Siemens Digital Industries Software

Smart manufacturing for semiconductor

Solving pressing production issues through smart technologies

Executive summary

This white paper examines the benefits of smart manufacturing for the semiconductor industry and how companies need to embrace this digitally-connected approach to ensure they can keep up with increasing business demands and secure future success.

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Abstract

Semiconductor manufacturing organizations need to build smart manufacturing into their strategic plan. The vision for smart manufacturing must spring from a clear view of how it can accelerate business success.

New technologies and approaches present great opportunities for semiconductor manufacturing to finally achieve high levels of innovation, yield and improvement at the same time. This white paper explores some of these cutting-edge technologies and how they can be applied effectively in the semiconductor industry.

Semiconductor is, arguably, the most advanced manufacturing in the world; yet most companies have not yet embraced smart manufacturing. It is time. The pressure is on and the technologies and approaches to succeed have arrived.

Smart manufacturing is the element of Industry 4.0 that uses digital means to ensure continuous improvement. It is a key digital enterprise thread for consistent, high yield processes.

How is smart manufacturing different from what most semiconductor companies do today? It's not the goal, which remains a high yield manufacturing process. What's different is the reality of meeting this goal. Smart manufacturing is more comprehensively digital, allowing greater and more reliable information flows. It also has a broader base, from process simulation through execution control and analytics to drive continuous improvement.

So while the focus is the fab, it's an enterprise-wide information flow. Smart manufacturing requires and enables various disciplines such as design, engineering, production, quality, scheduling etc., to interact far more readily. Smart manufacturing goes beyond current state understanding to leverage both history and advanced predictive analytics to shape future outcomes.

"Smart manufacturing utilizes a mix of simulation, execution control, and analytics to drive continuous improvement for a make-it-right-the-first-time, high yield manufacturing process. Focus is on the right lot, right recipe, right resources at the right time. Optimization through managed simulation drives process and product improvements through analytics applied to the manufacturing process."

Why: What's the vision?

"To survive disruption and thrive in the digital era, incumbents need to become digital enterprises, rethinking every element of their business,"[1] says The World Economic Forum, the international organization for public-private cooperation. The digital enterprise relies on using digital threads, creating end-to-end, top-to-bottom and across-ecosystem information availability. This opens up new opportunities for the business and its performance.

Smart manufacturing is one of the digital threads in the Digital Enterprise (figure 1). That means it digitally connects the entire manufacturing process lifecycle. This spans well beyond traditional manufacturing execution systems (MES) and their track and trace functions – and even well beyond the most modern semiconductor MES capabilities. Smart manufacturing ties all MES functions together with fab, line and automation design using simulation to test options and optimize processes and production outcomes. It also includes manufacturing and production planning and scheduling. Further, it feeds sensor data from equipment and other Industrial Internet of Things (IIoT) equipped devices into analytics systems for historical and current insights and also future predictions.

Imagine if all of the information about a fab were readily available. The smart manufacturing information flow includes data from sensors at the equipment level up through every level of product and process recording and tracking. This enables a digital twin of the production process and its performance.

The most anticipated new capability in smart manufacturing is increased flexibility and agility. Whether striving to improve coordination across the ecosystem or move to greater vertical integration and make modules as well as chips or both, companies must be able to respond more rapidly, confidently and with better results. Only with such detailed information flowing within manufacturing and the enterprise can a semiconductor company expect to thrive.

Digital enterprise	
Ideation → Realization → Utilization	
Semi lifecycle management	Provide the foundation and master data management (MDM) to manage semiconductor design and manufacturing blocks.
Requirements management / functional safety	Delivering high quality products requires an enterprise level of collaboration and process management throughout the entire product lifecycle and across the value chain.
Package design (ECAD/MCAD/ Thermal)	Breaking down barriers between teams using multiple concurrent design systems – seamlessly integrating electronic, mechanical and thermal design into the overall product development workflow to get to market quicker, with better products.
Thermal quality assurance	Allows for a calibrated thermal model to be used in production in combination with a non-destructive test on an assembled package to guarantee quality in the field.
Smart manufacturing	Utilizing a mix of simulation, execution control and analytics to drive continuous improvement for a make it right the first time with a high yield manufacturing process.
Closed loop quality	Closed-loop quality management unifies quality product design, manufacturing and process data from across the enterprise and value chain enabling cross-functional collaboration to deliver first time excellence, reduce warranty costs and improve customer satisfaction.

