Maintenance Pooling to Maximize Fab Uptime

Mike Czerniak, Alan Ifould, Michael Mooney, Angelo Maiorana
Edwards Ltd
Crawley, UK
Mike.Czerniak@edwardsvacuum.com

Abstract – **Maximizing process tool uptime has remained a core challenge for the manufacturing of advanced semiconductors over time. This becomes more important than ever with newest process technologies and the scale of 450mm fabs that are under consideration, driving an ever increasing value of each wafer. One key step towards this goal is to synchronize the timing of scheduled maintenance of peripheral equipment and critical sub-systems such as vacuum pumps and abatement (exhaust management) systems with that of the process tools they support.**

Transitioning from calendar-based to a knowledge-based solution is dependent upon increased intelligence within the critical sub-systems and concomitant improvements in communications between them and the process tool. This demands a significant degree of intelligence in the peripheral equipment itself so that an accurate Remaining Useful Life (RUL) indication can be realized, and used to synchronize maintenance activities with the maintenance schedule of the process tool.

Effective knowledge sharing direct to the process tool and/or via the factory information and control system (FICS) is required, allowing the peripheral equipment to interactively calculate RUL, assess the risk of operation beyond routine maintenance intervals and to potentially suggest appropriate actions to minimize this risk.

Robust risk analyses can be performed to determine if RUL of critical sub-systems can be managed in such a way to extend operation until the next planned process tool PM, enabling a later synchronized maintenance activity. In the absence of alternative solutions the least risk decision is to schedule maintenance activity and absorb the implied cost if a fault is predicted to occur before the next tool PM.

Together, these approaches empower the tool owner to make evidence based judgments of both the pro's and con's of synchronization with other maintenance procedures. This paper discusses how such synchronization might be achieved, and the risks and considerations required for a successful implementation.

***Keywords** - predictive; adaptive; maintenance; synchronization; remaining useful life; vacuum; abatement*

I. INTRODUCTION

Throughout the semiconductor industry, a recent cost saving focus has been in the control and reduction of energy. Key learning points are that practical implementation is restricted by ROI challenges: capital investment in high efficiency tool components can be substantial; implementation of component idle modes is impossible in the absence of cohesive tool signaling capability and uncertainty over negative effects on process security. Realistically, measures to improve energy efficiency will be most effective into the future as technologies evolve and capital is invested in new facilities.

The 2011 ITRS (Factory Integration) [1] marks a strong shift in focus towards factory operations efficiencies, and the significance that Enhanced Equipment Quality Assurance (EEQA) and predictive technologies, e.g. Predictive Maintenance (PdM), Prognostic Health Management (PHM), has to play in that. The focus extends from the process tool to peripheral equipment and critical sub-systems, of which vacuum and abatement (exhaust management) systems are a good example.

Concerns over process security are mitigated: the very nature of productivity and reliability improvement activity is to eliminate that risk. A question that remains to be asked is whether full realization of this initiative will fall foul of capital investment and ROI restrictions, or whether technology can be readily and effectively leveraged today to deliver the perceived benefits.

This paper summarizes Edwards' research deployment of predictive tools and technologies in respect of vacuum and abatement critical sub-systems.

II. MAINTENANCE SCHEDULING TODAY

A. Traditional Approaches to Scheduling of Peripheral Equipment Maintenance

The practice of Predictive Maintenance is well established within the domain of the process tool, but less so in critical sub-systems such as vacuum and abatement systems, where more traditional Planned Maintenance (PM) or Run to Fail (RTF) regimes are practiced.

