



ISMI Predictive and Preventive Maintenance Equipment Implementation Guidelines

**International SEMATECH Manufacturing Initiative
Technology Transfer #08064934A-ENG**

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Abstract: This report from the MFGM032M project introduces equipment predictive/preventive maintenance (PPM) guidelines for the semiconductor industry, in particular equipment suppliers and equipment PPM implementers. It defines equipment data requirements, equipment capability concepts, and factory integration protocols to help equipment suppliers implement PPM. Specific requirements for implementers are listed and explained through use case scenarios and examples.

Keywords: Cost of Ownership, Data Quality, Equipment Performance, Equipment Reliability, Overall Equipment Effectiveness, Preventive Maintenance, Reliability

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1 EXECUTIVE SUMMARY

Predictive/preventive maintenance (PPM) is an initiative to improve equipment maintenance programs to increase fab performance. This document describes equipment PPM functions derived by consensus of the International SEMATECH Manufacturing Initiative (ISMI) Next Generation Factory (NGF) – Predictive/Preventive Maintenance Working Group. Specific requirements for the equipment supplier are explained through use case scenarios and examples. Interactions between integrated device manufacturer factory systems and equipment are included to help equipment suppliers understand how PPM is expected to work. Because a complete PPM solution will involve equipment- and factory-level components that are expected to work together, PPM roles for both the equipment and factory are defined.

2 BACKGROUND

Today's equipment maintenance programs are not efficient. Current preventive maintenance (PM) practices consist of exchanging/repairing parts at a predetermined time or usage interval to prevent equipment failure. With this approach, some parts are replaced before their condition has degraded beyond specification. Other parts degrade or fail prior to the scheduled maintenance. Replacing parts too early or too late results in economic loss from the resulting tool downtime, parts and labor cost, and product loss.

PPM addresses these losses using equipment component degradation information. PPM requires collecting process data and hardware data. This data is used to systematically predict future equipment performance degradation.

PPM benefits the user. The user of the equipment, the device manufacturer, will know the likelihood of equipment problems before committing product to be processed on the equipment. Once equipment performance predictability is established, the factory can optimize product flow to the equipment and maintenance costs. Failures will be predicted in advance, allowing for a planned response. The device maker can make data-based, effective cost versus performance decisions.

PPM benefits the original equipment manufacturer (OEM). Device makers want PPM-capable equipment; supplying PPM-capable equipment is a competitive advantage for the OEM. Equipment with PPM is seen as having high quality. Equipment is often supported in the field by the OEM. When the OEM supports installed equipment, the OEM reaps the parts and labor efficiencies of PPM.

3 PPM GUIDELINES

1) PPM capabilities are intended to be independent of wafer size and technology node.

Wafer size and technology node will significantly impact and may limit the ability to implement PPM capabilities on installed base equipment. PPM capabilities should be modularized to allow independent selection and implementation.

2) PPM is comprised of preventive maintenance (PM), condition-based maintenance (CbM), predictive maintenance (PdM), and breakdown maintenance (BDM).

CbM and PdM capabilities should be developed and available as individual or incremental modules so that the end user can choose to implement one, some, or all of the capabilities.

3) PPM capabilities, methods, and decisions must be based on data.

The complete PPM solution hierarchy should use data from all available sources: equipment process variables data, equipment performance index (EPI) hardware data, new data sources, product data, materials data, statistical process control (SPC), inline monitoring, schedules, resource planning, inventory, and any other available sources. PPM applications within the hierarchy may use subsets of data consistent with what is available to them.

4) The goals of PPM are to eliminate unplanned maintenance events, thereby improving equipment predictability and controlling costs.

This includes sufficiently advanced warning of impending or imminent failure to plan a response, have high confidence in the successful processing for a given period of time, and manage the useful lifetime of consumable parts. Consolidation of PM, CbM, and PdM events may be possible, reducing the overall number of maintenance events and reducing downtime.

5) PPM must use existing SEMI standard communication interfaces and protocols.

The applicable standards include SEMI E30, SECS/GEM, and SEMI E134, –Equipment Data Access.

6) Equipment will implement onboard predictive and preventive maintenance capabilities.

Adequate sensors and data sources to provide equipment state and performance data, analytical and performance monitoring models, predictive and prognostic monitors and notification, and equipment health and performance metrics form the basic capabilities. Input from the factory end user to equipment PPM capabilities must be supported. Equipment should use models for prognostics, monitoring lifetime of consumables, and other appropriate applications. Specific additional methods and applications will be appropriate for differing equipment types, impacting the priority, sample rate, and resulting action.

7) Equipment PPM data collection, analysis, and solutions will be implemented as a non-invasive subsystem or equipment applications that will not negatively impact equipment productivity, quality, or run rate.

Data storage should be limited to what is required to effectively implement PPM. The possibility of using factory computing resources as the primary data repository and for computing-intensive operations such as predictive calculations may be considered.

8) Equipment must make available to factory systems sufficient data and data types to meet PPM requirements.

Process variable data, equipment performance index (EPI) calculated, derived, or absolute values data at the atomic, aggregate, and summary levels, after market and third-party sensors and options, and new data sources will be identified. Equipment data fingerprinting must be supported for static and process-transient data, available ad hoc or as scheduled. These data must be provided in a format appropriate for client consumers outside the equipment, with adequate context information available.

- 9) **Data from auxiliary equipment or subsystems that are functionally part of the equipment must be integrated into the main equipment as part of the complete data set.**

Auxiliary equipment data must be managed and used by the primary equipment, integrated with all other data, and made available to factory system clients for analysis and action.

