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IT@INTEL

Using Big Data in Manufacturing at Intel's Smart Factories

Intel has seen year-over-year gains in uptime and output by using big data to automate manufacturing processes.

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Executive Overview

In the rapidly changing business and technology environment, manufacturers are striving to stay competitive, now and into the future, by increasing productivity and lowering costs.

Like many companies, Intel has evolved over the decades to provide competitive advantages through sophisticated automation—smart manufacturing—which has helped its factories increase product yields and quality, reduced costs, and improve safety. Intel's smart factories are among those that now use edge computing and the Internet of Things (IoT) to enable automated control systems with real-time data. This data is categorized and prioritized in off-line systems as big data for ongoing analysis and decision making.

Today, Intel manufacturing consistently reaps the benefits of year-over-year improvement in the following areas:

- **Reduced costs.** Accurate and timely information in the hands of process engineers improves product cycle time, process equipment uptime, maintenance, and other factors that save money.
- **Accelerated velocity.** Automated product flow enables dynamic routing of products to available tools for processing, reducing bottlenecks and wait times.
- **Improved quality.** Statistical process control, advanced feed forward/back process control, and decision-support systems produce consistent results, allowing engineers to focus on opportunities for improvement.

Through real-time capabilities, automation based on Intel® architecture provides a competitive advantage by using IoT and edge computing in manufacturing. Intel's investment in real-time data and automation provides significant value to the products we create.

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Acronyms

GEM	Generic Equipment Model
HMI	human-machine interface
IoT	Internet of Things
MES	Manufacturing Execution System
SECS	SEMI Equipment Communications Standard
SEMI	Semiconductor Equipment and Materials International
SSD	solid-state drive

Intel's Long-Term Vision of Automation

Manufacturing automation and the effective use of data are central elements of Intel's competitive strategy. Factory management has evolved from manual processes toward the goal of being 100 percent automated. Our vision for smart manufacturing is based on the realization that all types of data—real-time and big data—can help improve capabilities in the factory and increase efficiency. Smart manufacturing relies on real-time data from edge computing in automated process control as well as big data that is derived for ongoing analysis and decision making. Big data is instrumental in successful factory automation that leads to improved productivity and quality.

Intel's investments in people, processes, and technology are integral in making Intel a leader in factory automation, dramatically decreasing costs and increasing year-over-year manufacturing safety, uptime, output, and product quality. To achieve this sustained improvement, Intel had to lay a foundation for success as well as identify ways to measure performance.

Laying the Foundation for Success

Developing standards for controlling equipment and using data in automated decision making began decades ago when Intel factory technicians manually carried products between factory tools and used handwritten methods—manual processes that introduced possibilities for defects. Using guidelines consistent with Semiconductor Equipment and Materials International (SEMI), Intel standardized its automated systems, software interfaces, and tools, including interoperability with important vendors.

Intel IT supported the automation of Intel's assembly-and-test and wafer-fabrication factories by focusing on the following capabilities:

- **End-to-End Infrastructure.** The infrastructure comprises a robust IT network of servers, network-attached storage (NAS) and storage-area network (SAN) data storage devices, and clients on the factory floor as well as standard software and hardware protocols.
- **Factory floor.** Automated materials handling systems in Intel's wafer-fabrication facilities are installed and precisely tuned for managing direct and indirect materials and performance. These automated systems also provide traceability for work-in-process and finished materials as they move through the process flow. Additionally, these systems eliminate the need for manual processes previously performed by workers, which improves safety on the factory floor.
- **Manufacturing Execution System (MES).** Intel IT uses an MES at each factory to track equipment and material production state for each process step. Equipment and material transactions are mainly handled by the MES, which orchestrates the rest of the automation system. Data from the MES database is replicated to offline data storage for further decision support and reporting uses in the factory.