Fig. 1 describes the confidence in estimating the Remaining Useful Life (RUL) of the equipment and is used for conceptual purposes. The figure presents a situation where a range of failures on a given process are contained within a certain region of parameter space. Most failures lie within the heart of the region and the failure PDF (probability density function) approximates to that of a Gaussian distribution (in reality it is more complex, as discussed in [2]). Therefore, the shortest life expectancies and the longest life expectancies are represented within the

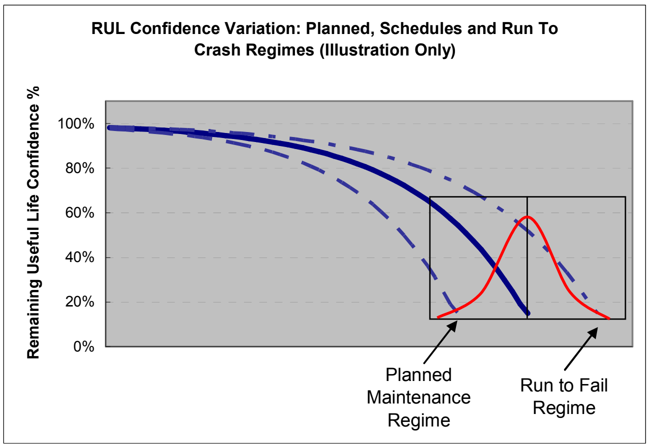

Figure 1. RUL Confidence Variation over a Population of Equipment

two tails of the distribution. A planned maintenance regime will aim to account for all unplanned issues and will therefore be set at an interval of the shortest life expectancy. The best running time an RTF regime can achieve is to run equipment to the longest life expectancy.

Actual process conditions, recipes, measurement, process noise and tool utilization, as well as mechanical wear contribute to the variation. Using traditional empirical methods, predictability (and confidence) of RUL changes quite drastically as soon as the critical point at which the critical interaction of multiple parameters is reached.

For vacuum and abatement systems, planned maintenance (PM) is traditionally driven on fixed time intervals, or occasionally an elapsed number of process runs or duty cycles, established largely through empirical means. The goal is to perform maintenance in sufficient time to reduce to an acceptable level the risk of an unplanned equipment failure.

Although intentionally a conservative approach, PM can drive unnecessary equipment maintenance and/or scheduled downtime. Fig. 2 shows a trace from a vacuum pump that was due for a Planned Maintenance at the end of the month. A simple interrogation revealed basic health parameters were within tolerance and the unit remained on process. Automated prognostic application of the same health parameters can validate and adjust scheduling decisions in realtime, effectively extending maintenance intervals.

PM regimes were at one time a significant driver of peripheral equipment maintenance. Under the drive to reduce operational costs, the industry has tended towards a RTF (Run to Fail) regime in an attempt to reduce scheduled downtime and maintenance costs of peripheral equipment. The effect is maintenance becomes reactive, can drive loss of wafer throughput from unplanned downs, and drives cost through significant or catastrophic damage to the equipment or the tool it supports, adding more variability to cycle time increasing its length by hours or days.

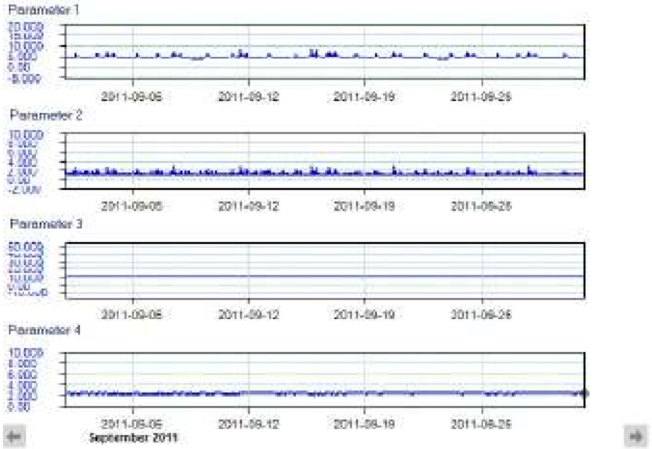

Figure 2. Prognostic Health Monitoring Can Minimize Unnecessary Maintenance Intervention, Associated Costs and Downtime

B. *Predictive Maintenance (PdM) on Vacuum and Abatement Systems*

PdM technologies have been used with success on vacuum and abatement systems, but require fundamental understanding of the complex interaction of multiple variables.

