Achieving Fab performance metrics from the SubFab to the Cleanroom

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Achieving Safety, Quality, Delivery, Cost, People & Environment Metrics (SQDCPE)

How do vacuum and abatement processes impact Fab metrics?

Vacuum pumps and abatement systems are a critical part of the semiconductor manufacturing process. Regardless of the device type or process node, there are hundreds, even thousands of vacuum pumps and abatement systems in the SubFab.

Up until recently, they have also been largely ignored as a possible source of process and yield variability. However, as other, larger and more direct Fab-based detractors are being eliminated or controlled, the search is on for the “hidden variables”. The SubFab equipment is on the list of suspects to increase performance and drive competitive advantage.

Semi manufacturing is already a highly digitalised and automated environment, where Smart Manufacturing tools and Industrie 4.0 principles are coming into play. The complexity of the manufacturing process, the dynamic nature of day-to-day operations and the continual need to advance and improve emphasises the need for a data driven approach.

In this e-book we will review each Fab manufacturing metric and summarise the findings or recommendations to get the best performance from the SubFab to the Cleanroom.

Explore Each Metric

Safety

Delivery

Quality

People

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Safety

The vacuum and abatement system funnels all hazardous materials used in semiconductor processing to render them harmless for disposal. Many of these gases and by-products are toxic, flammable, pyrophoric, or environmentally damaging and pose significant threats to the health and safety of Fab personnel and the surrounding community, if not handled with great care.

A substantial part of the vacuum and abatement system is found in a SubFab which is a very different environment to the cleanroom. It lacks the level of automated material handling, which is common in cleanrooms. It is crowded with equipment, all crammed tightly within the footprint, either under or defined by the associated process tool, and relies on the close interaction of people, machines and processes for safe operation. Considered application of the Occupational Safety Health Association (OSHA) hierarchy of controls is a necessity.

Performance Indicators

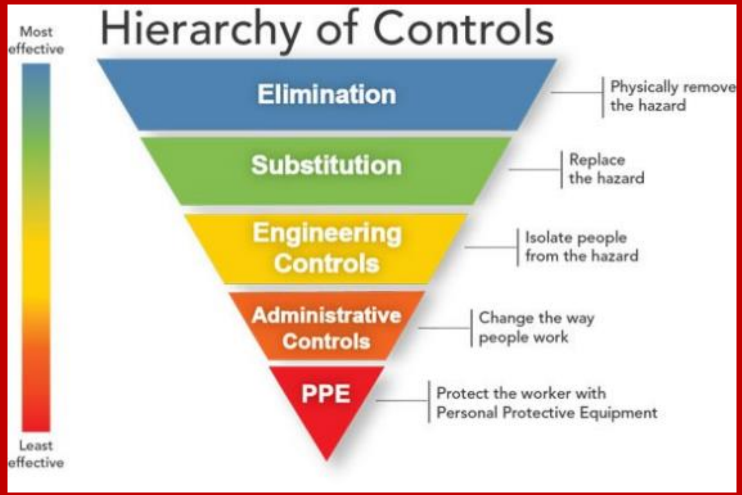
Recommendations

Performance Indicators

SubFab	Impact Across the Fab
Personal Injury Often defined as Total Recorded Case Rates(TRCR) and Lost Work Case Rate (LWCR) *Accidents and ill health cases as defined by the Occupational Health and Safety Administration (OSHA).*	Key personnel are injured or at risk. These personnel are unavailable and have to be backfilled. **A survey of leading Semiconductor companies revealed world class bench mark is to achieve a TRCR of 2.35 per million hours worked and a LWCR of 0.35.*
Safety Incidents	Also can cause injury to personnel as well as interruption to production tools.
Hazardous Material Excursions	Fab evacuation (lost production time – cost of recovery and cleaning). Hours of production time across the whole fab could be lost for each evacuation.

*Source: Occupational Safety and Health Administration OSHA

Best practice for managing risks



Source: National Institute for Occupational Safety and Health

Key Recommendations

Recommendations

Develop the safety culture: Make safety reporting accessible to all personnel and encourage a culture that challenges procedures for continual improvement. Seek partnership with your SubFab supply chain. Ensure that safety is an attitude that guides behaviour.

Implementing industry standards and best practice: Managing these risks requires a comprehensive approach to operational excellence that codifies best known methods and encourages a culture of safety. Industry guidelines and best practices are a starting point, including Semi S30 guidelines and OSHA hierarchy of controls.

