. Warning must be given in advance so that activities can be scheduled.

#### 4.2.3.3 Output

- Early warning must be given of impending or imminent failure conditions to distribute the workload and avoid simultaneous downtime of many pieces of equipment.
- The maintenance schedule should be automatically adjusted. This means that although the IC makers (using the PdM system) determine the best time to do a PM, there still needs to be a time window to allow scheduling.
- Unscheduled downtime is reduced by early warnings giving a chance for scheduling.
- Maintenance-related costs are reduced as maintenance is done close to the latest possible time reflecting usage, condition, data, etc.
- Repair and overhaul time is reduced as early indication gives a time window for preparing activities.
- The spare parts inventory is reduced as early indication gives the chance to order parts when needed.

#### 4.2.3.4 Use

- The scope of predictive maintenance should ideally be expanded so that it would naturally include smart preventive maintenance.
- PdM should be used to improve preventive and condition-based maintenance.
- PdM may be applied to a subset of equipment where unique requirements or failure modes have been identified and need to be prevented.
- Whether such a system can be used depends on factors like availability of data and knowledge to interpret the data into an estimate for equipment behavior and on related costs for implementation.

## 5 IMPLEMENTATION

Realizing the PPM vision described above will require cooperation and collaboration between the IC makers and equipment supplier community, based on a common understanding and mutual benefit. Establishing and maintaining open communication channels and a collaborative environment early and throughout the development and deployment of PPM is essential to its success.

PPM is intended to improve the predictability of equipment availability and utilization in manufacturing fabs. While it may reduce the number or frequency of maintenance events and contribute to reducing variability, these do not constitute the primary purpose, which is *predicting the need for maintenance in advance to allow for planned response and providing predicted confidence for the successful completion of production.*

PPM is expected to be a continuum of capabilities, applications, and solutions involving the equipment and the factory systems. In some cases, a specific function or role will reside solely on the equipment or at the factory level, and in other cases, complementary instances of the same functionality will be found on the equipment and factory working together.

## **5.1 Equipment Implementation**

When implementing PPM on semiconductor manufacturing equipment, two essential roles should be considered. First, the equipment should incorporate in its design functions, architecture, and capabilities that provide predictive and condition-based preventive maintenance within the scope of the equipment hardware and software operation. Second, the equipment should generate and make data available on all of the equipment functions and operations as well as performance and health metrics.

### **5.1.1 Equipment “On Board” PPM Capabilities**

The equipment design should include predictive and preventive maintenance capabilities that are based solely on the equipment hardware and software, without consideration for the process, product, or operational model of the production fab. As a result, the PPM capabilities should closely align with the equipment operational design parameters and philosophy. This approach will allow for deterministic handling and solutions within the boundaries of the equipment solutions as part of the overall PPM environment.

Equipment designs should try to include as many PPM capabilities as are applicable and add value to the predictability and operation of the equipment. PPM capabilities that are expected to be implemented on the equipment include the following:

- Fault detection and classification (FDC)
- Model-based monitoring and prediction of consumable lifetimes
- Model-based parameter monitoring and statistical process control (SPC)
- Statistical predictive and prognostic systems
- Equipment health and forecast metrics
- Analytical performance measures

PPM capabilities may be added to the equipment incrementally. The scope of implementation may begin small and grow with experience and data. For example, a critical or problematic subsystem may be the initial focus for implementation, expanding to the rest of the equipment design as effective results and solutions are proven.

Equipment PPM capabilities should provide for end-user input for rigor and sensitivity. For example, the threshold level for an alarm or shutdown should accept input from the end user to raise or lower the trigger level. This allows for differentiation within the manufacturing environment and provides the equipment supplier protection for the implementation and intellectual property (IP) associated with the solution.

### **5.1.2 Equipment PPM Data**

To meet the vision of PPM, equipment is expected to generate, use, and make available a wide variety of data. The data will include many of the data that are available today, as well as new

data that has not previously been available. In some cases, this will require the addition of sensors or measurements that do not currently exist.