- 10) **The equipment must provide standardized, meaningful condition monitoring, performance, and health metrics.**
- 11) **The factory systems will include PPM capabilities that consider product, process, and other factors.**

The factory system will use additional data input in its decision-making, including product and process factors, tool data provided by the equipment supplier's system in addition to data sources available in the fab (e.g., SPC, inline monitoring, etc.). See *Equipment Engineering Capabilities (EEC) Guidebook (Phase 2.5)* (19280TD).

- 12) **Factory-level PPM systems should be capable of providing computational resources, support, and possibly data to equipment.**

This will enable computing or storage-intensive, complex analytical, or other tasks outside the reasonable capabilities of the equipment.

4 REFERENCES

- ISMI Consensus Preventive and Predictive Maintenance Vision Guideline: Version 1.1, ISMI Technology Transfer # 06114819C-ENG.
- *Data Quality Guidelines: Version 1*, ISMI Technology Transfer # 07024843C-ENG.
- Equipment Engineering Capabilities (EEC) Guidebook (Phase 2.5), ISMI TTID # 19280TD.

4.1 SEMI Standards

- **SEMI E120 – *Common Equipment Model***
Gives a snapshot of the equipment providing the accurate representation of major hardware and software components.
- **SEMI E125 – *Metadata and Equipment Self-Description***
Allows clients to know the available data such as parameters, events, exceptions, and machine states.
- **SEMI E132 – *Client Authentication and Authorization***
Verifies the client credentials during an attempt to establish a session and stores the information. Once the session has been established, client authorization features approves the client's privileges.
- **SEMI E134 – *Data Collection Plan Management***
Allows the client to create a data collection plan based from the SEMI E125 Metadata. Other References.

5 EQUIPMENT DATA

Because data are the fundamental basis for all PPM functions and applications, the creation and availability of sufficient real-time or near real-time data are critical when developing PPM. While the integrated PPM environment uses many different sources and types of data at the equipment, factory, and intermediate levels, the equipment is the primary source of PPM data. PPM equipment data requirements are limited to data that can be used to improve predictability, resulting in overall factory productivity improvement. Process control, yield, and other factors are outside the scope of this guideline.

The requirements, definitions, and specifications for equipment PPM data are applicable to all equipment types. Expected results are consistent across different models, manufacturers, or types. The complexity, process type, and important relevant data set will vary widely among equipment, even the same types but of different models or from different manufacturers. A PPM application must at a minimum supply a complete set of data that allows for the tracking, modeling, and predictive control of equipment maintenance and process performance. A complete PPM application equipment data set includes point source, discrete, calculated, and derived data sufficient to represent the equipment condition to a high degree of statistical confidence.

The following sections include data sources and formats expected to be supported on PPM-enabled equipment. General requirements for the data environment, relevant data types and the way they should be created and managed are presented. Required special case data sets are presented with examples to promote discussion.

5.1 General Data Requirements

PPM data general requirements are expected to be universally supported regardless of data type, frequency, source, position in the data hierarchy, or other factors. These general requirements are expected to be consistently designed into the equipment.

Each data in the complete PPM data set must be available locally within the equipment, available externally for use by the factory or other applications, and accessible from the local equipment control interface or GUI.

Calculations, algorithms, applications, custom I/O device, command sequence, or other proprietary elements used to create or communicate a datum need not be exposed or made available. PPM is primarily using context-free data, which by definition should not compromise intellectual property boundaries. Context-free datum should not be declared proprietary simply because it exists.

5.2 Data Quality

Data quality is critical for process analysis and advanced process control (APC) as well as fault detection and classification (FDC). Fault prediction and PdM rely on high quality data to produce reliable prediction models. Model accuracy and precision depend on data quality. Data must be reliable, accurate, and repeatable. Data must be available at the right sampling rate. Data must be correct, consistent, complete, and time-relevant (to reflect actual time of the event and transferred in a timely manner).

Making a wrong decision and/or taking wrong actions due to poor data quality can be costly.

5.3 Equipment Performance Index Data

An EPI in the context of PPM is a metric provided by the equipment that is directly related to maintenance. This metric is an indicator of the probability that maintenance will be needed on a particular system, module, subsystem, component, or subcomponent. An EPI could indicate a pending failure or periodic PM need.

EPIs are not limited to time- or count-based parameters. Time and count can be factors in generating the metric. The metric should include input from all relevant sources including process data, sensors, setpoints, timers, and counters. These inputs combined make up the EPI. An EPI for a system could be the result of a calculation using data from multiple subsystems in a hierarchical structure.

Guidance on how the value of an EPI is interpreted should be provided by the equipment manufacturer, based on the supplier's knowledge and experience with the equipment. EPIs should be set up to allow the IDM to interpret the EPI data based on the IDM's experience with the equipment in the context of their factory.

An EPI should provide a value or formula indicative of the probability of failure for critical components tied to a specific maintenance item. Where applicable, an EPI should be based on multi-variant data. An EPI should not depend on the nature of the component, but rather the probability of failure. Current EPI data should be reported and/or accessible at any time.

Suppliers have the extensive knowledge of their tools and, therefore, should be in the best position to provide EPIs for those tools. Based on that knowledge, suppliers should develop EPIs and provide a first-level FDC for the defined EPIs. At a minimum, first-line FDC should be established with SPC rules set by the supplier for alerts and/or aborts. These limits and alarms should be configurable by the IDM based on its production needs. All raw equipment data that do not compromise suppliers' IP should be made available to the IDM.

Example: The OEM creates a "Filter Health" EPI by using known parameters/characteristics for various parts of the equipment such as the filter, pump, and chemicals, etc., to develop a model/algorithm correlated to filter degradation.