Figure 1: Smart manufacturing is one of several digital threads that make up the digital enterprise for semiconductor.

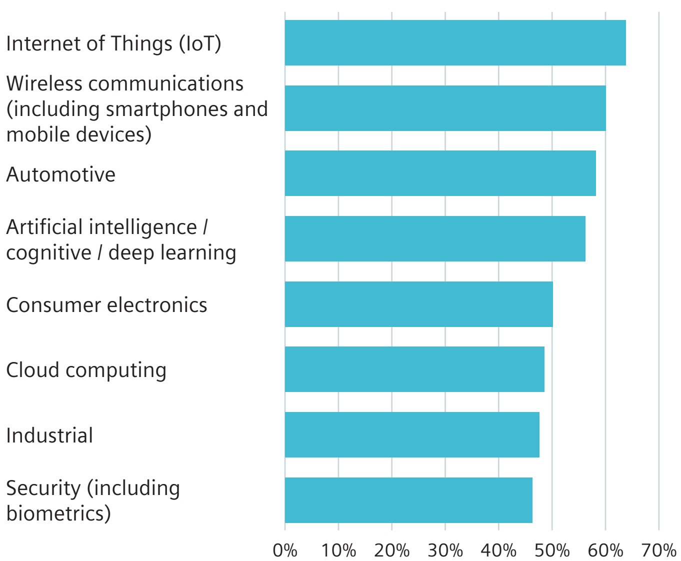
Why now: Industry needs

KPMG's Global Semiconductor Outlook 2019 is titled "Semiconductors: As the Backbone of the Connected World, the Industry's Future is Bright."[2] There is no doubt there is a wide array of products and industry applications that can fuel success.

Growth opportunities

Interestingly enough, smart manufacturing in nearly every industry – along with smart products, cities, and services – are driving the need for smart manufacturing in semiconductor. As the technology that makes anything smart, semiconductor companies have enormous opportunities. For the first time, IoT tops the list of applications driving companies' revenue, according to KPMG for the Global Semiconductor Alliance (figure 2).[3]

Top eight applications driving semiconductor revenue 2018-2019

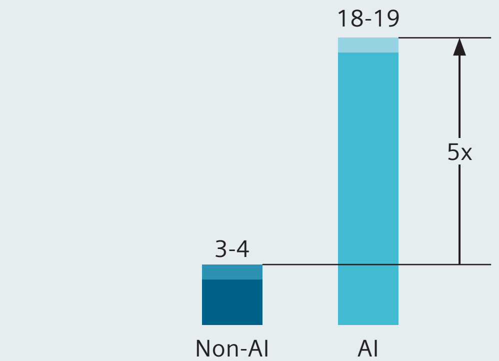


Source: ©2019 KPMG International Corporation, 2019 Global Semiconductor Outlook: Semiconductors: As the Backbone of the Connected World, the Industry's Future is Bright

Figure 2: IoT is expected to be the top driver of revenue for semiconductor companies in 2019, with nearly two-thirds of companies expecting revenues from IoT. Wireless communication is still a very strong market as well as many others.

- IoT is the top application driving growth for semiconductor companies according to KPMG's Global Semiconductor Outlook 2019. As a result, sensors are the top growing device type by volume. Beyond that, IoT means dramatically different things, since devices for IoT can be very simple or relatively complex edge devices.
- The mobile communication industry continues to drive the most revenue for semiconductor. Even as smartphone growth slows due to penetration, 5G cellular technology is on the way. This will require not only mass quantities of semiconductors, but significant innovation with new devices fueling new ways of working across mobile as well as computing and other segments.
- Artificial intelligence and related cognitive and deep learning applications are also growing. A McKinsey & Company report "Artificial-intelligence hardware: New opportunities for semiconductor companies"[4] points out that AI needs accelerator devices such as memory, storage, logic, and networking. This segment is growing at five times the rate of the rest of the semiconductor market (figure 3).

Estimated AI semiconductor total available market CAGR,[2] 2017-25, %



Source: © Jan. 2019 McKinsey and Company, Artificial intelligence hardware: New opportunities for semiconductor companies.

Figure 3: Artificial Intelligence may not be the largest market, but it is growing extremely rapidly, much more rapidly than the rest of the market.

