WHITE PAPER
JUNE 2018

IT@INTEL

Developing a Scalable Predictive-Maintenance Architecture

Robert Colby
Principal Engineer,
Intel IT Infrastructure

Stephanie Cope
Yield Engineer, Technology and Manufacturing, Intel

Steven J Meyer
Sr. Principal Engineer,
Intel Manufacturing IT

Shai Monzon
Industrial Manufacturing Engagement Manager, Intel IT

Ravinder Singh
Strategic Engagement Manager, Industrial Solutions Division, Internet of Things Group, Intel

Eric Xiaozhong Ji
Engineer, Technology and Manufacturing, Intel

Executive Overview

To gain and maintain a competitive advantage in today's world, manufacturers from all industries are turning to Industrial Internet of Things (IIoT) technology. IIoT can help identify excursions[1] in standard processes, prevent unscheduled downtime due to tool failure, decrease overall maintenance costs, and improve productivity. But implementing IIoT solutions can be challenging.

Intel has used IIoT in our factories for years, and our solutions are often built on existing tools and processes. As we continue to learn, we now focus on connecting the unconnected and interconnecting intelligent devices to reduce strain on our network. In addition, we develop autonomous functionality that moves capabilities to the edge. Our goal is to design solutions that achieve interoperability and scalability that meet our needs today and in the future.

In early pilots, we reduced unscheduled downtime due to fan filter unit (FFU) failure by 300 percent over manual inspection.

When we designed a new use case to monitor the health of our fan filter units (FFUs) with predictive maintenance, our goals included minimizing data volumes across the network, defining baselines for FFUs, alerting technicians to potential problems in real time, and more accurately predicting maintenance needs. We partnered with GE Digital to develop a solution based on Intel® Internet of Things (Intel® IoT) Gateways and GE's Predix* platform that performs analytics at the edge, while collecting summary-level data for long-term trend analysis in the cloud.

Successful implementation of our FFU solution includes these benefits:

- Improved operations on factory floor
- Fewer excursions
- Better visibility
- Less unscheduled downtime

FFUs represented a process small enough in scope, and large enough in impact, to demonstrate the positive return on investment (ROI) of predictive maintenance and the scalability of the solution. In early pilots, we reduced our unscheduled downtime due to FFU failure by 300 percent over manual inspection. The solution also provides a foundational platform that we can scale to more complex implementations in the future.

[1] Excursions indicate undesired changes in the manufacturing process that result in significant damage to materials.

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Acronyms

AI	artificial intelligence
FFU	fan filter unit
IoT	Internet of Things
IIoT	Industrial Internet of Things
MQTT	Message Queuing Telemetry Transport
PaaS	platform as a service
ROI	return on investment

94%
TRAFFIC REDUCTION

IoT analytics and data summarization can reduce cloud traffic by nearly 94 percent.[2]

[2] Results based on Intel internal testing.

Background

Intel's factories are some of the most advanced in the world, with thousands of process and automation clients on the factory floor, hundreds of analytics servers in the data center, and hundreds of thousands of feet of fiber for transmitting data. Manufacturing semiconductors entails a degree of precision that not every factory requires. But all modern manufacturers can benefit from better understanding the health of their tools and processes. Industrial Internet of Things (IIoT) solutions can help overcome these common problems:

- **Excursion.** An excursion in the manufacturing process, due to failing tool components, can impact yield and forecasting, making it more difficult for the factory to meet goals and objectives.
- **Unscheduled downtime.** Without visibility into the health of all parts of a tool, it is difficult to predict maintenance needs, resulting in unscheduled downtime and less productive workers.
- **Higher cost of maintenance.** When tools unexpectedly fail, in addition to the loss of productivity, repair costs increase due to expediting parts and the impact of secondary failure modes.
- **Labor-intensive processes.** Relying on the labor-intensive process of having humans visually check tool health can be costly over time. In the past, technicians placed a hand on the fan to determine if it was spinning differently from the previous day. The lack of data made it difficult to identify anomalies and increases the risk of error.

