Precision-guided Equipment Maintenance in a Modern Foundry – Case Study

Co-Authors - Dimitry Gurevich, Ariel Meyuhas, Marino F. Arturo

MAX I.E.G. LLC – 180 Old Tappan Rd Old Tappan NJ 07675, (201) 750-7888,
Ariel_Meyuhas@maxieg.com,
Dimitry_Gurevich@maxieg.com,
Marino_Arturo@maxieg.com,

Keywords: Variability of Availability, Precise Equipment Maintenance, Total Productive Maintenance (TPM), Predictive Maintenance, MPM™

Abstract

The challenge all compound semiconductor maintenance teams face is maintaining high equipment uptime together with continuously decreasing maintenance costs and allowing enough flexibility to fulfill complex production plans. These become even more sophisticated in a foundry environment, where production mix changes frequently and there are more product/customer equipment dedications.

The MAX Group explores the ultimate approach to maintenance management through this case study in a medium-sized semi-automatic foundry and claims the necessity of stepping away from traditional evaluation of Uptime towards a Precision-oriented thinking and working methods

INTRODUCTION

In modern semiconductor manufacturing, medium-sized 6-8" foundries occupy an important niche, providing their customers with flexible solutions. To achieve such flexibility these foundries sustain complex production mixes consisting of small products' runs and specifically dedicate different types of equipment to meet customer manufacturing requirements. This leads to a lower level of equipment resource redundancy compared to larger foundries and puts their maintenance teams to the ultimate test of delivering great performance.

The questions of man-machine ratio, proper maintenance regime and different options of cost reduction have been discussed for quite a while, leading to the implementation of the equipment engineering discipline, Lean manufacturing methods and metrics, 2nd and 3rd source spare parts etc. as standard fab practices. MAX continuously evaluates the ways these practices are applied and offers here its own approach to foundry maintenance management practices

MAX defines its Global Approach to foundry Maintenance as follows:

> ***Focusing on Precision*** *in maintenance practices execution will enable highest equipment availability, and reliability of equipment performance and minimize cost of equipment ownership.*

A perfect example of precise maintenance work is a Formula 1 pit crew operation, where maintenance events are precisely scheduled (based on number of laps, car sensors, driver's feedback etc.) and precisely executed by an extremely proficient team. To achieve the needed level of execution the pit is set up in a unique way and each team member is specially trained to perform a specific task in a team routine. The speed and quality of a pit stop is a direct consequence of Precision of both individual and teamwork, and that's what makes the difference between a good race team and great race championship winner.

As we already mentioned, the challenge is combined performance; therefore, MAX breaks it to several topics/spheres of responsibility and formulates Precision methods/techniques and metrics for every topic.

Precision metrics allow sensitive monitoring of the maintenance team's performance and pin-pointing of sources affecting the variability of equipment performance. Precise working methods and techniques allow the flexibility needed in continuously changing foundry environment dynamics, eliminate sources of performance variability, and create and sustain a culture of continuous improvement.

Table 1 – Examples of Precision Maintenance methods and metrics

Topic/ Responsibility	Methods and Techniques	Metrics
Management	1. Creation and following structured procedures for normal and crash working modes 2. Daily reviews of manufacturing plans, equipment status and HR status. Look ahead 24 hrs. and make necessary adjustments 3. Weekly HR forecast (skills and headcount) with a respect to maintenance plan. Utilization of CMMS for more	1. Periodical survey, score card 2. Shiftly attendance levels vs. targets 3. Number of scheduled PMs vs. actually performed,