Process knowledge is essential to understand the process gas reactions that occur before, within and after the vacuum pump, and throughout any associated abatement system. These are the major non-mechanical contributors to varying maintenance intervals, for example solids formation, corrosion etc.

Fig. 3 illustrates a successful example of a the application of a multi-variate PdM algorithm that provided notification of a required maintenance intervention more than 3 weeks ahead of the eventual failure (the equipment was run to failure to verify the PdM model).

Predictive technology is not without its own pitfalls. It may appear relatively easy to establish a prediction based on

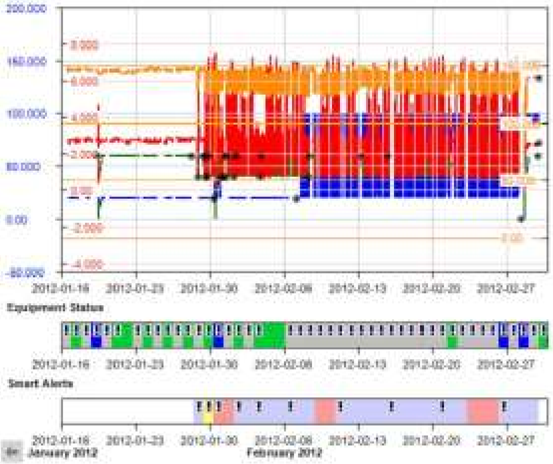

Figure 3. Successful Prediction of Vacuum Pump Failure

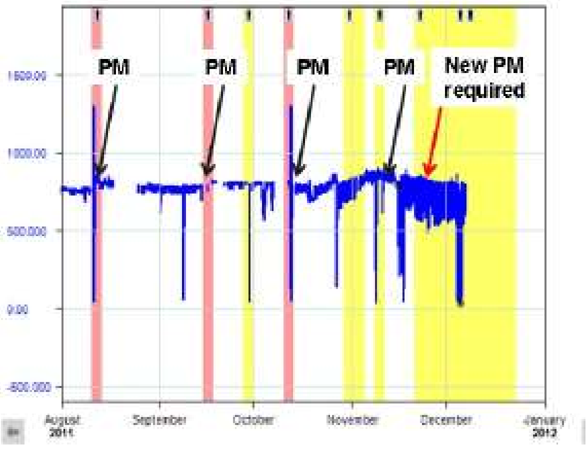

Figure 4. Changing Process Duties or Equipment Utilization Drives Scheduling Requirements

a demonstrated behavior, but that behavior can change dramatically with process recipes, or with significant changes in tool utilization (Fig. 4). Adaptive approaches are required to allow for dynamic changes in conditions.

Similarly, prognostic analyses have to be able to recognize external causal influences. By way of an example, referring to Fig. 5, if examined in isolation, conclusions could be drawn that the pump under examination was approaching end of life.

Using expert applications knowledge, the fault was shown to be further downstream. The fault was rectified and the pump returned to a normal operational fingerprint. Into the future, predictive models have to be built around autonomous subsystems rather than individual components with sufficient diagnostic capability to indicate true source of a fault.

III. MAINTENANCE POOLING: PRINCIPLES AND CHALLENGES

A. Challenges of Maintenance Pooling

In comparative terms, the MTTF of vacuum and abatement systems can be long compared to that of a process tool. The tool may require several PM interventions for every one the peripheral equipment requires. The challenge in achieving step gains in unscheduled downtime improvement is to be able to synchronize respective tool and peripheral equipment PM, as illustrated in Fig. 6.

Whilst PHM and PdM technologies are a key enabler of this, it should be recognized that the predictive horizon may not be long enough to span a full tool PM cycle. There exists the possibility that at the time a tool PM is required, PHM/PdM signatures indicate normally operating equipment, but that shortly after the tool PM these signatures change to indicate PM is required prior to the next scheduled intervention.