Implementing IIoT solutions can be challenging. Intel has been using IIoT for years, for a variety of processes, but we needed a new process to monitor the health of our fan filter units (FFUs)—which are ubiquitous in the factory (see Figure 1)—to better understand trends and predict failure. We also wanted to maintain a high degree of security and move analytics to the edge to reduce the amount of data transmitted across the network. We partnered with GE Digital to co-develop a highly scalable solution using Intel® Internet of Things (Intel® IoT) Gateways and GE's Predix* platform.

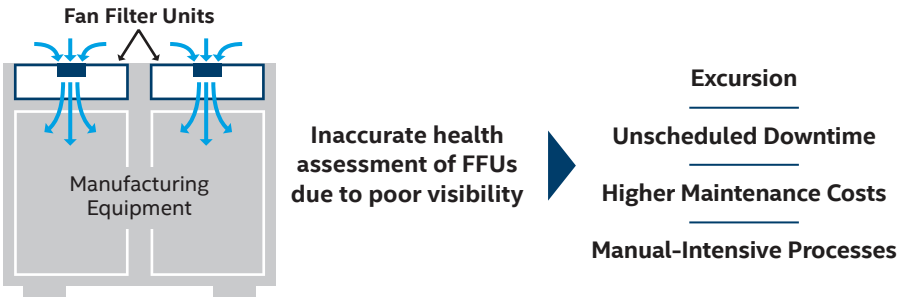


Figure 1. Manufacturing equipment often includes fan filter units (FFUs), which draw in fab air and push it through high-efficiency particle filters. This keeps the air inside the machine cleaner by filtering it and reducing particles in the machine's clean chambers. Detecting FFU health is often a manual process, which makes predicting failure difficult.

Solution

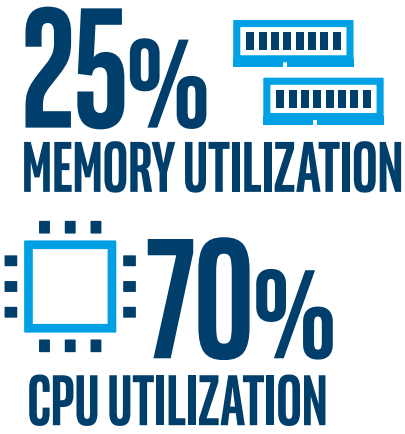
At Intel, we have learned the importance of connecting the unconnected to enable data generation and collection, driving edge analytics to deliver real-time insights, and using IIoT and artificial intelligence (AI) solutions to push filtered data to the cloud. Intel IT selected FFUs as an excellent use case for predictive-maintenance IIoT using edge-to-cloud technologies to store manufacturing data off-premises. FFUs represent a single process that is small enough in scope, yet large enough in impact, to demonstrate return on investment (ROI) in the factory. We used Intel IoT Gateways with GE's Predix platform to achieve this. Our goals included the following:

- **Edge processing.** We implemented edge analytics to limit the amount of data transmitted across the network and to the cloud.
- **Reporting.** We needed to identify the long-term behavior and trends of each FFU through traditional reporting—statistics, graphs, and charts—based on summary data. Essentially, our data collection and research needed to provide fan vibration fingerprints in various states for analyzing changes.
- **ROI.** We selected FFUs because they represent a stand-alone process and are exceptional for demonstrating the ROI potential of an edge-computing and cloud-based IIoT predictive-maintenance solution.

We evaluated several products, and GE's Predix platform met the requirements of our solution. It also provided a high degree of security that met our criteria for storing confidential intellectual property data. The FFU solution included the following:

- **Sensors.** We installed an accelerometer at the top of each FFU to measure variations in the fan's function, creating a baseline for each fan that allowed us to compare behavior across the tool and fleet.
- **Edge integration.** We integrated the accelerometers with Intel IoT Gateways and edge applications using GE's Predix platform. We then developed an edge architecture compatible with running machine-learning algorithms. This process created a baseline performance for each FFU, measured changes, and generated alerts for anomalies and potential problems. Alerts were sent to the cloud, and from there technicians were notified.
- **Cloud-based visualization.** We transmitted summary data to GE's Predix platform in the cloud to give tool owners a view into baselines and long-term trends in traditional, easy-to-use report formats.