Topic/ Responsibility	Methods and Techniques	Metrics
	precise PM scheduling 4. Creation Tech training and certification matrix and Area/Module targets 5. Projects 6. Periodical review of cost targets and performance	M-Ratio 4. Area/Module certification levels vs. targets 5. Cost of Maintenance vs. targets
Engineering	1. Practicing Golden Tool approach for equipment Availability, Continuous standardization and improvement of working procedures and methods of troubleshooting, Active mechanism of corrective actions driven by the periodical OEE reviews 2. Continuous cost reduction 3. Precise spares stock management	1. CV of Availability 2. Monthly/Quarterly cost of maintenance per toolset 3. Stock inventory vs. target
Are/Module Tech Teams	1. Sustain close cooperation with production management team 2. Learn and practice of Pit Crew methodology and techniques 3. Precise work place organization 4. Maintaining individual proficiency and excellency	1. Waiting tech 2. Green-to Green (PM speed), variability of PM duration 3. 5S or similar grades for work place organization 4. 1st time qual success (PM quality), first 48 hrs. failures (PM quality)

In fact, we may summarize table 1 using again the race team pit crew analogy, when the race team management (high and medium level maintenance management and maintenance engineering) enables and demands a creation of a precise work environment (work procedures and work place organization) together with a continuous improvement of team proficiency (training and certification plan, and performance metrics) it facilitates quality and reliability of tool performance with effective and speedy execution.

THE CASE STUDY

Background

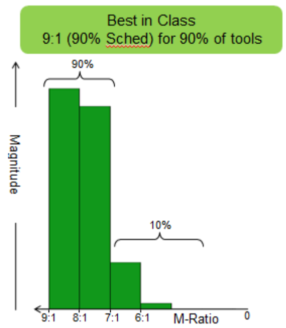
This case-study took place in a mature medium-size 8" American foundry. The foundry was selected by the MAX Group as a top performer in the area of equipment engineering in the US based on the 2012 FOA benchmarking survey and has kindly agreed to participate in the assessment of its EE organization by the MAX Group. The study objectives were to evaluate the maintenance practices that allowed them to achieve such performance and the ways of boosting that performance to Best In Class level. In this paper we will discuss the great things we have observed and the improvement potential we identified using the actual findings from the Photolithography module as an example.

Evaluating Precision of Maintenance

In order to quantify maintenance practices effectiveness MAX has developed a simple set of metrics as part of its overall Precision Maintenance package termed MAX Precision Maintenance™ - MPM™. MAX analyzed toolsets Availability data, using two primary metrics, as seen in figure 1:

1. **M-Ratio** = $\frac{Sched.Maintenance\ Time}{Unsched.Maintanance\ Time}$, expressed as X:1, for example M-Ratio of 4:1 indicates that the total maintenance time consists of 80% Scheduled maintenance and 20% of Unscheduled maintenance. MAX benchmark for the BIC average M-Ratio is 9:1.

Figure 1: BIC foundry M-Ratio



High M-Ratio indicates the capability of predicting and planning maintenance events, which is the fundamental requirement for Precision of operation.

2. Graphical representation of equipment Availability fitted by its statistical *coefficient of variation* (CV).

CV of Availability $= \frac{\sigma}{\mu}$ or $\frac{s}{\bar{x}}$, where σ, s represents standard deviation, μ, $\bar{x}$ represents mean for population or sample accordingly.
Looking at mean Availability combined with CV of Availability enables the maintenance team to achieve target equipment uptime and also evaluate and improve the degree of Precision maintenance work which leads to predictable and repeatable results.

During the evaluation of work practices MAX conducted series of interviews and observations and used specially developed score cards for benchmarking, see figure 2