In such circumstances, the predictive horizon needs to be extended by developing other metrics that indicate a measure of peripheral equipment utilization or other process counter, for example total flow of chamber cleaning gases, wafers processed which will have direct influence on MTBS. However, this information is regarded as sensitive: as is likewise behavioral information of the process equipment and associated equipment components.

It is possible to infer a process count from other parameters if not available from other sources. For example, peripheral equipment utilization has been successfully derived from observation of, for example, power spikes. There are risks and inaccuracies: very powdery processes will create more spikes than others, with a large proportion related to material ingestion rather than process cycles, but can be an acceptable alternative in the absence of more robust measures.

The ITRS has identified the challenge of data sharing in its requirements to establish "Equipment bidirectional visibility". Nevertheless, historical perception of the proprietary nature of such data remains to be overcome. For process counters to be effective, the challenge is to find methods of sharing sufficient information without compromising proprietary knowledge of the device manufacturer, tool OEM and equipment OEM.

B. Equipment Service Life Extension

In view of the considerations discussed in III.A, and with reference to Fig.6, it would clearly be desirable to extend the service life of peripheral equipment such as vacuum pumps, gas abatement and chillers such that maintenance activities can be synchronized with the process tool. A method to achieve synchronized maintenance activities has been previously discussed [3], whereby information transmitted from the process tool is used by peripheral equipment to generate a reciprocal signal regarding an operating characteristic or status of a component of the peripheral equipment to enable synchronization.

Activities undertaken to realize a service life extension are dependent on the nature of the process, the fault prediction horizon, and the nature of the equipment. Timing

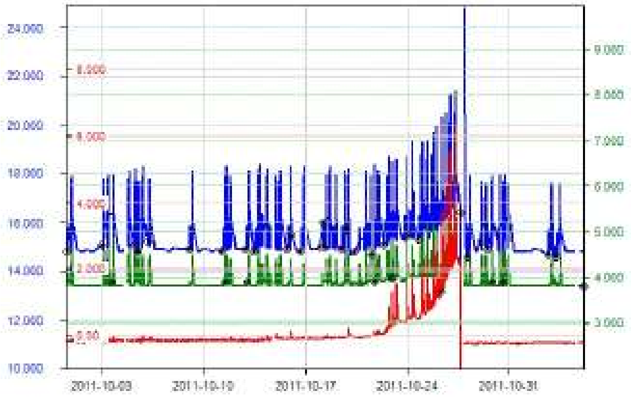

Figure 5. Application Knowledge is Essential for Good Decisions

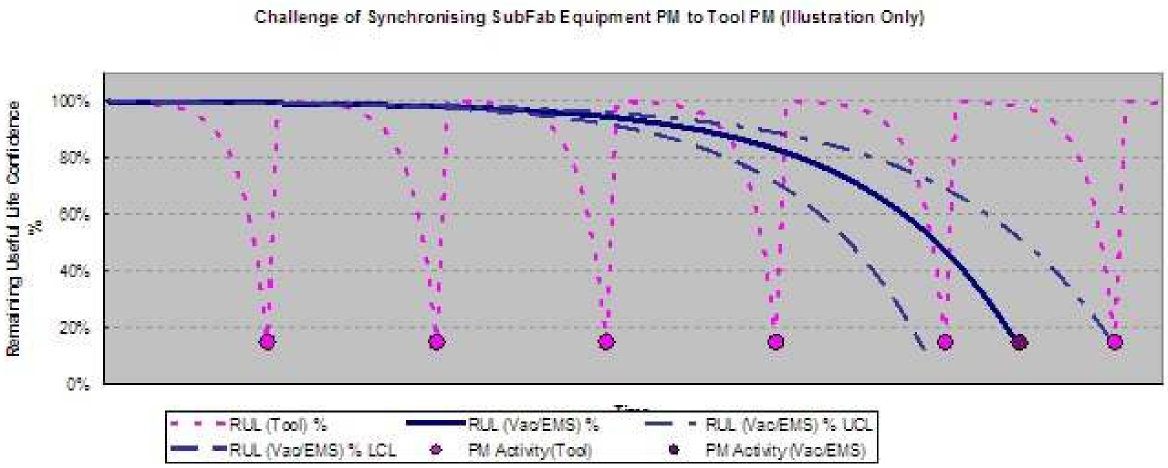

Figure 6. Challenge of Synchronising Subfab Equipment PM to Tool PM

of such activities is critical: premature deployment may not extend service life sufficiently; late deployment may not achieve any service life extension at all.