5.4 Equipment Fingerprint Data

Equipment fingerprinting is a method of taking a snapshot of the configuration of the equipment including all hardware/software settings, parameters, states, setpoints, calibrations, variables, etc. Fingerprint data can be collected at any time (e.g., while processing wafers or sitting idle). The fingerprint should be stored in a local file for local or remote diagnostics.

Triggering the capture of fingerprint data should be automatic or manual (invoked through SECS/GEM or directly from the tool). A fingerprint captured at the equipment supplier before the tool is shipped can be compared with a fingerprint captured after installation at the IDM's factory as part of the tool acceptance procedure. The IDM can compare fingerprints before and after a PM is performed to verify the efficacy of the maintenance. When tool monitoring by PPM, SPC, or other means indicates a tool issue, a fingerprint can be captured and compared with a fingerprint from a previous, known good state to identify the specific tool problem. Fingerprints from different tools or process chambers can be used for equipment matching purposes. Fingerprints can be captured on a regular basis and stored in a user-defined rolling buffer to track tool history.

A fingerprint must be captured quickly to preserve the equipment settings and conditions at a specific moment accurately. The enhanced capabilities of using EDA should be considered.

Fingerprinting should generate files that can be analyzed and/or compared using file comparison and manipulation software. The comparison result should indicate which parameters changed. The IDM should be able to define the critical parameters and the amount of allowable variation. A resulting flagging report can be generated based on those defined statistics.

Example: A technician/engineer captures a fingerprint of the tool before starting a maintenance activity. When the maintenance activity is completed, a fingerprint is again captured. Running a comparison of the before and after fingerprints should provide an indication of the effectiveness of the maintenance activity.

6 EQUIPMENT CAPABILITIES AND APPLICATIONS

Equipment utilization in semiconductor manufacturing fabs has always been a challenging issue. An overall equipment effectiveness (OEE) of 40–60% shows much potential for improvement. Over time, the lack of available data from the equipment has hindered predictive maintenance development on existing tools in the fab.

PPM applications on fab equipment will access process and hardware data to inform the IDM of unscheduled failures in advance. This will allow the IDM to make data-based decisions about WIP and maintenance scheduling. PPM will allow the IDM to minimize unscheduled maintenance.

Several options are presented below as a guideline for making equipment able to use the concepts of PPM. New generations of equipment are expected to reflect these capabilities as a required feature and a part of the basic design structure.

On a macro level, equipment is expected to have the following features to be able to improve local (tool-level) performance and inform the factory of problem/conditions:

- First-line FDC
- Condition-based consumables monitoring and notification
- Predictive analysis
 - Known failure signatures
 - Anomalous data or behavior
 - Accelerated rate of change
 - Advanced notification
- SPC
 - Trend charts
 - Model-based control/adaptation
 - Adaptive error handling
 - New charts/controls without a software upgrade

6.1 First-Line Fault Detection and Classification

FDC is a proven technique to visualize, identify, classify, and notify error actions to outside systems. Some issues addressed in the past included data collection, processing, and successful classification of identified faults. FDC has been an integral part of factory systems and works efficiently with the availability of the required data. First-line fault detection and classification (FLFDC) is expected reside at the tool-level allowing the tool to self-check and detect any anomalies from its normal expected operating behavior. To introduce such capability in tools, tools must be able to generate the required data related to its subassemblies or parts that are crucial to its normal, expected behavior. FLFDC strategies on the tool can then use these data directly, either based on specified limits or models that have been proven to work robustly under various operating scenarios.

The onboard FLFDC is expected to provide tool-level monitoring, identification, and control at the hardware, software, and design levels. Each level will require different, separately specified limits to warn IDMs of different anomalies that are being observed while in operation. Such limits will be specified or defined based on the severity and importance of the component/process in the tool/operation hierarchy.

Based on the model/limits-based control, false positives must be kept in tight control. A range or limit of false positives will be defined at all levels. All possible false positives should be well defined based on the specifics of the tool and frequency of false positives.

All the possible faults that can cause a specific tool to perform abnormally are expected to be classified in different categories for each level (i.e., hardware, software, and design levels). This, in turn, will help define and classify false positives and expected faults when they cause tools to shut down or raise warnings/flags.

6.2 Condition-based Consumables/Components Monitoring and Notification

Condition-based consumables monitoring and notification is expected to work on a “functional and state-based model” approach. Tools are expected to have a clearly defined hierarchical structure with all the subassemblies and components parsed to the levels where each end component can have its own state-based operation model. Several degradation factors affect the performance of subassemblies, parts, components, etc., at various levels. Such degradation factors associated with specific subsystems may reflect unique behavior patterns and hence should be modeled using available data from the equipment. The functional and state-based model approach is expected to identify and use these factors to allow the equipment to notify the IDM of any unexpected failure in advance.

SEMI E120, Common Equipment Model, and SEMI E125, Equipment Metadata, provide condition-based information. Condition-related attributes can be defined for specific components in the hierarchy that will be used by EDA clients to access the condition of the components. SEMI E120 states that equipment can have one or more process modules, several subsystems associated directly with the equipment or with the module, and I/O devices that are accessible from equipment, module, and subsystem levels. Figure 1 shows a simple functional and/or condition-based tool model approach in which L-1, L-2, and L-3 represent the equipment, module, and subsystem levels, respectively.

A component is defined as a part that can be a system and/or assembly component and a consumable or non-consumable. A similar approach is expected to be implemented on all tools to allow them to monitor and notify the user of abnormal behavior. Abnormal behavior is defined

as component performance that exceeds a margin or confidence limit from an historically-based (statistically significant) nominal operating value. The confidence limits can be established by the user and/or recommended by the OEM. The variability from the expected mean value can be caused by anomalies in one of the subassemblies/subcomponents within their hierarchical structures. Confidence limits would be optimized to minimize false notifications and escapes (missed or unrecognized impact events).