Data analytics: Predict maintenance events to enable better planning and preparation. This eliminates the temptation to rush potentially dangerous tasks. Enables learning on fault modes to feedback back to improve future designs.

Quality Metric

Quality

As the number of processing steps required by leading edge processes has grown, so has the impact of vacuum and abatement on line and even die yield.

Vacuum and abatement equipment behave differently from process to process, depending on the type of process (deposition, etching, or cleaning) and the specific materials and gases used.

Equipment selection and maintenance decisions are critical at each process step. Making reactive choices can create inefficiency, process tool downtime and critical safety hazards.

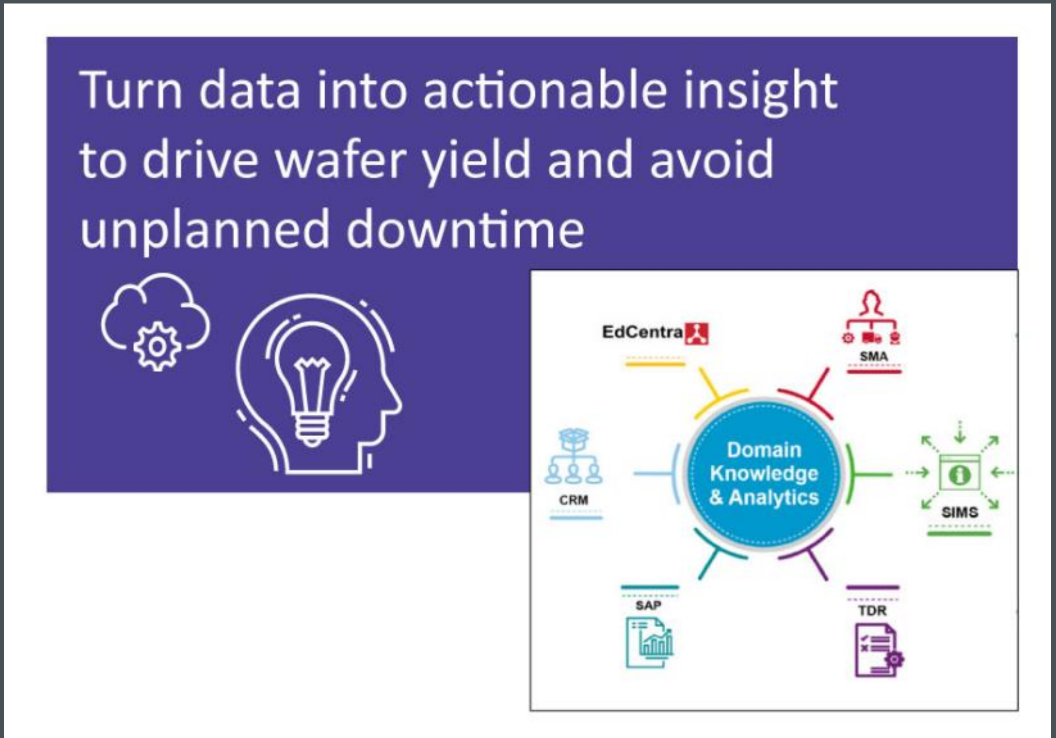
Impact on Line Yield

Key Findings

Impact on Line Yield

Yield is also the single most important factor in overall wafer processing costs. Incremental increases in yield, often of less than 1%, significantly reduces the manufacturing cost per wafer.

Unscheduled vacuum and abatement equipment faults or downtime can cause wafers to be scrapped. *For a fab output of 40k wafers per month two scrapped furnace run of 125 wafers impacts yield by 0.625%.*



SubFab Impact

SubFab equipment faults have a greater impact on line yield as processes become more complex

Vacuum and abatement data offers a wealth of insight into the operational status to avoid downtime

Data collection, analysis, and turning data into useful information and actionable insight, is the necessary foundation

Key Findings

Key Findings

To make improvements to line yield with more effective management of SubFab equipment, it is important to understand the interactions between machines, people and processes to gain actionable insight.

Collection

Collection means the ability to collect all the relevant data from all the equipment in the SubFab. SubFab equipment is varied, with many different suppliers and of different complexity. Collecting all the data in one platform is a challenge, both from an infrastructure perspective and Fab connectivity perspective

Connection

This captures connecting not only to equipment but also to other monitoring and process control software platforms. This is a challenge because up until recently these platforms were not connected, and were usually optimized for specific and dissimilar tasks.

Context

Relates to the challenge of turning data into actionable information - of making sense of it all. Engineers combine information from different sources with domain expertise – and they create value by uncovering more efficient ways of working, or sustainable improvements in performance.