- Automotive customers have always been extremely demanding. They expect a narrow range of parameters in each shipment. As self-driving cars become more popular, they will need even more devices with high reliability to ensure safety.
- Industrial is driving revenue for many companies as well. These can be from very simple and inexpensive to complex systems-on-a-chip. It's good to remember that your products are fueling the digital transformation in nearly every other type of manufacturing plant. Even if they are your customers' customers' customers, you have a connection.

The vast array of other application industries driving semiconductor revenue now tells a story too. The growing expectation that every aspect of our lives will be smart and automated is driving a variety of needs.

Fab challenges

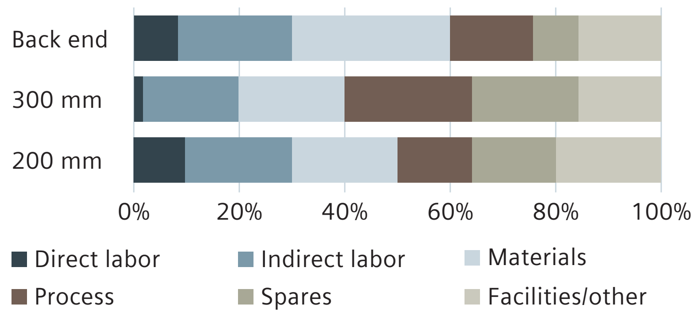
To capture these various growth opportunities, companies face a number of challenges. There are far more for each company and fab than we can list. However, here are a few common and pivotal issues device makers must address to maximize success.

Device level track and trace is increasingly important and expected. Automotive customers' high expectations that each shipment of devices test within very narrow ranges is no longer new. Yet their expectations continue to rise. Regulated industries such as medical devices, aerospace and defense, security and biometrics also require complete genealogy for each individual integrated circuit.

SEMI is working on standards for single device traceability[5] to allow buyers to specify a unique identifier on each device. This traceability starts at incoming materials such as die, lead frames, epoxy and bond wires and will build up to a full traceability record throughout the supply chain to system integration.

While some product uses won't require device-level genealogy for a while, others already do. This requirement creates an exponential explosion of data. Device level tracking puts an enormous strain on the information systems that run most fabs and back end facilities. Most have some form of manufacturing execution system (MES), but many of these systems are over 10 years old. These systems were not designed to support this level of detailed information gathering and processing. Yet track and trace is not something that lends itself to being primarily an add-on system; it is a core function of MES.

Yearly manufacturing costs for example fabs



Source: © Aug. 2019 McKinsey & Company Reducing indirect labor costs at semiconductor companies

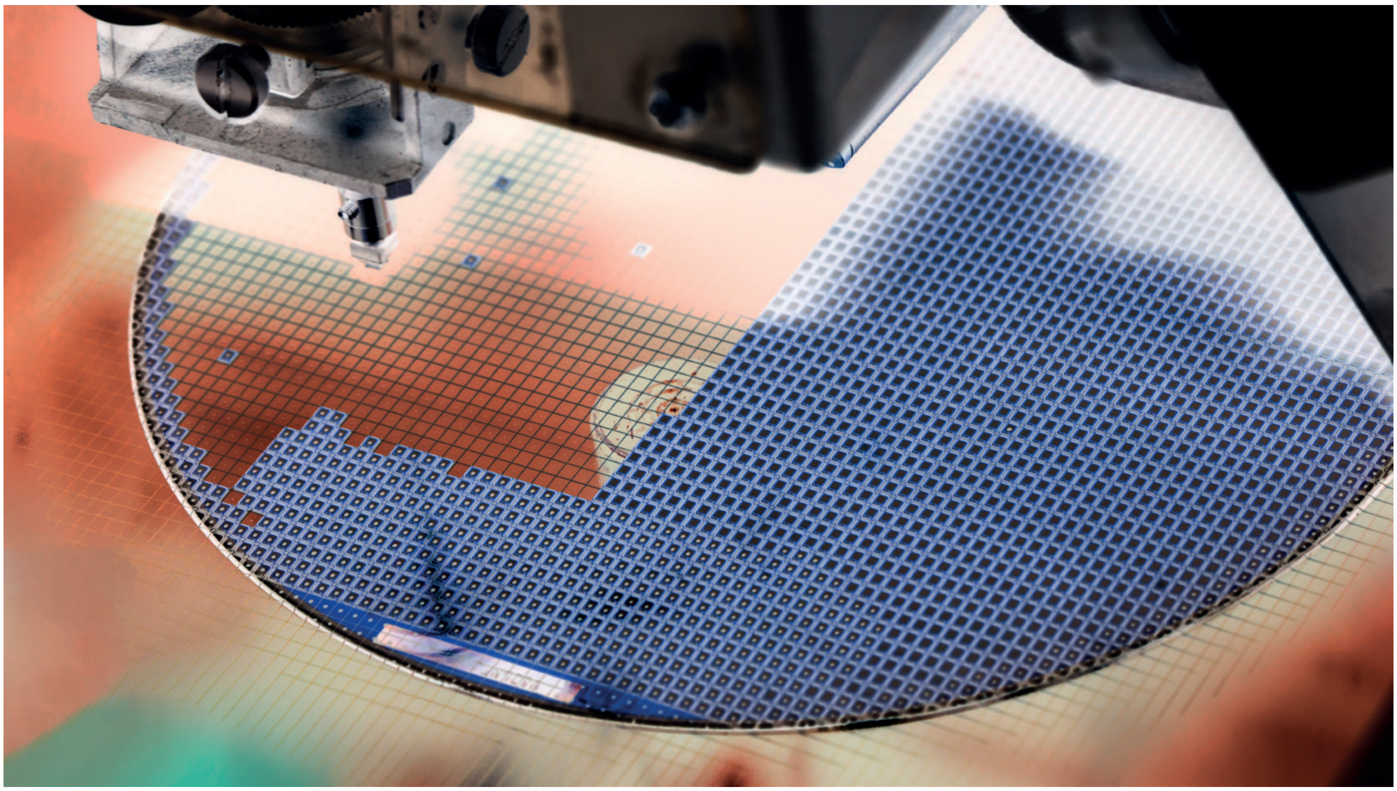
Figure 4: Indirect labor is a significant portion of manufacturing costs – as much as one-fifth of the total – and there are many technologies available to help reduce those costs.