We use our gateways for edge analytics to reduce the amount of data we send to the cloud. Software on the gateways use the algorithm inference to identify signals that predict failure. We send only these signals to the cloud to alert the technician that the fan needs to be replaced. Our edge workload utilizes 25 percent memory and 70 percent CPU, with network traffic of 15 GB per day.[3]



Our edge workload utilizes 25 percent memory and 70 percent CPU, with network traffic of 15 GB per day.[3]

[3] Results based on Intel internal testing.

We also used this design to provide technicians and tool owners with real-time summary alerts and statistical reports for long-term planning (see Figure 2).

We used the trend data we collected from the FFUs to predict failure more accurately and help avoid unscheduled downtime, increase worker productivity, and reduce the cost of replacement parts through better planning. The potential value of automatically detecting failures in other common sub-assemblies spans the entire manufacturing process, and the FFU solution has allowed us to validate the output and demonstrate positive ROI. The scalable, interoperable platform can be applied to more complex implementations in the future.

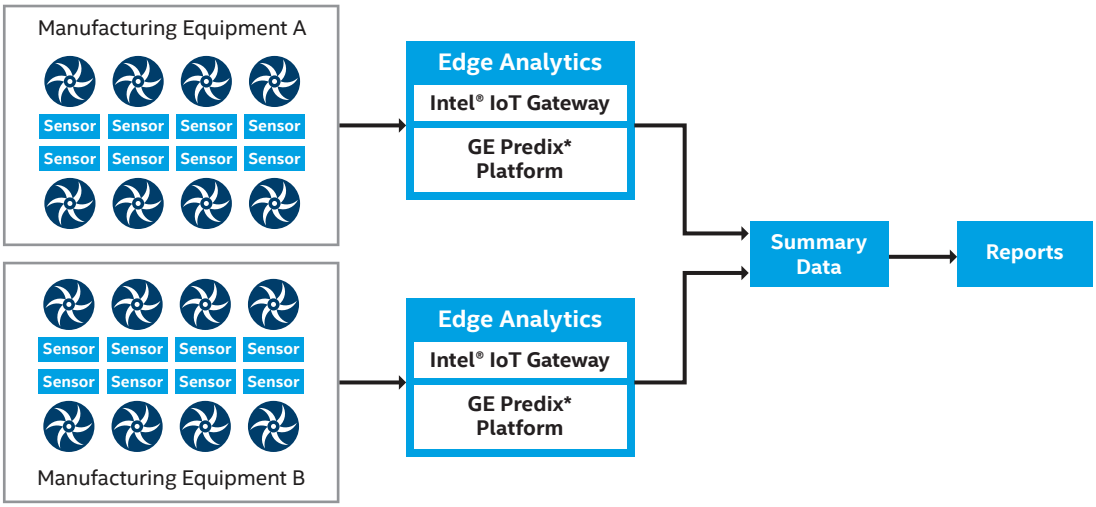


Figure 2. We installed sensors on each fan filter unit (FFU) to measure vibration and transmit that data to the edge application. We then employed an edge architecture compatible with running machine-learning algorithms to generate real-time alerts based on inconsistencies and potential problems.

Benefits

Our IIoT solution for FFUs provides the following benefits:

- **Improved factory floor operations.** Understanding the health of equipment is critical to energy efficiency, forecasting, yield, and worker productivity. We have increased FFU uptime by over 97 percent by ordering replacement parts upon potential failure detection and proactively replacing them before the failure occurs.
- **Decreased excursions.** Detecting FFU inconsistencies helps avoid one of the leading causes of excursion in the process. Our solution has allowed us to order replacement FFUs in advance, and in those instances, we have experienced no excursion and no impact to product.
- **Improved visibility.** In the past, failures were manually identified. Now, our technicians and tool owners can use summary data to more quickly identify changes in FFU health.
- **Reduced unscheduled downtime.** Better visibility allows us to predict maintenance needs before FFUs fail, helping to avoid unexpected downtime and loss of worker productivity. We have reduced our unscheduled downtime by 300 percent over manual inspection. Based on the prediction of upcoming FFU failure, the FFU is now ordered days ahead and we can plan for downtime.