Delivery Metric

Delivery

Thousands of hours
of process tool time is lost per year, due to unplanned SubFab maintenance

If an unexpected event in the SubFab causes a tool or chamber to be down, wafers can be lost or delayed when waiting for the tool and the cycle time for those wafers will increase. A particular concern for bottleneck tools where there is no capacity to catch up.

Performance Indicators

Key Findings

Key Performance Indicators

Delivery Metrics	How do unplanned vacuum and abatement events impact delivery metrics?
Cycle Time	A 40k per month capacity Fab with a 3 months planned cycle time will have in excess of 120k wafers in the line at any point in time. Delay can cause production line imbalances and bottlenecks to move around the production line.
Wafer Outs	Downtime which causes wafer scraps have an obvious impact on wafer outs. What is overlooked is the impact on throughput where one chamber of a cluster tool is down even though the whole tool is not.
	Individual tool impact: Parallel cluster tool: losing vacuum on a single chamber will take out a portion of the tool capacity. Serial cluster tool: losing vacuum on a single chamber may take the whole tool down if the chamber runs a unique process. **Impact across all tools:** Losing abatement will take the whole tool down if there is no backup and the customer cannot run in bypass.

Average Processing Time Lost to Maintenance Actions

TYPICAL TOOL DOWNTIME FOR MAINTENANCE

UNPLANNED
18 HOURS

PLANNED
11.5 HOURS

An average of 7.5 hours of process tool time is wasted each unplanned maintenance stop

Key Findings

Key Findings

The service maturity model that we incorporate in our own model of Operational Excellence, describes a progression through five levels.

The lowest level is to **do nothing** – worry about it later. The next is **reactive maintenance** – run to failure and fix it when it breaks. This is a risk-based strategy that looks at maintenance costs as a non-productive expense and focuses mostly on minimizing that cost.

The next level up is **planned or preventive maintenance**. Often time-based. At this level manufacturers are beginning to look at the value added by maintenance through improvements in efficiency and performance. Maintenance is scheduled periodically to occur before the equipment is likely to fail. Essential components of this approach are determining the optimal period, standardizing performance and procedures, and finding opportunities for improvement. The approach is often cautious and not optimized for maximum processing time.

Predictive maintenance, the next level, is condition-based and relies on increased monitoring of operational parameters to predict imminent failures. It seeks to maximize the time between interventions while avoiding failures. The highest level in the **progression is prescriptive**, in which close collaboration between the user and the service provider and a shared commitment to continuous improvement promote a prescriptive approach to maintenance, by better understanding of root causes of failures and making required adjustments to optimizes outcomes to achieve the user's goals.

Further Learning

For full definitions of the Service Maturity Model download the Service Maturity Infographic

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Cost Metric

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Cost

The value of a single leading-edge semiconductor wafer is estimated at $17,000*. One down event on a batch process type could mean the forfeit of more than $2million in additional costs and revenue.

*Source: Centre for Security and Technology (CSET) REPORT, 2020
https://www.techspot.com/news/86813-analysts-believe-single-tsmc-5nm-wafer-costs-17000.html

Performance Indicators

Recommendations

Performance Indicators

Cost Metrics	How do unplanned vacuum and abatement events impact delivery metrics?
Maintenance costs	These are the costs in consumables, spares, labour, production. Although a pump can be exchanged if it fails unexpectantly, extra servicing is unavoidable, the pump needs to be removed, remanufactured, the furnace cleaned, new pump installed, leak checked, up to temperature and only then is the tool ready to be handed back to the tool owner. The cost to recover the process tool can vary quite considerably depending on whether the tool goes down in a controlled or uncontrolled manner. For example, it might cost many thousands of dollars to replace critical parts, or to clean the chamber to remove dust particles.
Extra throughput	Improved availability equates to additional throughput. A chamber may be down for more than 12 hours if the vacuum system fails unexpectantly. If there are 150 unplanned events each year, that is 1,800 hours of tool availability which has been lost. There is also an indirect cost, if wafer throughput is reduced, the cost of running and owning process tools is spread over fewer wafers, equating to low overall tool utilisation
Lost wafers	This is the cost associated with scrapped wafers during an unplanned down. Minimising wafer scrap events also reduces the required inventory provision and costs.