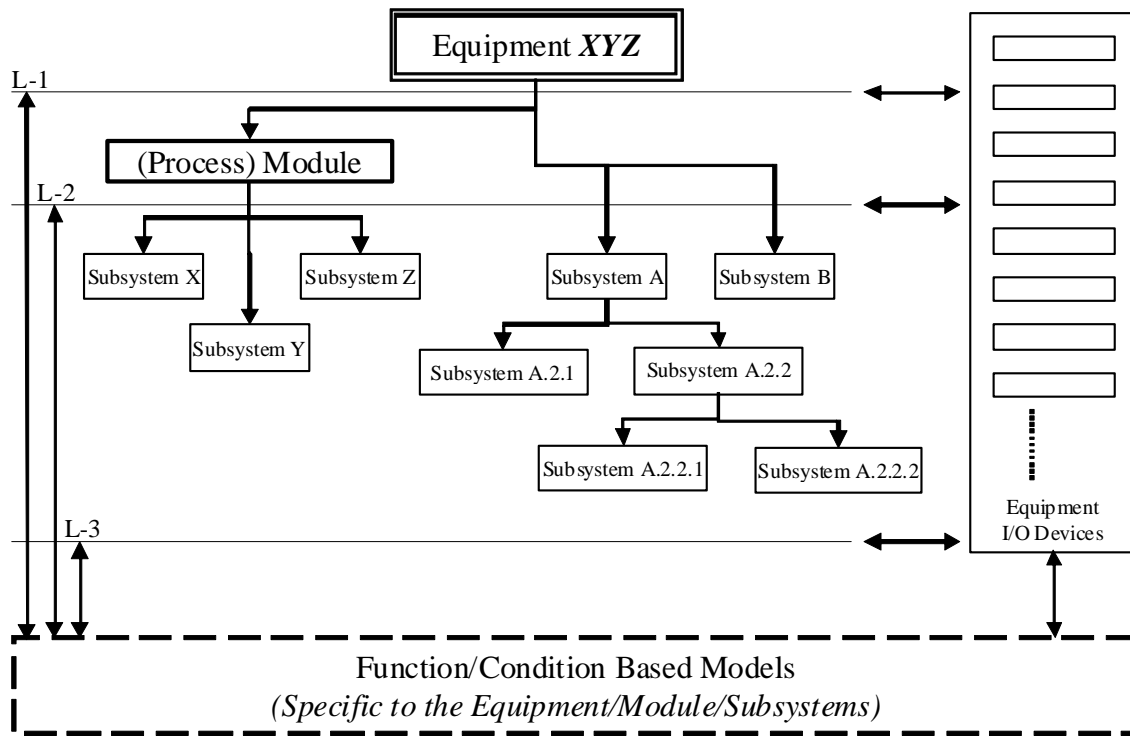


Figure 1 Hierarchical Model to Implement the Functional/Condition-based Modeling Approach

Function/condition-based models are expected to use the historic and current data generated (and probably saved) by the tool components and sensors. The models are expected to use this data to generate results (e.g., EPIs, productivity indexes, etc.). Additionally, the tool will be expected to record and save operational-based data (e.g., operating hours, number of wafers produced over time, past PM schedules, triggers (e.g., operating hours, number of wafers produced over time, past PM schedules, triggers associated with the various subassemblies, components, etc.).

Example:

- Equipment: Etcher
- Subassembly: Material handling robot
- Subsub-part: End effector
- Attribute: Time from release wafer command to release wafer confirmation
- Attribute value: 185 ms
- Attribute normal range: 100–300 ms

6.3 Predictive Analysis

Predictive analysis is identifying anomalies and impending failures at various significant levels of complexity (i.e., assembly, critical subsystem, subsystems, or overall system behavior). The equipment should be able to foresee or observe the current deviation of the tool/subassemblies/components in terms of the expected performance results. To make tools capable of having this feature, the following functions are suggested:

- Identification of known failure signatures
- Identification of anomalous data or behavior
- Identification of accelerated rate of change
- Provision of advanced notification

6.3.1 Known Failure Signatures

Known failure signatures refer to a known set of values of different variable data generated by the tool that will indicate a known but increasing critical condition in the tool's operability. A set of specified values for all variables will be used to define these failure signatures based on the performance history of tools/subassemblies/components. Failure signatures must be classified at different levels (hardware, software, design, etc.) to let the IDM take the appropriate action for the tool/section/module.

Example: The degradation of a scrubber pad on a chemical mechanical polishing (CMP) tool can be based on collecting process data since the last pad exchange. Another example of a signature is the increased vibration and extended position correction on equipment handling systems at the end of the bearing lifetime due to normal degradation.

6.3.2 Anomalous Data or Behavior

Anomalous data or behavior is similar to known failure signatures in that equipment is expected to have the ability to raise a warning alarm based on observation about the data that are being collected at a constant rate. Such a capability is useful when observing the operation/behavior of specific parts/components while in operation.

Example: Data being collected from a gas valve can indicate the improper functioning of a valve that regulates a gas flow into a chamber on the tool. By comparing the requested vs. current value of the gas flow, the condition of the gas valve can be determined. Assuming a properly functioning sensor, any difference between these two values (data anomalies) indicates a problem with the gas valve.

6.3.3 Accelerated Rate of Change

An accelerated rate of change (see Figure 2) is an increase in the difference between the expected value and the current value. A warning message will be generated at a defined level of maximum discrepancy (ratio threshold).