Indirect labor costs may mount up to 20 percent of total costs, per McKinsey & Company (figure 4). Materials costs may be even larger, but those are out of the company's control. While many companies have applied advanced technologies for the direct manufacturing operations and staff, fewer have adopted them to automate tasks or augment indirect workers to make them more efficient. Some examples:

- Maintenance technicians may need to shuttle back and forth to terminals to log activities and use their standard operating procedures (SOPs) and checklists. As experienced technicians retire, the inefficiency is mounting.
- Capacity planners and production schedulers often waste time and create unrealistic plans or schedules. This is because they do not have instant access to data about the latest process improvements or the impact of changing materials, new products or a different mix of products. Some may also lack underlying intelligence in the systems they use to accurately leverage the data as products, materials, methods, and mix change.
- Semiconductor engineers (industrial and test) typically must scrape together information from dozens of different systems to make good decisions and find improvements. These might include decisions about dispositioning wafers and lots on hold, production or test processes and parameters for new products as well as to improve yield for existing products. Most semiconductor companies' information systems do not easily facilitate pulling out, let alone pulling together into a context, data from across the design, planning, processing, and reporting stages.

Margin pressure from yield is not a new challenge. Yet it continues to haunt companies as they seek ways to fund new product initiatives and also keep shareholders happy. Pinpointing opportunities for improving yield and other margin factors such as equipment availability and throughput is not obvious. Even companies with the latest equipment and terabytes of data are struggling mightily to improve yield. Part of the issue is that older MES typically provide little in the way of reporting or analytics to support improving yield. Particularly with today's shortage of skilled production and engineering people, if you cannot easily and quickly see a problem, it's unlikely to be addressed in a timely fashion, if at all.

Both opportunities and challenges point to one conclusion: It's time for a new approach. Semiconductor companies must now consider and move toward smart manufacturing.



What and how: Smart manufacturing foundations

The vision is of semiconductor production that is optimized, reliable, high yield, and completely documented. This can happen when information flows freely where it's needed not only within a fab, but also to sister fabs, to support and office personnel and out to customers, suppliers, and distributors.

Each semiconductor manufacturing organization needs to build smart manufacturing into its overall strategic plan. Seeing both the opportunities and challenges in the current state is the starting point. The vision for smart manufacturing must spring from a clear view of how it can accelerate business success.

What is common is the opportunity new technologies and approaches present for semiconductor manufacturing. Here we will explore some of these and how companies can apply them effectively.