6 Areas of Support

Intel IT supports the automation of Intel's assembly-and-test and wafer-fabrication factories through:

- Infrastructure
- Factory Floor
- Manufacturing Execution Systems
- Decision Support
- Human-machine Interface
- Engineering Analysis

- **Decision support.** Smart—or automated—decision making stores, monitors, and analyzes off-line big data derived from the manufacturing floor, work-in-process tracking, product-test results, equipment states, and failure bins. This process helps to determine performance improvements using direct-trend monitoring, categorization, and complex statistics and machine-learning analytics.
- **Human-machine interface.** Where humans interact with machines, processes are analyzed for automation opportunities. We standardize the user experience for human-machine interface (HMI) to ease the transition for operators between machines.
- **Engineering analysis.** After-the-fact analysis of big data captured from automation processes helps identify opportunities for improved efficiency, velocity, and quality as well as identifying additional areas to automate.

Manufacturing management is transitioning away from manually running production tools and moving toward the principles of Industry 4.0[1] using edge computing and IoT to extract and transform data into actionable information, making data a competitive advantage for the factory. By segmenting the work into specific areas of focus, we have transformed Intel factories from a pen-and-paper process to data automation and smart manufacturing.

Measuring Performance

The rapidly increasing pace of decision making, as well as geographically distributed workers and activities, add to the complexity of today's work environment. It is crucial in smart manufacturing to be able to measure and characterize every aspect of the manufacturing process, from products to machines and processes, without scrambling to consolidate data. A consistent and detailed strategy for collecting, analyzing, and categorizing data is essential. At Intel, machines collect and log parameters such as alerts, measurements, and settings in real time so that any deviation can be quickly acted upon. Parametric data is recorded during processing at every operation, and the ID and state of every unit is stored for traceability.

Intel aims to maximize efficiency in all its factories. However, reaching this goal requires more than real-time process control; big data needs to be used for optimized factory flow, predictive maintenance, and pervasive robotics and tool control.

When analyzing big data, Intel focuses on the following performance measures:

- **Efficiency.** True operational efficiency is measured by input (operational costs) as well as output (revenue, customer satisfaction, and quality).
- **Velocity.** Velocity is derived from three key measures—lead time, amount of work-in-process, and the average completion rate per process.
- **Quality.** Automated process products, such as silicon wafers, adhere to strict quality standards. Measuring quality, including traceability, is critical in understanding the overall efficiency of the process.

[1] For more information about Industry 4.0, go to www.mckinsey.com/business-functions/operations/our-insights/manufacturings-next-act

For these three measures—efficiency, velocity, and quality—factories extract data from various sensors, such as real-time location-sensing tags that track products at every step of the manufacturing process, and transform that data into off-line big data. This data can help us implement improvements that result in more consistent quality and faster time-to-market.

Intel's Smart Factory Today

Intel's smart factories are designed to make it easier to collect data by developing reusable, modular automation software, which in turn helps engineers analyze and act on the information. We participate in the creation of industry standards, such as SEMI Equipment Communications Standard (SECS) and the Generic Equipment Model (GEM) that are used to start and stop equipment processing, collect measurement data, and change variables. These standards have been adopted by our equipment vendors, which improves compatibility. Intel IT transforms data extracted from the factory floor into actionable information for ongoing analysis and decision making.

Putting Data to Work

Intel's smart factories run 24/7, using mission-critical decision-support reporting and analytics solutions. Operations personnel can monitor factory inventories, velocity, equipment statuses, and output in real time. And standardized collection and analytics tools provide consistent calculations that migrate easily between tools so engineers can spend more time working on solutions without being concerned about the accuracy and compatibility of the data.

Intel uses IoT gateways and sensors in its factories to collect and analyze data (Figure 1). That data is used to improve automation, such as defining the control limits that produce high-quality results within a process. For example, by connecting an external IoT gateway to collect vacuum data on its ball attachment module process, Intel was able to correlate sensor readings with various machines and execution systems. Decisions based on the data resulted in increased yields and predictive maintenance capabilities that reduced machine downtime.