Figure 2 – Working practices score card example

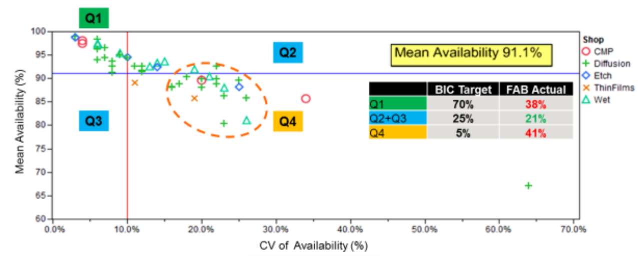
Topic	Gap	Priority
Green-to-Green Mode	• Not practiced	1
KPIs	• Uptime variability is not reviewed in most cases • PM duration and variability is not reviewed by the EE • PM quality metrics (1st time qual success, etc.) are not reviewed by the EE • First Time Qual Mode is not practiced • OEE is not reviewed • A80 is not tracked/reviewed	1
Response and Service Levels	• No structured definition of RedBox tools and escalation procedures	1
CMMS	• Implemented, but partially utilized, definition process is still ongoing	1
PM Scheduling Rules	• Conversion from time-based PMs to usage-based PMs is in progress • Development of Predictive & Preventative Maintenance (PPM) is in progress	2
Visual PM/Repair Spec	• More visual material could be included	2
Golden Tool Matching	• Not practiced for Availability	2
Spare parts management	• Bulky stock management system • Refurb. parts tracking is comlex • High amount of OEM parts in use	3
Tech Effectiveness	• Very mature and self-sustaining maintenance team • 80% if personnel are Tech 4 cross trained for all tools in their Shop	
Pit Crews	• Practiced as BIC	
Toolbox design and maintenance	• Tools are in good condition • PM carts are utilized and maintained	
PM/Repair Kitting	• Kitting is practiced, kits are being reviewed and refined	

Good Implementation | Some Implementation | Not Implemented

BIC values for metrics together with the BIC work practices were developed for over 15 years of experience in dozens of semiconductor fabrication factories around the globe.

Precision KPI - CV of Availability:

Figure 3 - Example of CV chart



As it is shown in figure 3, the actual mean availability (horizontal blue line) and the BIC CV of Availability vertical red line divide the chart area into the four quartiles (Q1-Q4). The distribution of the red circles, representing actual means of 52 weekly Availability data points of single tools.
The tools in upper left corner (Q1) are performing with highest precision levels, repeatedly (CV<10%) achieving high Availability values.

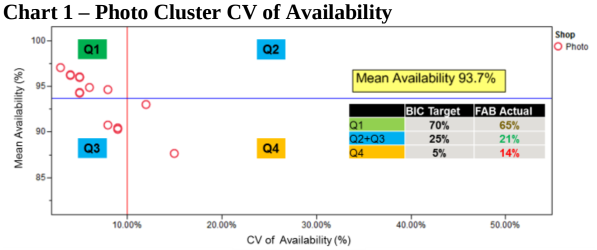
- Despite of high mean Availability of the tools in Q2, their Precision of Maintenance requires improvement and improving it will yield lower variability of performance and better predictability of lot delivery to the next operation in the manufacturing process. The sources of higher performance variability of these tools are often the consequence of non-precise technician and equipment engineer work or poor maintenance management practices. Fine tuning of tool maintenance regimes (PM schedules, standards and specifications) and/or working procedures can easily move the tools from Q2 into Q1.
- From the management levels standpoint, modern foundries prefer sometimes lower mean Availability but higher Precision – lower CV of Availability (a tool plotted in Q3 over Q2) to assure steady supply of lots to the next operation. Highly variable Availability performance is often a result of chronic and well-known equipment issues, waiting for the right resource (people, parts or time window) to get resolved.
- The tools plotted in Q4 perform with the lowest level of Precision, showing lower Availability and highest CV values. These are the toolsets the Foundry will focus on first in any improvement program initiated by the maintenance team. Such performance is a result of both equipment and maintenance issues, such as long waiting for the parts and high rate of failures due to the lack of specific knowledge.

Case study – Photolithography

Photolithography tools are widely considered to be every FAB's bottlenecks due to their high utilization and complex maintenance, therefore this area was a natural subject of interest during the study.

Step 1 – Data Analysis

Chart 1 – Photo Cluster CV of Availability



As it is clearly seen through the CV of Availability chart, Photo cluster performs at near-BIC level of Precision achieving great mean Availability of >93%. However M-Ratio was un-expectedly low, showing the values below 1:1 (less than 50% of Scheduled Maintenance time). In order to understand how it is possible to reach such levels of Precision without a proper planning and tracking of Maintenance time we need to take a look at the contributing factors.