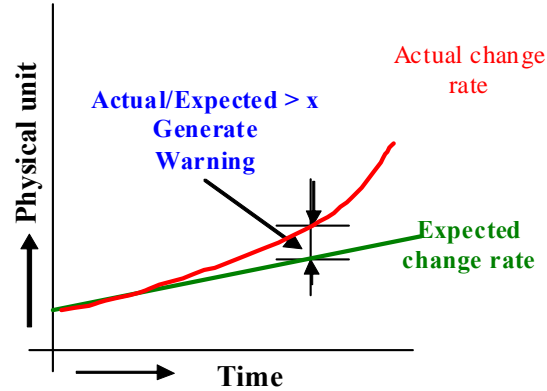


Figure 2 Accelerated Rate of Change

6.3.4 Advanced Notification

Advanced notification (see Figure 3) allows equipment to predict deviations from normal behavior using a probability horizon over the spectrum of expected functionality for subassemblies, parts, or subparts. With this capability, the equipment issues advanced notifications of possible failures in a defined (future) time period due to failure of a particular part/sub-assembly.

Example: A probability-based function can be defined on a time scale used to track the expected performance against a predefined/calibrated behavior and to notify the IDM of any expected deviations in the equipment or assemblies.

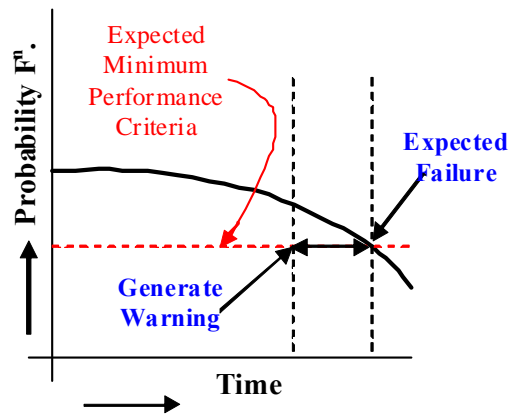


Figure 3 Advanced Notification

6.4 Onboard PPM

Onboard PPM should incorporate traditional SPC methods. Equipment manufacturers and suppliers use SPC tools and techniques to provide solutions for their tools to operate within IDM-specified control and specification limits. To deploy PPM capabilities on semiconductor manufacturing tools, SPC capabilities will likely play a crucial role in current and next generation equipment.

Equipment is expected to generate different data related to equipment sub-assemblies/components and processes to be used in predicting the deviations from expected behavior. This in turn will help the IDM avoid unscheduled down times by scheduling the required maintenance procedures well in advance. Current practices for predicting deviations include tracking several tool-related indexes, which are based on either univariate or multivariate indicators. New indexes specific to tool maintenance requirements will be need to be defined. Such indexes can be based on functional and state-based models in which several data variables can be tracked simultaneously to monitor and predict anomalous behavior.

Several SPC-based solutions to make tools PPM-capable are suggested below.

6.4.1 Trend Charts

Trend charts are used to observe data over specified time periods to identify meaningful trends or shifts in performance. The OEM has the knowledge of what critical parameters should be measured for each component/subcomponent and the target goals for each of these parameters. Charts of these pertinent data are used to extrapolate the future health of different components and subassemblies, resulting in fewer or no unscheduled downtimes.

Trend charts should have the following characteristics:

- A clear title to describe the subject of the chart.
- Labels on the vertical Y-axis and horizontal X-axis to describe the measurement and the time period.
- A legend to differentiate the plotted lines (e.g., the actual vs. the goal).
- Appropriate scales that are narrow enough to show variation.
- Limited characteristics on each chart to avoid the confusion of too many lines.
- An appropriate timeframe.
- Targets or goals noted on the chart for reference.

6.4.2 Ability to Initiate New Charts/Controls

IDMs require the ability to create new charts to represent tool performance using specified control/specification limits based on their production experience. This allows them to define, customize, and control new indexes that can ultimately be used in defining the tool's health from different perspectives. Such indexes can be made to activate based on either the specific behavior of other tool variables (univariate or multivariate) or indexes that are already being used to monitor the tool's performance.

6.4.3 Model-based Control – Adaptive or Static

Onboard PPM capabilities should implement adaptive or static model control depending on the component or subsystem characterization results. Initial models can be static or adaptive, with OEM-provided known failure signatures such as upper/lower control limits (UCLs/LCLs). The OEM is responsible for reporting these known failure signatures to the IDM. To adapt to the changing process context, the equipment should adjust the known failure signatures based on trend calculations and adjusted limits. The equipment should use its own data calculations as well as IDM inputs. With the increasing complexity in tools and high product mixes, tools must be able to monitor themselves irrespective of the device, recipe, volume, size, or complexity of the product being manufactured. Adaptive models are expected to adapt over time from the new data and information being generated by the tool, factory, or user to identify new failure or fault signatures for future reference. Models should also be able to stage the behavior of all the subcomponents and assemblies in the tool hierarchy. With the help of such models, the IDM will be able to schedule the maintenance procedures that will reduce or eliminate unscheduled downtime.

6.4.4 Adaptive Error Handling

Adaptive error handling involves continuous classification of current and past errors generated from false positives and alarms. This will help IDMs differentiate between actual and false alarms based on the matching from the error repository.

Adaptive error handling also helps the tool health monitoring system to identify remedial procedures based on the specific errors generated and on similar errors previously handled by the system.