Digital twin (not just static models)

Virtual views can create real benefits. One way to gain a more comprehensive view of product, production and performance is to create and use digital twins. A digital twin is "a virtual system that contains all of the information about the physical system," according to Dr. Michael Grieves of Florida Institute of Technology, who is commonly credited with creating the concept in 2002.[6]

This concept of a digital twin is most heavily used in industries such as aerospace and defense and automotive to describe the as-designed product. In smart manufacturing, the focus is more on production and performance (figure 5). Fortunately, modern equipment comes from the provider with a 3D model and plus specifications and performance expectations. Engineers often have models they developed to simulate a line or process as well. Together, these can form a design basis for simulating processes and production flows and outcomes. A digital twin or virtual production model enables semiconductor companies to optimize throughput, yield and cost with a fast ramp time.

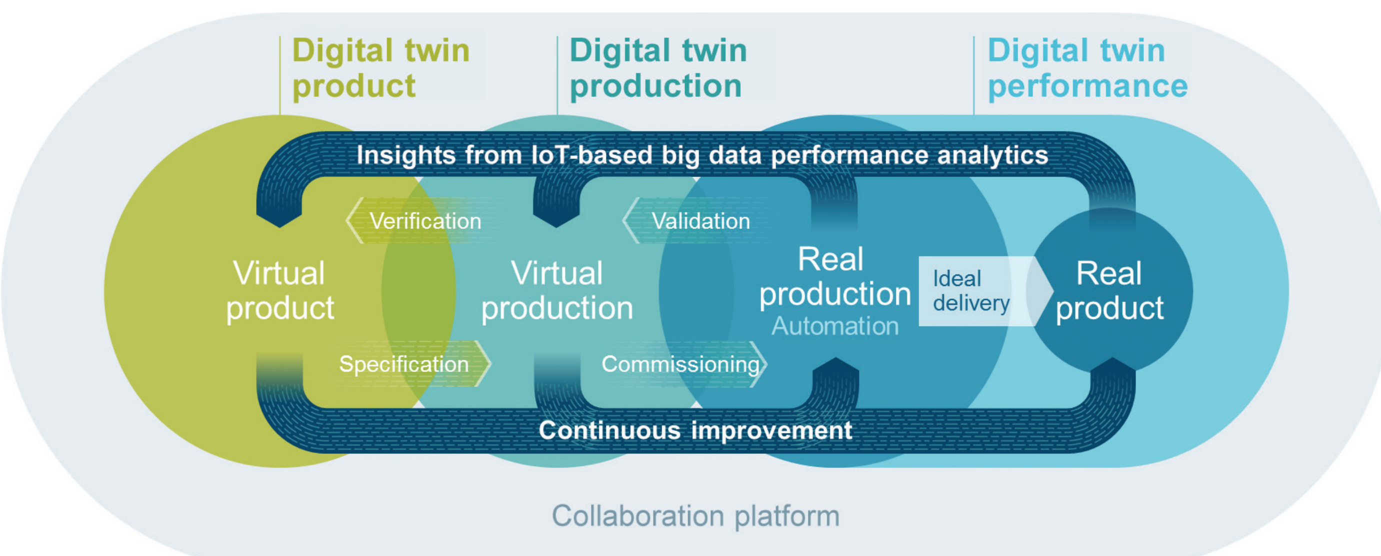


Figure 5: Digital twins can be of product, production, or performance. Particularly the production and performance elements are key to enabling Smart manufacturing. Ideally these digital twins feed each other for insights and continuous improvement.

Running simulations against a digital twin of a running fab is also useful. As materials, products, mix of products, or customer demands on parameters change, a digital twin can help to optimize new equipment settings and standard operating procedures. These simulations can also speed new product introduction and provide the ability to advance quickly from prototyping to full production volumes at entitlement yields.

Perhaps most powerful today is a digital twin of production that can also reflect performance in real-time. Information can flow back to the digital twin from the actual results from MES, maintenance, test, and scheduling to keep the digital twin fresh. Going the other way, having the digital twin of what's happening also suggests where actual performance might improve.

Scheduling integrated with MES (not just daily updates)

Finite production scheduling is increasingly essential for semiconductor companies, with product mix growing and profits being squeezed. This detailed level of scheduling goes far beyond basic production planning (figure 6). It answers the questions that the production team needs to know to run a shift.