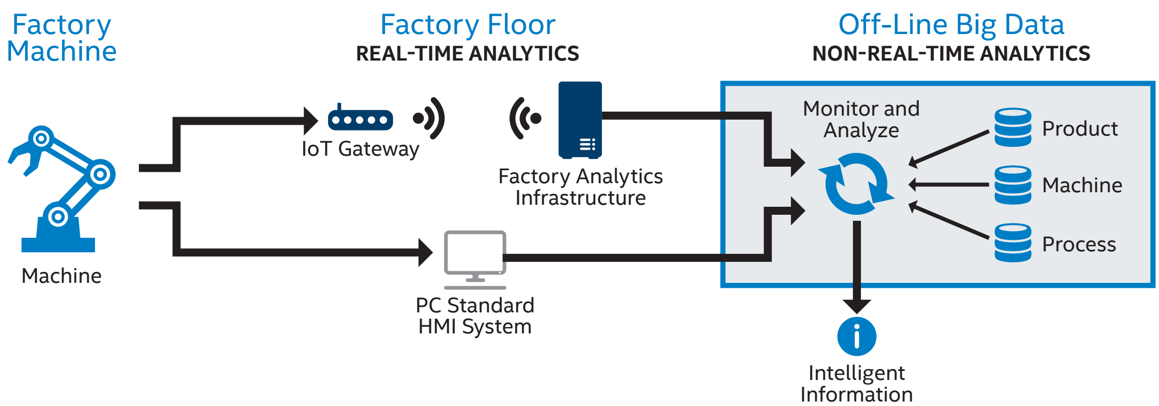

Figure 1. Data from edge computing and Internet of Things (IoT) is extracted for real-time analysis on the factory floor as well as big data analysis in off-line databases. Engineers have relevant statistical data at their fingertips at all times.

Intel's manufacturing process relies on real-time work-in-process and process-control data to manage factory operations and track goods and materials. Factory machines communicate with HMI systems using standard SEMI protocols. Through the HMI systems, client desktops orchestrate materials processing by sending commands and responding to replies from the machine. A middleware layer acts as central management for rules and logic. This middleware layer also communicates with backend components that track work-in-process and product specifications. The data from these processes is extracted to off-line databases for analysis and decision making. All of this occurs in a secure environment using Intel® architecture that is resilient, flexible, and cost-effective.

Information is analyzed by engineers from three perspectives:

- **Historic state**. Understanding what happened and why it is necessary to prevent issues in the future and to identify opportunities for better future decision making and new automation.
- **Current state**. Real-time process control, or on-the-fly management, responds to alerts and identifies anomalies. Under certain circumstances, the system may even shut down a tool automatically. The information gathered is further analyzed for opportunities to improve automation.
- **Future state**. Historic and current data are used in combination to plan and implement new or improved automation for better quality, cycle time, and yield in the factory. Engineering analysis targets product quality improvements as well as increases equipment performance over time.

To every extent possible, Intel uses big data to refine automated processes to allow employees to focus on innovation and problem solving. These automated processes fall into one of the following categories:

- **Advanced process control**. Incremental changes are made to processes automatically, adjusting them based on incoming information; for example, monitoring climate for temperature- and humidity-sensitive processes. This real-time feedback is also extracted for use in proactive automation designed to prevent the same issues from occurring in the future.
- **Statistical process control**. When processes exceed statistical thresholds, production tools are taken off-line and materials are rerouted or put on hold for quality validation. Engineers intervene to determine the cause and correct the issue based on data analysis.
- **Fault-detection classification**. Frequent process data samples are compared against expected process results to identify deviations. If deviations exist, a production tool may be taken off-line and materials can be automatically routed to redundant tools or put on hold for quality validation. The process engineers can then analyze the data.

As Intel improves factory automation to enhance performance, Intel IT looks for ways to innovate within established processes. We continuously improve IT infrastructure with rapid response and high-volume data transfer capabilities through advanced high-speed networks, servers, and storage. We proactively use pervasive application instrumentation, real-time indicator dashboards, alerting on configurable thresholds, automatic event correlation, and corrective action for consistently repetitive events drawn from big data.

Investing in Innovation

Intel's successful transition to the smart factory is largely due to its culture of innovation. Factory systems change frequently and Intel is constantly introducing improved processes and equipment, new run rules, and better data analysis tools. Intel's culture of innovation helps employees expect and embrace these changes as a part of the improvement process.