7 FACTORY INTEGRATION & COMMUNICATION

PPM assumes that the improved prediction of failures will ultimately increase overall equipment productivity. While equipment currently provides high level performance and process data, PPM requires these data to be expanded to include base and equipment individual capabilities. Base capabilities consist of mechanical movements such as transparent functions of pumps, robots, and chillers. Equipment individual capabilities are defined by critical components such as temperature controllers, mass flow controllers (MFC), radio frequency controller, generator, and others.

The equipment will use existing communication protocols to relay messages detailing the health and performing status of the equipment.

A complete PPM solution environment involves both the factory and the equipment. Equipment should communicate data and results of onboard PPM functions to the factory. Equipment PPM systems should be able to accept any required data from factory systems, such as sensitivity settings and yield data.

7.1 Communication Protocols

A PPM solution should use existing SEMI standard communication interfaces and protocols like SECS/GEM or EDA. PPM-related data must be integrated into the existing data models currently used by the equipment. PPM-related data sources that will be communicated from the equipment to the IDM are as follows:

- Equipment process variable data
- Equipment raw data
- Equipment performance index (EPI) hardware data
- New data sources (after market and third-party sensors)
- Fingerprinting data

7.1.1 SECS/GEM

7.1.1.1 Using SECS/GEM to Acquire PPM-Related Data

The SECS/GEM interface (E30) should be extended to provide PPM-dedicated SVIDs, CEIDs, and ALIDs to report metrics, events, or alarms. By extending E30, IDMs can use SECS II messaging (E5) to request PPM data from the tool; i.e., the IDM can request the value of a specific EPI. For example, assume Pump EPI corresponds to a SVID equal to **10001**. The following SML notation denotes the status request message (primary) from the user/factory to the equipment as well as the responding message (secondary) from the equipment back to the IDM. Assume also that a **zero (0)** value means the overall health of the pump is acceptable.

Example:

S1F3 - Selected Equipment Status Request (SSR)

```
S1F3 W * H-> E
<L
<U4 VID> 10001 → Status Variable ID
> .
```

S1F4 - Selected Status Data (SSD)

```
S1F4 W * H<-E
<L
<V> 0 → Status Variable Value
> .
```

Several VIDs can be specified if desired. Normally, only VIDs of class SV (i.e., Status Variables) are used in this message. However, the equipment allows the host to use any VID of class DV, EC, or SV. If S1F3 contains a zero-length list, then the equipment tends to report all variables of class SV in order by VID.

7.1.1.2 Using SECS/GEM to Control Onboard PPM Capabilities

With the extension of E30, other possible E5 capabilities become available. E5 capabilities can be implemented to control onboard PPM capabilities. Stream functions such as S2F15 (New Equipment Constant Send) could be used to set embedded FDC control limits. Table 1 shows a subset of S2 functions that is useful in controlling onboard PPM capabilities.

Table 1 S2 Functions

Primary	Secondary	*CState	Description
S2F13	S2F14	4,5	Equipment Constant Request
S2F15	S2F16	4,5	New Equipment Constant Send
S2F17	S2F18	4,5	Date and Time Request
S2F23	S2F24	4,5	Trace Initialize
S2F29	S2F30	4,5	Equipment Constant Namelist Request
S2F31	S2F32	4,5	Date and Time Send
S2F33	S2F34	4,5	Define Report
S2F35	S2F36	4,5	Link Event Report
S2F37	S2F38	4,5	Enable/Disable Event Report
S2F41	S2F42	5	Remote Command with Parameters
S2F45	S2F46	4,5	Define Variable Limits Attributes
S2F47	S2F48	4,5	Variable Limit Attribute Request

***Values of Control States (CState)**

- 1 Off-Line/Equipment Off-Line
- 2 Off-Line/Attempt On-Line
- 3 Off-Line/Host Off-Line
- 4 On-Line/Local
- 5 On-Line/Remote

SECS/GEM, however, has some limitations:

- Most SECS/GEM capabilities are available only when the tool control state is set to On-line Local or On-line Remote.
- There is an intrinsic limitation of the SECS/GEM interface in providing data throughput without interfering with the equipment control.

EDA, however, does not have these limitations. Thus, EDA will be a pipeline to allow data from PPM applications to be better transported to factory systems. PPM should take advantage of these benefits.

EDA, also known as Interface A, is the third generation of communication standards. Currently, most OEMs use the SECS/GEM interface to communicate with factory control systems. Because it does not replace SECS/GEM ports, Interface A will provide numerous benefits to OEMs and IC makers. Like PPM, EDA will also help increase equipment productivity. EDA also provides faster data throughput than SECS/GEM. Table 2 details some differences between SECS/GEM and EDA.

Table 2 SECS/GEM vs. EDA

	SECS/GEM	EDA
DATA RATE	300 data per second	>10,000 data per second
ACCESS RATE	Access rate = 1 second interval	Access rate = <100 millisecond
DATA FRESHNESS	Log file, historical	Near real time
CLIENT DATA	Data for individual factory applications must be included in a single large data set	Each factory application can get exactly the right data at the right rate for optimum effect
FACTORY ACCESS	Complicated custom programming, slow, risky, and expensive to change	Flexible software, changes can be made in minutes with low risk
COMMUNICATION PORT	Data shares command/control line, can cause control interruptions or delay critical commands	Dedicated data line guarantees unrestricted, immediate command/control access

7.1.2 EDA

With EDA architecture, data consumers such as PPM systems can interrogate the equipment to determine its structure and data. The EDA standards suites should be extended to include available PPM metrics. Metrics such as EPIs should be assessed through a hierarchical representation of specific equipment components. With this structure, PPM data consumers can create ad hoc data collection plans such as custom fingerprinting reports or a user-defined summary of failure predictions and probabilities. Additionally, OEMs are encouraged to implement built-in data collection plans (DCPs) for tool-specific functionality to avoid exposing components of their control model.