Improvements to Operating Profit Ratio (OPR)

- ✓ Minimise wafer scrap costs
- ✓ Improve cost per wafer from increased efficiency and tool availability
- ✓ Reduce inventory provisions and maintenance costs

Key Findings

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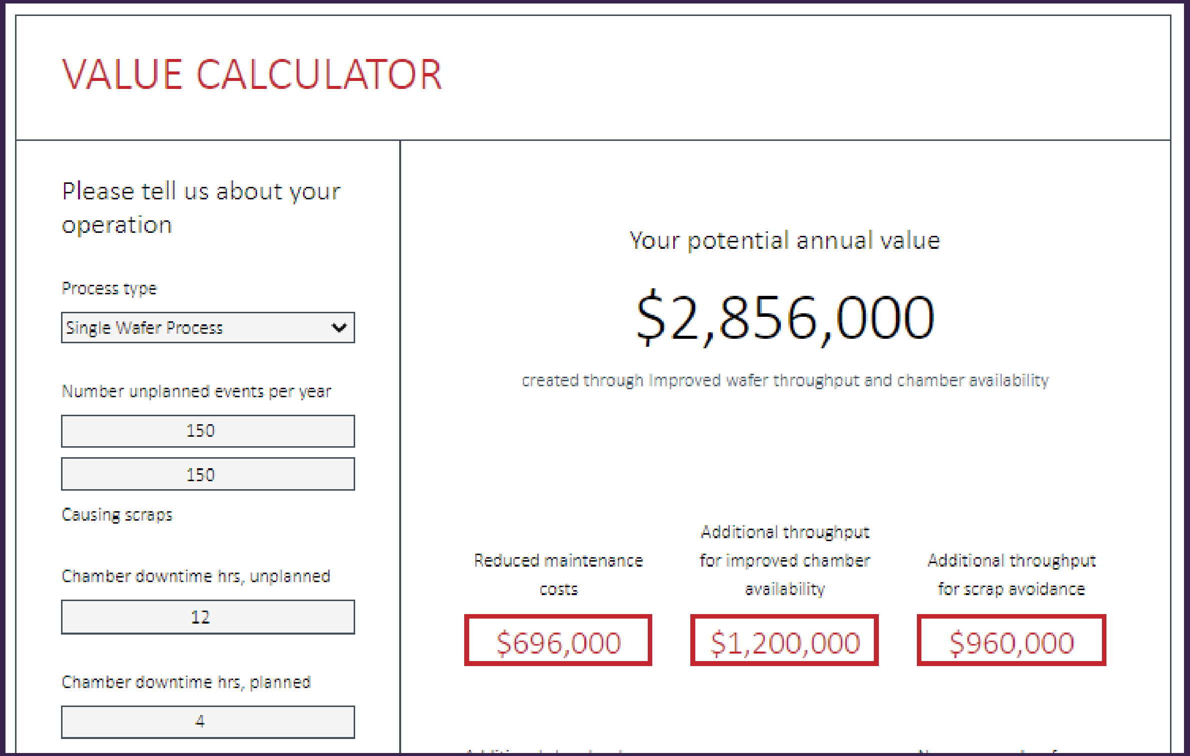
Key Findings

In order for the vacuum and abatement process to contribute towards improved OPR, understanding how vacuum and abatement can contribute to wider fab profitability is an important first step. It is possible to estimate the reduced maintenance costs, improved chamber availability and reduced scrap value, based on the number of vacuum equipment unplanned events (crashes) per year.

Illustration: An operation on a single wafer process with 150 unplanned down events per year

REDUCED MAINTENANCE COSTS	VALUE OF CHAMBER UPTIME	REDUCED WAFER SCRAP VALUE
$696,000	$1,200,000	$960,000

$2,856,000
Total Potential Annual Value



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[People Metric](#)

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People

To bring the knowledge of vacuum and abatement to bear on the challenges in the cleanroom, it is critical to integrate principles, tools, and people to achieve operational excellence. Industrie 4.0, emphasises the need to train people to use and work alongside technology. Industrie 5.0, the next phase, shifts its emphasis to the skills and creativity of people in relationship to technology, knowledge, safety, and more.

Key Capabilities

Key Findings

Key Capabilities

Human intuition, problem solving, and domain expertise are flexible assets to be shaped to address business needs. Empowering humans with new technology will change the way our teams work. Jobs will become richer as machines take over mundane tasks. People will have more time to use their creativity to solve problems and create value. These are the key capabilities to maximise the value of people when achieving Fab performance objectives.

Nurturing Expertise

Analytical models and data need training for truly effective analytics. That puts new demands on teams as they must become familiar with new data gathering technologies in order to achieve the desired results. From a people perspective, operational excellence can be articulated as the three Cs: competence, confidence, and commitment – having a workforce that is competent to undertake the work required of it, has confidence in its capabilities and knows when and where to seek support, and is committed to completing the work to the highest quality.