In the PPM vision, the equipment is both a data provider and consumer. In the data provider role, the equipment will generate and supply data to solutions on the equipment, and make the data available to the factory systems. The factory systems will use the equipment data to combine with data from other sources, such as process and product considerations, upstream and downstream processing requirements and results, incoming materials factors, etc., to provide operational PPM functionality and direction.

#### **5.1.2.1 Equipment Performance Indexes**

Equipment data come from a variety of sources that produce data of different types. The data can represent a fixed value, the duration between control sequence events, a derived or calculated value, or other format that represents a value of interest. Since these data are generally independent of the process or operation, in process or idle status, and other product or process context, the datum is referred to as the Equipment Performance Index (EPI).

Protection of IP is an important consideration in making data available outside the equipment. Limiting the EPIs to the result of a control sequence operations, such as the time between an action command and the completion of that command or the value returned from the equipment component or subsystem, protects the design IP of the equipment. Conversely, since the data do not contain any context from the recipe or product, the manufacturing operation is protected as well.

Equipment Performance Indexes should be generated at the lowest possible level. In many cases, these low level EPIs may not be the most useful or interesting representation of the data. Additional EPIs can be generated by aggregating low level EPIs, producing a hierarchy of equipment data. The specific data to be communicated to the factory system can be selected from this hierarchy based upon the target condition or result being monitored or indicated. Statistical summary or analysis of iterative EPI datapoints should also be made available as output data. Additionally, the potential to significantly improve fault classification and to use the data hierarchy to improve and accelerate troubleshooting and problem resolution should be investigated.

The equipment PPM capabilities will make extensive use of EPIs, and the equipment data set required by the factory application will include EPIs and more traditional process and performance data points. The communication of these data must use standardized communication protocols and interfaces.

#### **5.1.3 Prioritizing Equipment Implementation**

While ubiquitous implementation is the vision for PPM, a more practical incremental development and implementation model should be adopted. Tactical deployment of individual PPM capabilities that deliver proven results commensurate with the effort and investment, establishing a steadily increasing PPM infrastructure and environment, is the preferred strategy.

Equipment should be analyzed to determine the PPM capabilities and target subsystems or modules that will provide the greatest return and improvement to equipment predictability and productivity. Analysis of the extensive field service databases collected and maintained by the equipment suppliers can provide direction for prioritizing PPM development activities. Critical

process resources as identified by the IC makers and manufacturing maintenance records can augment the field service data.

It is strongly recommended that suppliers establish a data-driven PPM implementation plan that includes demonstrating and quantifying results. This will allow for the application of critical manpower, knowledge, and financial resources for the highest return on investment.

## **5.2 Factory Implementation**

PPM implementation at the factory systems level is expected to take a larger, systemic view of equipment predictability and use. The factory systems should consider the effects of specific product and process sensitivities or other factors outside the equipment on performance, predictability, and productivity. The factory systems should use the PPM data and health metrics from the equipment as one set of inputs to PPM systems and analysis. Additionally the factory systems may provide computing power and solutions for advanced prognostics that would pose an unacceptable burden on the equipment.

Factory PPM solutions are expected to conform to the functions and expectations that have been established for equipment engineering requirements (see the Equipment Engineering Capabilities (EEC) Guidebook, Version 2.5). These capabilities play an essential role in enabling the use of common capabilities to meet the varied needs of different operational modes of IC makers.

The PPM vision extends the expectation of the EEC Guidebook to include more manufacturing operational considerations, such as WIP scheduling and management, maintenance resource allocation and management, indirect inventory impacts, e-Diagnostic leverage, and other global enterprise factors. The common capabilities for PPM at the equipment and factory level should allow for flexible application and results.





**International SEMATECH Manufacturing Initiative  
Technology Transfer  
2706 Montopolis Drive  
Austin, TX 78741**

**<http://ismi.sematech.org>  
e-mail: [info@sematech.org](mailto:info@sematech.org)**