Figure 4 shows a relational hierarchal EPI structure of a pump. The master or generic EPI is the single point that shows the overall health of the pump performance. This EPI would be the only EPI visible to the initial DCP. Once this indicator shows some abnormality for the pump performance, the IDM should be able to query the object model to find the critical parameters. The IDM would then decide which additional EPI should be included in the DCP that will indicate the root cause of the problem. In Figure 4, this would be the Flow Rate EPI. The important aspect that should be communicated through the hierarchy is the relationship between all the included EPIs. For example, the performance of the valve and motor has more significance to the overall pump performance than the flow rate.

Figure 4 also shows that pump performance EPI is a function of [Valve * weight1] + [Motor * weight2]. In other words, the health of subcomponents results in the overall health of the main component. This hierarchal structure is a way for the equipment to represent which subcomponent is a major contributor to the degradation of the overall component. The valve EPI consists of a Cmd/completion EPI and flow rate EPI. The Cmd/completion EPI is an EPI derived from the difference between the time a command was issued such as <Valve Open> and the time the action was completed by the equipment. The flow rate EPI is a real-time value. The colors in the diagram are indicators of the performance of each component.

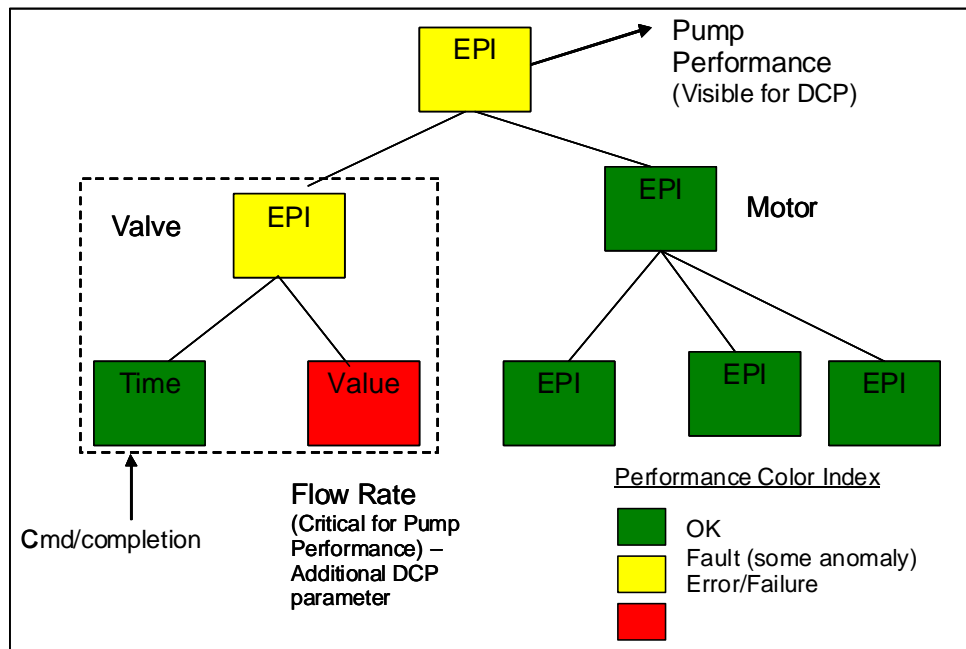


Figure 4 Hierarchical Representation of EPIs

7.1.2.1 Using EDA for Sensor Data

EDA can also support the collection of detailed sensor and operational data at the bandwidths needed for online monitoring and diagnostics. All embedded and add-on sensors that support PPM capabilities should use SEMI E54. The data collection rate for sensor data and other parameters must be defined appropriately for specific types of process and recipe settings.

7.2 Health and Performance Metrics

The equipment must implement an architecture that allows the software to “self-monitor” the performance of various components/subcomponents with no impact on the tool controller. This architecture creates an excellent environment to develop items such as degradation models with PM prediction capabilities.

To improve equipment predictability, the equipment must provide real-time health and performance metrics. The equipment must self-check, detect, and notify the IDM of any operating anomalies. The data should include the summarized results and raw values of all EPIs and the onboard PPM results with context. The equipment should provide enough context in the data for the IDM to determine exactly how a parameter relates to the equipment performance metric. For example if the onboard PPM systems (i.e., first-line FDC) reports a fault, the IDM must know what the equipment predicts is the root cause and with what probability. The equipment must also summarize or aggregate the various onboard indicators into a single health metric that can be used by the IDM to assess the overall health of the tool.

7.2.1 Component Degradation Probabilities

The equipment should provide degradation prediction models for critical components/subcomponents. The models must calculate the probabilities of the component/subcomponent lifetime and the degradation rate of change.

For example, tool messages such as the following should be communicated to the IDM:

“This component will stop working in 24 hours at 95% confidence level unless maintained. Component degrades at a rate of x/hour.”

7.2.2 Error Handling/Notifications

Error handling and notifications are important communication between the equipment and the IDM. The equipment should establish an operational incident handling capability that includes adequate preparation, detection, analysis, containment and recovery, and user response activities. The equipment should track, document, and report incidents to the IDM. Advance notifications of faults, error, and failures allow the IDM to predict information that can be used advantageously. The equipment should allow the IDM to set the notification levels, but it should also provide a suggested notification level for each critical component/subcomponent.

Notification levels should be defined as follows:

- Faults – the origin of any anomaly. It is the adjudged or hypothesized cause of an *error*.
- Errors – characterization of a particular state of a component/subcomponent. This is the part of a component/subcomponent state that is liable to lead to a *failure*.
- Failure – a deviation of the delivered service from compliance with the specification. A failure is a particular event; i.e., the transition from correct service delivery to incorrect service.