C. Fingerprinting

Using arbitrary default models for RUL prediction on peripheral equipment could lead to highly inaccurate predictions. There is a distinct hierarchy of influences on the behavior for each type of peripheral equipment (e.g. vacuum pump, abatement): application/process (e.g. PECVD), process tool, local factors (e.g. customer recipe, foreline configuration, and quality of utilities).

Process induced failure mechanism can be predicted once the model used to characterize it is "trained" with enough data and events whilst ensuring concurrent variables of initial process are kept under a specified range. Access to global, historical databases provides a critical source of information from which predictive models can be rapidly tuned or "trained".

This training has a strong correlation with the practice of fingerprinting[1]: a well established principle, but not often applied to peripheral equipment. As integration of tool and peripheral equipment becomes ever more complex, fingerprinting principles must come to the fore. Because of the comparatively long working life of peripheral equipment, there is more opportunity for a fingerprint to change. Understanding this change, and how it relates to process counters aids control of process stability, as well as providing enhanced predictive capability.

Fingerprinting will need to be dynamic. Characteristics exhibited by peripheral equipment when new or freshly maintained will change over time. Understanding the nature of this change provides additional enhancement to predictive capability to enable the goal of maintenance synchronization: matching peripheral equipment lifetime/behavior to process parameter (e.g. wafer count, process gas flowed etc).

Understanding which parameters to monitor and which of those is critical, as is their correlation to equipment failure. Access to appropriate knowledge will demand collaboration across a new set of corporate divisions and boundaries.

IV. FUTURE COMMUNICATION FLOW TOOL/FICS/PERIPHERAL EQUIPMENT

Much of the work to date concerning PdM has been conducted on the vacuum and abatement equipment in isolation, i.e. without significant external communication. This limits its usefulness, especially as regards maintenance pooling. To gain the full benefits it is important that data is shared between peripheral equipment and process tools for optimization of the overall system as a whole.

At the moment, the background RUL "count-down" can be inferred using the fingerprinting techniques described above. However the precision could be greatly improved by providing additional data from the process tool or Factory Information & Control Systems system regarding parameters such as wafer counts, which provide a "coarse" measure of usage. However data on cumulative process gas flow, by type, enable more detailed analysis of mechanisms like solids accumulation, corrosion etc, especially if a variety of process recipes are in use, a situation likely to be encountered in a foundry environment in particular. This would provide a very effective "process counter".

Interpreting the impact of this data on vacuum and abatement RUL is very process, tool and even customer-specific. Elements such as pipe work configurations can have an influence, for instance lack of pipe work heating on a process with condensable by-products can result in build-up of solids and pipe blockage.

The specific vacuum pump or abatement system in use also has an impact, with newer models being designed to be more robust by incorporating improvements based on field

---

[1] Fingerprint: a representation of the equipment or equipment component state at a point or range in time (a practice closely associated with the EEQA methodology)

experience. The resulting RUL calculations can then be transmitted back to the process tool and/or FICS where it can be compared to the RUL of the process tool so that synchronization can be planned (Fig. 7).

There are significant advantages in processing the RUL for vacuum pumps and abatement systems "locally" rather than on the process tool or FICS, so only simple RUL data is reported. Firstly it significantly reduces the volume of data traffic across the fab network because the data is analyzed locally. As the peripheral equipment can be located some significant distance from the process tools, often on a different floor level in the fab, localized data analysis also significantly reduces the risk of data corruption in transit, and the risk of poor data handshake is greatly reduced. It also reduces the processing power required on the process tool and ensures there are no IP issues concerning the nature of the data required for the RUL calculations, which are likely to contain significant know-how and experience from the equipment supplier.