Having scheduling and MES be fully integrated (not just doing daily transfers) creates an environment for constantly updated, resource-constrained views of what to do next at every workstation. It allows for test runs and experiments to be scheduled and slotted in with minimal risk to delays of production runs. For most companies, this will require new software. Traditional independent scheduling systems and older MES do not offer this level of integration.

Simple, coherent process support (not just piecemeal data)

Today's advanced MES can model even complex process flows. This simplifies support for not only production itself, but critical ancillary processes such as managing specifications, recipes, masks, and tools. Modern MES for semiconductor also supports quality processes with tools such as statistical process control (SPC) plus capabilities to run and track experimental lots for new products or process improvement.

Ideally, all of these are re-usable workflows that the MES centrally stores and manages. If all of that also has central change management capabilities, process changes can reliably roll out to every fab or line with that process. In this scenario, MES powers smart manufacturing in a way that allows the company to design anywhere and build anywhere. Making zero-defect chips and packaged products reliably and consistently every time is much more achievable with this level of process, quality, and change management inherent in the core MES.

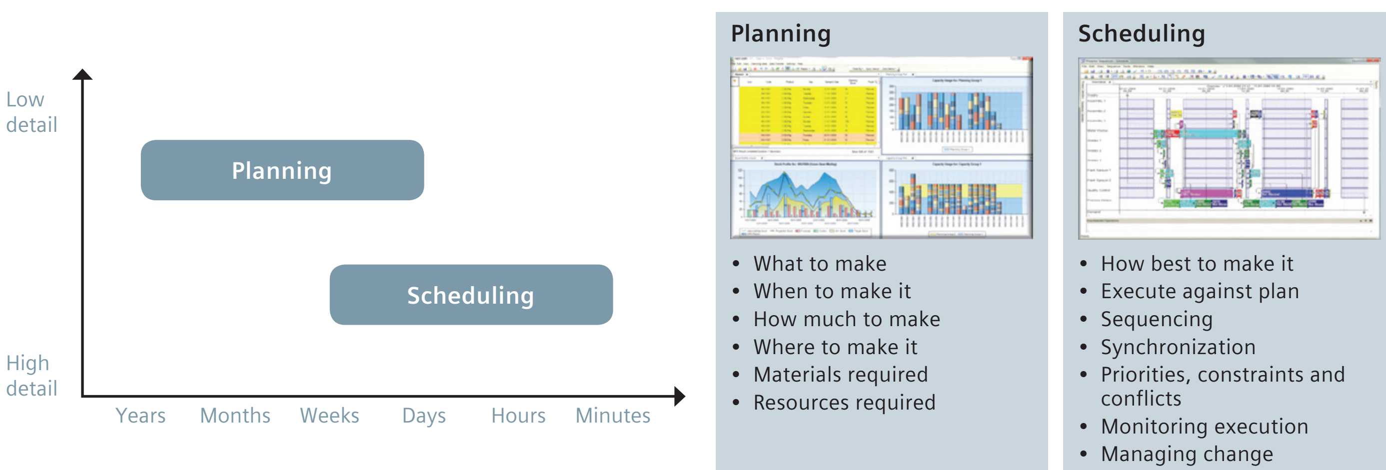


Figure 6: Finite scheduling answers a different set of questions from planning. It focuses on a short time horizon and is an essential component of truly Smart Manufacturing with on-time processes and wise use of resources.

Advanced analytics for deep insights (not just data and reports)

Smart manufacturing – and in fact company success – rests on getting beyond the data and into new insights. As operations and products grow in complexity, deeper insights are needed to reduce capital costs, improve quality and yield, and speed time to market. Dashboards can show this performance per fab or on an enterprise scale (figure 7).

Since semiconductor equipment collects large amounts of data, it might seem natural for companies to use big data and advanced analytics. Yet it is not nearly as common as traditional analytics.

A good MES system allows you to relate any measurement value to any other measurement value between any two points in the manufacturing flow, providing valuable insight into yield anomalies. It can show quality in terms of detailed understanding of non-conformances, scrap and rework (figure 8). This is important analysis, but still traditional analytics as the data is typically coming from just one source.

Big Data refers not just to the quantity and velocity of data, but to the variety of data used to gain new insights. Companies that have added IIoT often enable much richer data streams from internal machine sensors as well as older equipment. Many companies have not yet provided the context of many streams of data.