With each notification level, the equipment should provide a list of suggested corrected actions to the IDM to recover.

Figure 5 shows the relationships among the notification levels.

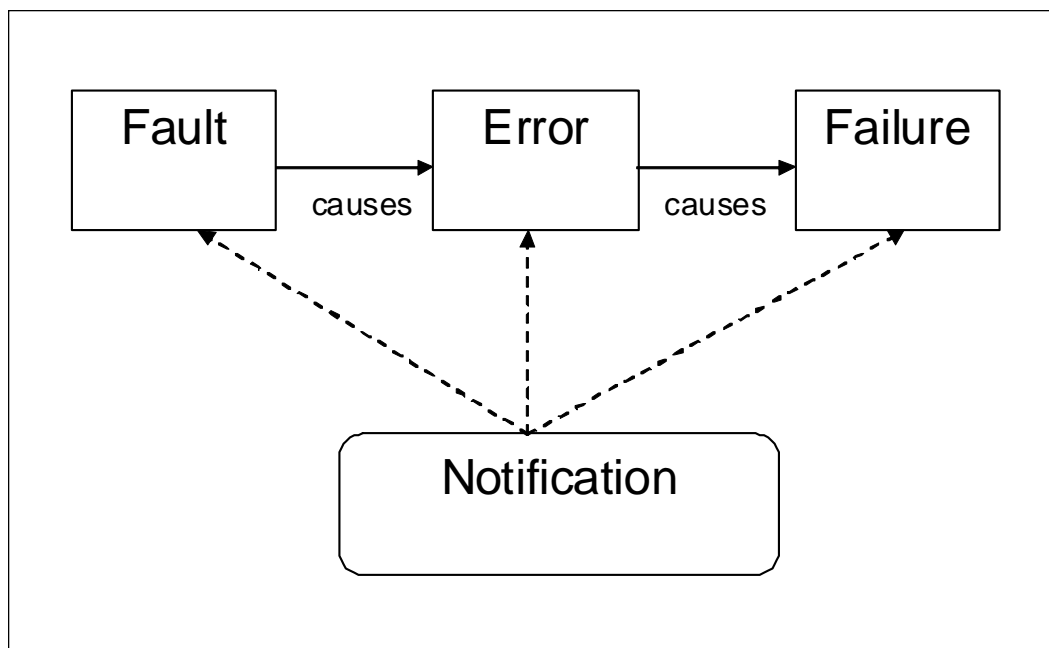


Figure 5 Error Handling/Notification Structure

7.3 IDM PPM Systems

The IDM PPM systems must use the equipment data to manage the onboard PPM systems as well as the IDM PPM systems. The equipment data consist of, but are not limited to, the following data sources:

- Equipment process variable data
- Equipment performance index (EPI) hardware data
- New data sources (after market and third party sensors)
- Fingerprinting data (static and process transient data)
 - Ad hoc/scheduled

7.3.1 Managing Onboard PPM

IDM systems must be flexible enough to set up and manage the onboard PPM features through the equipment's standard communication interface. The IDM must be able to enable or disable any onboard capability, such as FDC or EPI calculation. The IDM must also be able to set up limits, notifications, and actions. Management (control) or status inquiries of such features should be consistent with the equipment states of safety and operating procedures. For example, enabling the onboard FDC system in the middle of a lot processing may not be possible, but setting the fault limits for the next wafer may be.

The IDM should be able to select the level of detail or the logging of the equipment's notification report or health status. IDMs must be able to drill down into a fault by requesting fault contributors and setting the probability horizon. The fault contributors should also include a prioritized list of recommend actions.

7.3.2 Managing IDM PPM Systems

The onboard PPM model should be the primary source for information and decision making. However, the IDM must implement an external PPM system as a backup and control for the internal OEM-provided model. The IDM might have algorithms and predictions tailored to business cases that are slightly different from what the OEM forecasted.

8 CONCLUSION

Property, plant, and equipment are critical to all IDMs. Continually improving the effectiveness and efficiency of production equipment is an important factor affecting the financial bottom line. PPM allows IDMs to optimize their maintenance practices to reduce unscheduled down time, reduce parts and labor costs, reduce product losses, and manage WIP flow efficiently.

Appendix A – Abbreviations

ALID	Alarm ID
APC	Advanced Process Control
BDM	Breakdown Maintenance
CbM	Condition-based Maintenance
CEID	Collection Event ID
CMP	Chemical Mechanical Polish
DCP	Data Collection Plans
DVID	Data Variable ID
ECID	Equipment Constant ID
EDA	Equipment Data Acquisition
EEC	Equipment Engineering Capabilities
EPI	Equipment Performance Index
FDC	Fault Detection and Classification
FLFDC	First Line FDC
GEM	Generic Equipment Model
GUI	Graphical User Interface
IDM	Integrated Device Manufacturer
I/O	Input/Output
IP	Intellectual Property
ISMI	International SEMATECH Manufacturing Initiative
LCL	Lower Control Limit
MFC	Mass Flow Controller
MTBF	Mean Time Between Failures
NGF	Next Generation Factory
OEE	Overall Equipment Effectiveness
OEM	Original Equipment Manufacturer
PdM	Predictive Maintenance
PM	Preventive Maintenance
PPM	Predictive/Preventive Maintenance
SECS	SEMI Equipment Communications Standard
SEMI	Semiconductor Equipment and Materials International
SPC	Statistical Process Control
SVID	Status Variable ID
UCL	Upper Control Limit
VID	Variable ID
WIP	Work In Process

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