But measurable improvement requires more than change for change's sake. To achieve the best results for Intel's business, Intel IT prioritizes changes using the following three criteria:

- **Technology**. We adopt technology when it has value, such as refreshing servers to take advantage of Intel® Solid-State Drives (Intel® SSDs) for frequently accessed data and installing performance-rich clients equipped with Intel® Core™ i5 and Intel® Core™ i7 processors as intelligent host controllers. We also use Intel's "Copy Exactly!" methodology to transfer existing, proven processes onto new technology to maintain what works. For example, after a proof of concept illustrated the way Intel® vPro™ technology reduced deskside support visits, we deployed it to additional areas of the enterprise.[2]
- **People.** In the challenging manufacturing environment, balancing the use of data to automate decisions that minimize cost and maximize profit against the human aspect of business requires a commitment to people. Intel invests time and money in ongoing training to meet the constant demand for additional skills required to manage new technology. Intel also rewards innovative thinking that challenges the status quo with ideas that improve processes and product quality.
- **Processes.** Our factories produce enormous volumes of data through automation systems, which are used to improve process quality and equipment uptime. We constantly analyze this data for opportunities to improve processes with incremental changes or new automation. Ultimately, process automation must deliver the highest output for the lowest overall cost.

Intel's culture of innovation is integral to the decision making process. Whether it involves technology, people, or processes, the ultimate goal is improvement.

Factory automation has created a natural transition for personnel away from the factory floor and into data-centric roles. Manufacturing technicians, who worked on the factory floor in the 1980s, can now operate fully automated factories from remote operation centers anywhere in the world. Intel's culture of innovation encourages employees to challenge the status quo, as is evident in its commitment to lean manufacturing principles. With established methodologies designed to single out processes for analysis and improvement, we have enabled regular updates to the IT infrastructure that provide stability on the factory floor.

While not everything in a complex environment can be automated, where work is routine, automation makes sense. Where complex work is nonroutine, Intel IT provides advanced, flexible decision support. Lean manufacturing also helps define the boundary between stability and change. When it comes to manufacturing, stability and innovation are both important. The data we collect and analyze allows us to achieve continuous improvement. A look at factory transformation from the last 30 years (Figure 2) reveals a steady migration toward automated processes, robotic material transport, equipment standardization, predictive and adaptive maintenance, and advanced decision making. Edge computing, IoT, and big data provide the necessary platform for this transition.

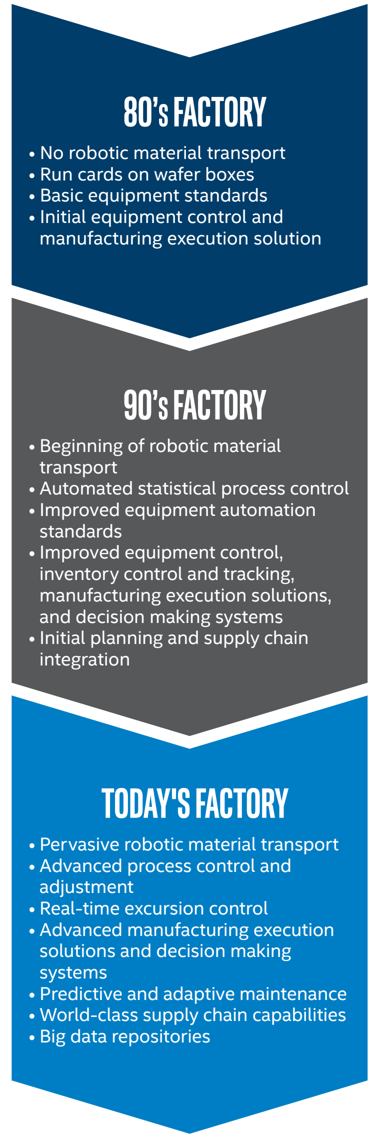

Figure 2. Today, Intel's smart factories use big data repositories and advanced analytics to deliver information to achieve improvements to the factory environment. Intel's world-class supply chain capabilities rely on big data for inventory control and tracking as well as standardization.