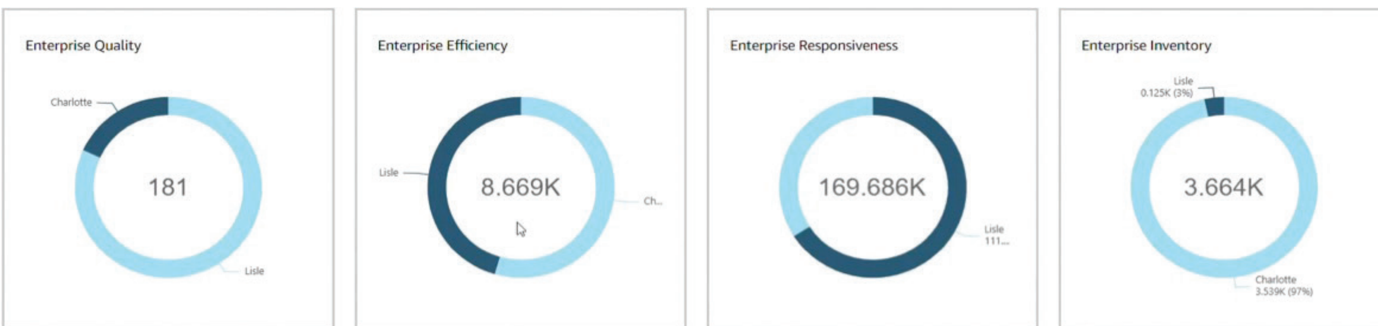


Figure 7: For smart manufacturing, companies must be able to easily see performance across an enterprise. This type of aggregated dashboard can support better decision-making and faster improvements.

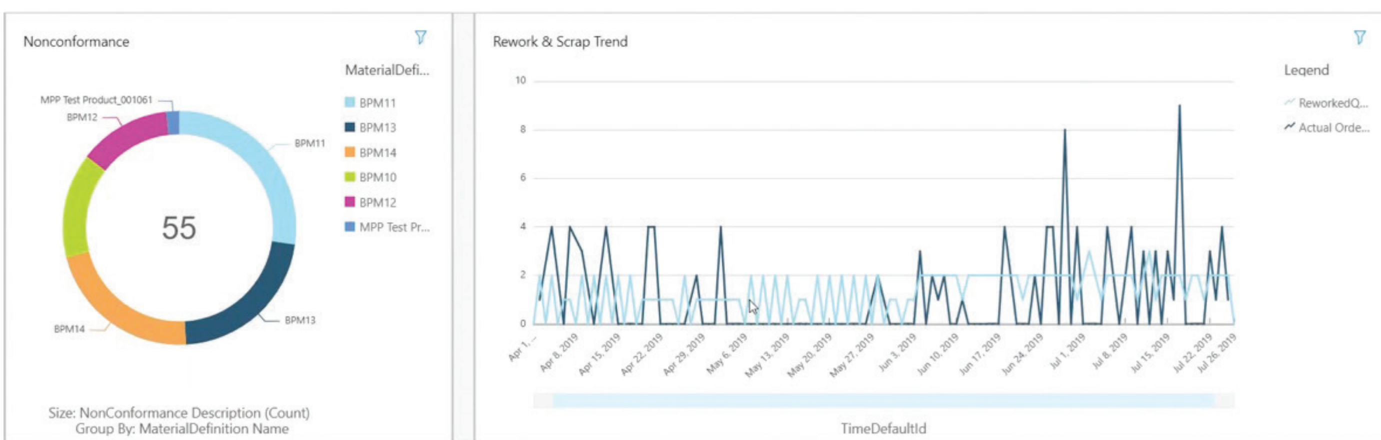
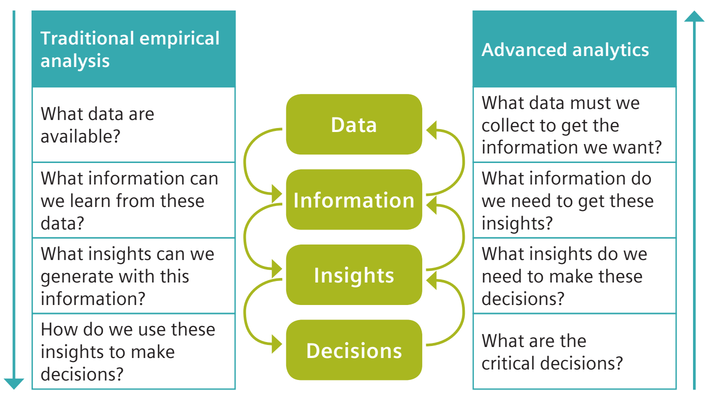


Figure 8: Modern semiconductor MES can deliver quality information at both aggregate and detailed levels, including non-conformances, scrap and rework trends. This is a foundation for smart manufacturing.