Step 2 – Benchmarking working practices

1. <u>Usage of systems:</u> the main reason for such a low M-Ratio was simply a false breakdown of Maintenance time: new CMMS was adopted several months before the study took place, therefore equipment down states in the system were inaccurate. Precise analysis of down time was impossible and implementation of Predictive maintenances was slowed down, leaving only the option of tech experience and commitment to plan to sustain precise maintenance.

2. <u>Team structure:</u> the foundry and especially the Photolithography module benefited from *highly experienced technician and engineering team*, with average tech experience level of over 12 years in one specific area. This level of proficiency allowed keeping a very lean tech team (10 tools per tech per shift) and still achieving great equipment performance. There was no formal certification and proficiency system. Rarely new hires were trained by their experienced piers and progressed to the more advanced tasks when their pier trainer considered them ready.

3. <u>Mode of Operation – Technicians team:</u> unlike in the vast majority of the foundries, the technicians team was *extremely empowered* to plan and execute almost all aspects of maintenance including PM planning and execution, all levels of equipment troubleshooting, development and implementation of working procedures, handling improvement projects and more. Another notable finding was a *very positive culture of shared learning and constructive competition* between the technicians, leading to the *continuous improvement* of Precision in individual and team skills. Figure 4 shows a pristine condition of a **14-year-old photolithography track** observed during a scheduled PM. Such condition could only be achieved by the repeated precise actions of maintenance team. *Pit Crew techniques* were seamlessly implemented into PMs and troubleshooting, making the working routines fluent and brief. Optimal *workplace organization* methods and techniques of the teams were also developed and maintained contributing to the Precision of execution of maintenance tasks, see Figure 5.

Figure 4 – condition of the 14 years old track

Figure 5 - examples of work place organization

Tool cabinets

PM cart

Failures right after the PM and repeated failures were considered as severe conditions; the team investigated the causes and shared the learning. The technician teams also built and maintained continuously updated database of Best Known Methods (BKM) called TechNotes, improving Precision by bringing *standardization* into equipment troubleshooting

4. <u>Mode of Operation – Engineering:</u> strong technician teams empowerment made it possible to bring the direct equipment engineer involvement in sustaining of day-to-day issues to minimum, putting the engineer in a sole position of supervision and continuous improvement. The evaluated foundry is among the fewest in the industry, where the equipment engineers actually supervise the technicians during shifts, being responsible for both professional and HR subjects. The Maintenance Engineering team also owns the process of the new tools characterization and purchase, usually the R&D/NPI sphere of responsibility. Such a practice allows gaining early engineering and tech knowledge of specific equipment issues, faster qualifications and in general a smoother process of new equipment integration, whilst the ownership is not transferred between the different organizations (Facilities, TI, Engineering) but stays in the hands of Maintenance Engineering from the moment the need for the new tool is raised by the IE department.

5. <u>Mode of Operation – Management:</u> Escalation MoO, roadmap of team development, KPIs/targets, and Continuous Improvement programs were still being planned, or at best, in early phases of implementation. Such a low involvement of Management was possible mainly due to:

   1. Technician and Engineering teams actually shared management responsibilities in everything concerning the day-to-day tasks, except of the tactical daily team meetings.
   2. Foundry loading was also a factor allowing maintenance teams to assume additional responsibilities without compromising Precision of the core tasks.

<u>Opportunities found in assessment</u>
By the end of the study MAX had compiled the list of improvement opportunities, derived from the gaps between current practice and best in class in Precision. The Top 10 items are described the in Table 2 below:

Table 2 – Top 10 improvement opportunities

	Opportunity	**Gain**
1	Setup Precise Cost targets per Maintenance Line Item	Precise control of spending, improved financial forecasting
2	Develop and implement Precision KPIs and targets	Achieve and sustain BIC maintenance team performance
3	Improve the visual technics of performance tracking, implement Visual Fab tools	Precisely focus the team on the goals, make the progress and the issues clear to and visible all the time
4	Establish structured procedures for standard and crash modes	Focus on critical tools, standardize working procedures across the shifts, improve communication efficiency
5	Establish OEE methodology as main improvement driver	Precisely concentrate on real issues, on-time escalations to prevent bigger line excursion
6	Fully utilize CMMS potential	Allow OEE KPIs tracking and report out, implementation of Predictive Maintenance tools, improved scheduling of Preventative Maintenance
7	Develop formal training and certification program	Move away from “tribal knowledge” culture to the well-established standardized training system
8	Precise Capacity Management by using real equipment performance assumptions	Assure the required capacity without unnecessary capital investments