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[2] For more information, see the IT@Intel brief "Managing a Factory IT Environment with Intel® vPro™ Technology"

Year-over-Year Efficiency Gains

Intel's smart factory automation shows consistent year-over-year gains in efficiency in three key areas:

- **Increased uptime**. Our analytics system interacts with data and investigates possible actions that reduce quality and labor costs as well as improve yield and time-to-market. By receiving the right data in the right format, engineers use critical metrics, such as fault detection, to track equipment performance and make decisions that increase uptime.
- **Accelerated output**. Real-time data provides insight into performance dynamically, identifying possible actions as issues arise. Proactive real-time data analysis and subsequent actions have saved millions of potentially wasted dollars. Real-time monitoring leads to shorter cycle times, greater tool availability and labor efficiency, which accelerate output (Figure 3).
- **Decreased faults**. Tool sensor data makes it possible to detect and control faults with more precision. Reporting tools allow engineers to differentiate between critical and noncritical errors, enabling them to focus on the most meaningful improvements within the manufacturing line. Instead of looking at thousands of graphs, technicians can prioritize the top issues, preventing faults from reoccurring in the future. Decreased faults improve equipment availability, which leads to a higher yield.

Through Intel IT's commitment to continuous improvement, we keep our IT systems 99.99 percent available on mission-critical manufacturing production flows.

As we integrate more automated systems, Intel uses big data to continuously refine its processes and seek new areas to automate. Process automation enables Intel's smart factories to be more flexible, run custom product variants based on customer requirements, introduce new products more quickly, and run multiple production processes

Real-Time Monitoring Using Data Analytics

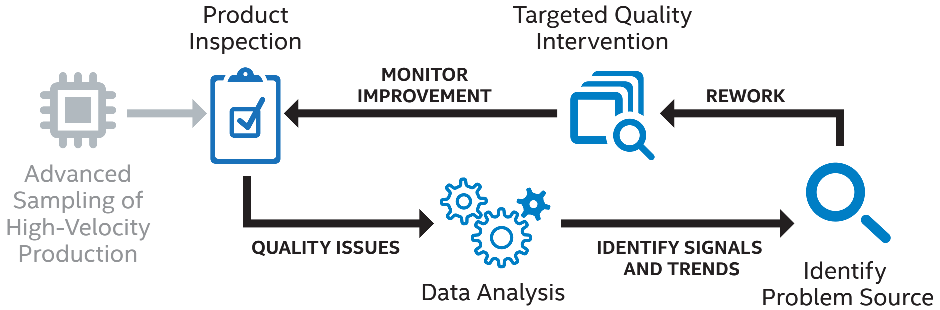

Figure 3. Quality rules are applied to real-time process data to determine whether material is viable to continue production, whether it requires rework, or whether it should be scrapped. Rapid responses to problems also increase uptime, accelerate output, and save money.

How Automation Transforms the Intel Workplace

Manufacturing automation has dramatically transformed work practices at Intel. The virtualized workplace empowers people to be productive anytime, anywhere.

Technology is one enabler of change in the way that work gets done in Intel's smart factories:

- **Advanced collaboration**. Geographically dispersed workers solve problems and share information without the barriers of tool compatibility. Social collaboration tools have opened the door to highly relevant information sharing and faster decision making.
- **Productivity**. Simplifying workflows through automation and providing targeted, categorized, and prioritized information frees workers to focus on the most important decisions in the manufacturing processes.

But technology alone doesn't account for all of Intel's gains in factory automation. Intel IT also helps people change the way they work in concert with new technology as a critical factor in realizing higher product quality, improved production velocity, decreased faults, and better yields.

simultaneously. The automated factory meets the goals of customer deliveries and competitive advantage through increased output and higher product quality.

Conclusion

Modern factories are becoming more complex and interconnected, creating new challenges that automation can address—areas like quality control at the individual machine, inspection points, and data-analysis stage. Intel's smart factories rely on the ability to transform data into actionable information.

Intel's manual manufacturing processes have evolved with automation and big data analysis. Materials are now delivered to the right place at the right time through analysis of downstream capacity and timelines using data-enabled algorithms.

Intel's factory automation has produced significant returns from its investments in technology, people, and processes. Intel IT continues to use its culture of innovation and Intel architecture to improve factory automation. In addition to traditional factory automation systems, we are using real-time data from edge computing and IoT to automatically adjust manufacturing processes as necessary and allow factory engineers to focus on the most relevant information. Big data resulting from edge computing and IoT has enabled Intel's smart factories to rapidly increase its efficiency and realize significant benefits in increased uptime, accelerated output, and decreased faults.

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Our goal is simple: improve efficiency throughout the organization and enhance the business value of IT investments.

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