Gartner defines advanced analytics as "the autonomous or semi-autonomous examination of data or content using sophisticated techniques and tools, typically beyond those of traditional business intelligence (BI), to discover deeper insights, make predictions, or generate recommendations. Advanced analytic techniques include those such as data/text mining, machine learning, pattern matching, forecasting, visualization, semantic analysis, sentiment analysis, network and cluster analysis, multivariate statistics, graph analysis, simulation, complex event processing, neural networks."[7]

Advanced analytics requires a totally different approach (figure 9). Until the company identifies key questions to ask, they cannot work up the stack to gain deeper insights. Once they do, results can be powerful. Here are just two scenarios to consider.



Source: © 2016 McKinsey & Company, Improving the semiconductor industry through advanced analytics.

Figure 9: Advanced analytics starts with what decisions to make, and then works up the stack to what data to collect and aggregate. Typically this data comes from multiple sources or the insights would already be in hand through traditional analysis.

- **Predictive maintenance:** Semiconductor companies that have used big data and analytics using data not only from within that machine, but also between machines in a family or in a line or fab increase availability and thus profitability.
- **Predicting process failure:** One company crafted analytics for deposition process failures and has prevented significant yield loss.

Digital thread (not just siloed applications)

Tying data together to create digital threads is an important element. Typically, these span multiple aspects of the product lifecycle, as well as horizontal and vertical integration. When data flows among various information technology (IT) and operations technology (OT) systems, the company can create new, more comprehensive and useful information flows.

Smart manufacturing is one of those digital threads (figure 1). Weaving it in with others creates a fabric of information for success in the digital enterprise. Information flows connected to design, engineering, planning, manufacturing, and maintenance create a richer context for everyone. Digital threads such as Smart Manufacturing create strong context for decisions and data sets for advanced analytics.

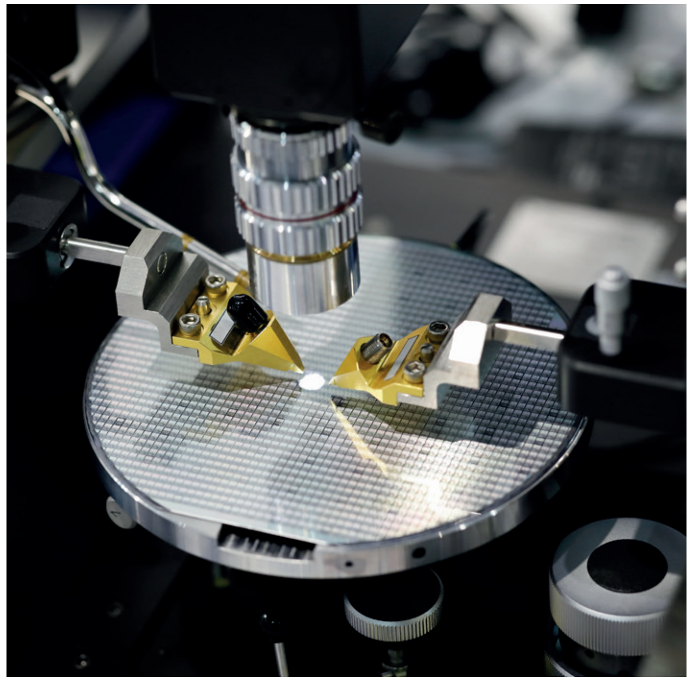
Smart manufacturing now

The future and present of semiconductor is smart manufacturing. And the time to act is growing short. Each of these aspects and technologies can be the starting point.

As with any digital strategy, success typically rests on having a very clear business benefit you expect. Pinpointing what matters most to the success of the company and its manufacturing is the starting point for smart manufacturing.

With today's high degree of automation, it may be difficult to envision what could be "smarter" in manufacturing. If this is the case, consider exploring what other industries are doing and how they are changing their production approaches to best leverage the intelligence your products offer them. They won't look like your fabs or back-ends, but they may reveal some very interesting and applicable ideas.

This is a time of exciting opportunities, but only by challenging the status quo can companies benefit fully from them.



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