9	Precisely model headcount requirements and set proper KPIs for staff effectiveness	Optimize tech team size, precisely track individual and team performance,
10	Improve spare parts stock management	More user-friendly system to speed up part search and delivery, cost reduction by maximizing the use of refurbish. and n^{th}-source parts and minimizing the use of OEM parts

Most of the improvement opportunities lie at the Management and Engineering spheres of responsibility, illustrating how the Precision infrastructures may boost performance of even the most proficient Tech team

Summary

This Photo cluster example shows how in order to gain the needed equipment performance, a small but very experienced and committed Tech and Eng. team developed and implemented the methods of Precision Maintenance in its daily operation. The teams were naturally forced into this direction because of a lean headcount where they simply couldn't handle the excess number of equipment issues but had to be able to predict those issues in advance and treat them in a quickest possible way. Direct supervision of Tech shifts by the Eng. created one integrated Maintenance team, transforming technicians and engineers to the members of the same pit crew. Management played an important role in this process by encouraging the Tech/Eng. team to take the responsibility and perform the needed changes.
However, there is a need to emphasize the fact that the main contributors to the teams' success were the rare experience level and low fab loading, and in order to sustain and be able to improve this level of performance with the increased FAB loading and a number of new hired techs, it would be absolutely essential to implement Precision-driven management and engineering infrastructures: Procedures, Systems, KPIs, Predictive Maintenance tools and etc.

About the MPM™ Methodology

Through our years of challenging our clients to achieve better and better Fab and equipment performance, MAX have been continuously searching for the way to achieve the right balance between the optimal equipment maintenances regimes and required equipment uptime. This research led to the formulation of the MAX approach to Precision in Maintenance and the development of the MPM™ methodology.

Building blocks of the MPM™ are:

1. Precision Management and Engineering infrastructures – systems, working methods, KPIs
2. Evaluation and reduction of the equipment uptime variability, by monitoring CV of Availability
3. Achieving High predictability of Maintenance events, expressed by M-Ratio
4. Practice Pit-Crew MoO. Individual and team excellence

MAX had developed and tested a set of practical improvement techniques, covering every maintenance topic, including right utilization of CMMS, Red Box™ MoO for critical tools, PM duration and quality, Vendor support effectiveness and etc.
Implementation of the MPM™ methodology is a key for the Best In Class maintenance performance.

Conclusion

Many Fabs still base their Maintenance on traditional evaluation of mean Uptime and Downtime metrics, without considering the variability of events; the Engineering is mainly busy in the office, disconnected from the Technicians teams; shift maintenance teams often communicate poorly, their working methods are not standardized and their success heavily depends on attendance of certain individuals. This is happening whilst the modern semiconductor space continuously challenges the device makers, especially mid-sized foundries, with progressively more aggressive demands on cost, quality and flexibility of product portfolio. MAX believes that in order to keep up with the challenge, the foundries in particular have to achieve and sustain high levels of Precision, especially in equipment Maintenance. MAX offers a Global Approach to Precision which is a next step of Maintenance evolution.

Acknowledgements

The authors would like to thank all MAX and clients' personnel who contributed the observations and data analysis

Acronyms

BIC	Best In Class
CMMS	Computerized Maintenance Management System
EE	Equipment Engineering
FOA	Fab Owners Association
KPI	Key Performance Indicator
M-Ratio	Maintenance Ratio
MoO	Mode of Operation
OEE	Overall Equipment Effectiveness (set of metrics)
PM	Preventative Maintenance
SPC	Statistical Process Control
TI	Tool Install (organization)