Knowledge Systems

Domain knowledge and context data are needed to truly understand why events happen and to then eliminate or mitigate causes. For example, what happened during that last maintenance activity (context data) and how did it influence that excursion in the vacuum system (domain knowledge).

Collaboration

New levels of collaboration and governance across functions. That is not just between teams in the SubFab, but between the many stakeholder groups throughout the Fab.

Key Findings

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Key Findings

Creating integrated circuits requires many people with a wide range of skills and both theoretical and hands-on knowledge. These skills range across physics and chemistry, materials science, electrical engineering and electronics, mechanical engineering, control systems and more. The skill sets and people needed again reflect the different aspects of the process carried out in the cleanroom vs the SubFab. In the cleanroom, operators, technicians, and engineers are highly skilled – PhDs are not uncommon.

On-site SubFab personnel are also highly skilled, particularly in view of the risks posed by hazardous materials. Much of the maintenance is performed off-site and our on-site personnel are complemented by technicians and PhD engineers working behind the scenes at the service and manufacturing facilities. Their in-depth knowledge of process chemistries and vacuum physics is crucial in designing both equipment and maintenance procedures, and, when needed, in solving problems on site. As a significant amount of the SubFab domain expertise is based off-site, maintenance complexity is hidden and opportunities to optimize its effectiveness are often overlooked.

SubFab equipment manufacturers must strive to make their domain expertise readily accessible to field service personnel.

Further Learning

To explore more opportunities to increase collaboration, download the infographic "5 reasons to align the Clean Room and the SubFab"

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Environment Metric

Environment

Environmental protection is one of the fastest growing performance indicators for manufacturers globally across the whole semi supply chain.

Adopting circular economy business models to ensure all resources and processes are used to their maximum efficiency levels is critical to Fab success. This means considering any and all waste to be an input back into the system.

Key Value Areas

Recommendations

The Business Value Areas

The circular business model must deliver real business value.

Sourcing - The direct financial value derived from reducing costs, eliminating waste and entering new markets.

Environmental – Achieving corporate sustainability objectives though energy efficiency programs, strategic renewable energy initiatives, reduction of greenhouse gas emissions and established climate change countermeasures.

Customer - value can be generated by new products or services that better meet the customers' requirements. Buy-back programs that give the customer a financial incentive to recycle also add customer value.

Information - is the value of the data and knowledge gained in a circular system, from interactions with the customer and from analysis of the products. Specific data on processes that can be developed to bring organisations closer to their sustainability goals or gain competitive advantage.

Recommendations

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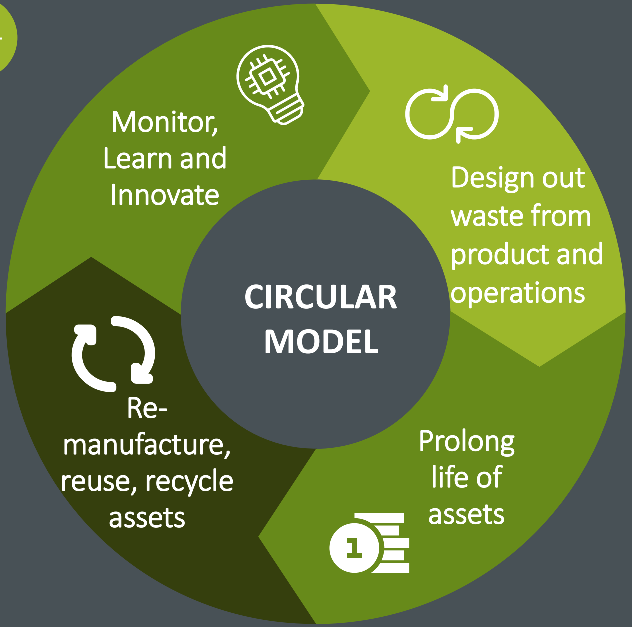
Recommendations

These core capabilities are vital to implementing a circular business model. Design for circularity prolongs product life through remanufacturing, reusing and recycling. A data driven approach to innovation underpins it all.



One customer achieved a 25% increase in pump lifetime, by transitioning from a time-based maintenance schedule to a condition-based maintenance plan, that integrated equipment monitoring with predictive maintenance (PdM) and remaining-useful-life (RUL) technologies.

Further Learning

To find out more on the value of circularity in vacuum and abatement systems download the E-book

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