Realization of the Maintenance Pooling goals will require extended sharing of data and information. The 2011 ITRS notes the increasing drivers for data utilization and bi-directional sharing. To be considered is where and how that data is shared and processed.

V. SUMMARY & CONCLUSIONS

Minimizing process tool downtime and scrap wafers are key targets for the semiconductor industry, especially with 450 mm wafers on the horizon, since this maximizes wafer throughput and ROI; synchronizing all tool maintenance activities with those of associated peripheral equipment is a major potential contributor to this activity.

Current unsynchronized maintenance strategies, such as PM and RTF have been compared and contrasted to that of synchronized maintenance and the benefits of the latter have been clearly identified, as well as the potential financial savings. Mechanisms to extend the RUL of vacuum and abatement equipment have been considered, including the "triggering" of such RUL-extension modes, and also the signaling requirements between FICS, process tool and peripheral equipment. The importance of equipment "fingerprinting" has been considered and the case made for RUL data to be generated locally in the peripheral equipment itself.

By all elements of the semiconductor industry working closely together, the benefits of synchronized maintenance could be realized in practice in a similar way to those of energy reduction being recently implemented.

REFERENCES

[1] ITRS, International Technology Roadmap for Semiconductors (Factory Integration) 2011

[2] Shane Butler, John Ringwood, and Michael Mooney, Elsevier Editorial System™ for Reliability Engineering & System Safety "Multiple Model Particle Filtering for Prognostics of a Thermal Abatement System", Unpublished

[3] JR Smith, MR Czerniak and NJ Gibbins, "Method of controlling operation of a process system", European Patent Application EP2264558,

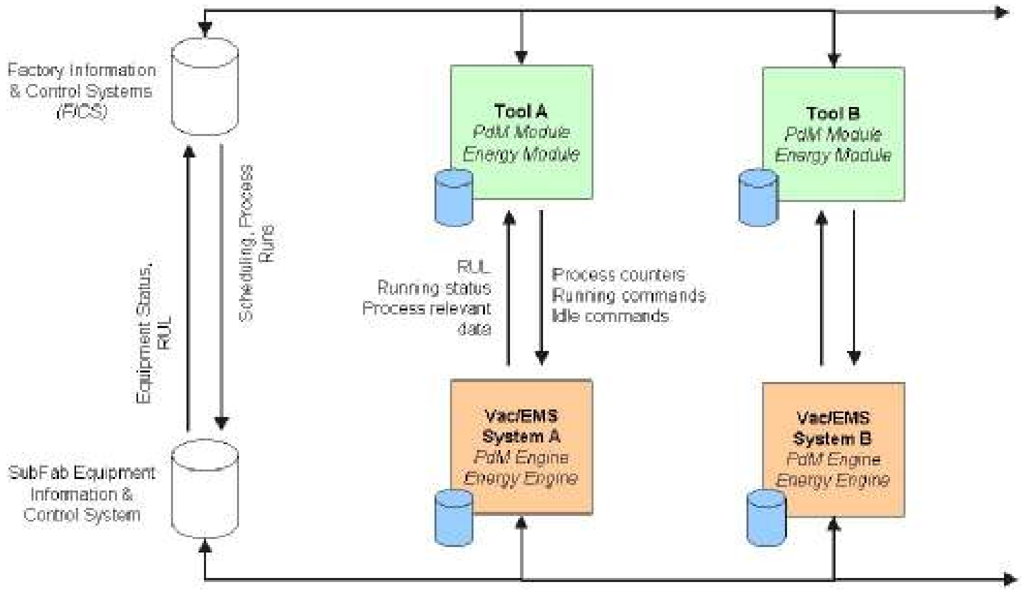

Figure 7. Required Information Flows: FICS, Production Equipment and Peripheral Equipment