Lessons Learned

Intel IT has been implementing IIoT solutions for years, and we have learned what common issues to consider when undertaking a manufacturing solution. Advanced planning can lead to a faster, more flexible deployment, and address the following:

- **Security.** Securing data both on- and off-premises is critical, especially in our ever-changing world. Our FFU solution uses GE's Predix platform because it meets our overall criteria, including storing sensitive intellectual property data. Intel IoT Gateways also include hardware-level security from edge to cloud that not only protects, but also detects and corrects security issues.
- **Data volumes.** Today's industry is data driven, and automated solutions generate enormous volumes of data that can slow networks and present storage challenges. It is important to develop a management strategy to handle these data volumes. We initially sent all FFU data to the cloud, but quickly understood that it was too much. By moving compute to the edge, our FFU solution reduces the amount of data transmitted across the network, including summary-level information for long-term analytics. Leveraging IoT edge analytics and data summarization can reduce cloud traffic by nearly 94 percent.[4]
- **Data structures.** IIoT solutions collect information from a variety of tools, produced by different providers. Each one can have its own unique data structure, which must be standardized in order to fully understand the processes and health of the tools. We standardize all data collected prior to integration so that our measurements and analytics are consistent across tools and providers.
- **Data validation.** When our FFU solution first uncovered potential problems, technicians were initially skeptical about accuracy. But testing and validation quickly confirmed the accuracy of the solution and gained technicians' trust in IIoT. IIoT technology for predictive maintenance is still new, and over time, with continuous input and fine-tuning, the accuracy of the results will improve. Technicians and solution architects will learn to trust predictive analytics by measuring and validating the output.

[4] Results based on Intel internal testing.

Defining Measurable Success Criteria

With any Industrial Internet of Things (IIoT) solution, defining measurable success criteria is critical. For fan filter units (FFUs), we used the following to evaluate the overall success of the implementation:

- **Hard failure.** Our goal was to detect 100 percent of hard failures within five minutes of failure, while minimizing false positives.
- **Soft failure.** Our goal was to detect 80 percent of potentially faulty fans that had not yet failed (soft failures) within 24 hours, while minimizing false positives.
- **Baseline.** We defined a baseline—or fingerprint—of a healthy FFU that could be used in detecting hard and soft failures.
- **Sensors.** The solution needed to support up to 10 accelerometers per tool with a sampling frequency of 1 kHz (1,000 data points per second).
- **Scalability.** The solution needed to scale to hundreds of tools with thousands of sensors without impacting our infrastructure, such as overloading the network with data transmissions.
- **Compatibility.** Our user interface for data extraction and analysis had to be compatible with approved mobile devices for integration with current factory operations.
- **Edge processing.** The solution needed to analyze data at the edge and single out only signals that predict failure before sending them to the cloud.

Architecture

Intel® technology allows us to reuse existing software and connect tools that may or may not have been designed for IIoT. The open, interoperable platform works with our existing data center software, and enables performance at the edge at a lower cost. Using Intel IoT Gateways and GE's Predix platform (see Figure 3), the FFU solution offers the following:

- **Scalability.** Standardized data structures, reduced bandwidth requirements, and cloud storage provide excellent scalability to multiple FFUs and other manufacturing processes.
- **Security.** Our high-security solution allows us to protect the data, both in the factory as well as the cloud. Cloud-based platform as a service (PaaS) security decisions require a thorough vetting of over 100 security data management policies.
- **Performance at the edge.** The Intel Atom® processor E3800 product family—system-on-chip (SoC)—delivers outstanding compute, graphical, and media performance while operating in an extended range of thermal conditions compared with previous-generation Intel Atom® microarchitecture.[5]
- **Interoperability.** Using the Message Queuing Telemetry Transport (MQTT) lightweight connectivity protocol, we can connect power-constrained devices. Designed for low-bandwidth networks, it allows smooth connection between devices to the cloud.
- **Open platform.** Open source embedded products allow us to use the latest code and the most recent technologies.

[5] intel.com/content/www/us/en/embedded/products/bay-trail/overview

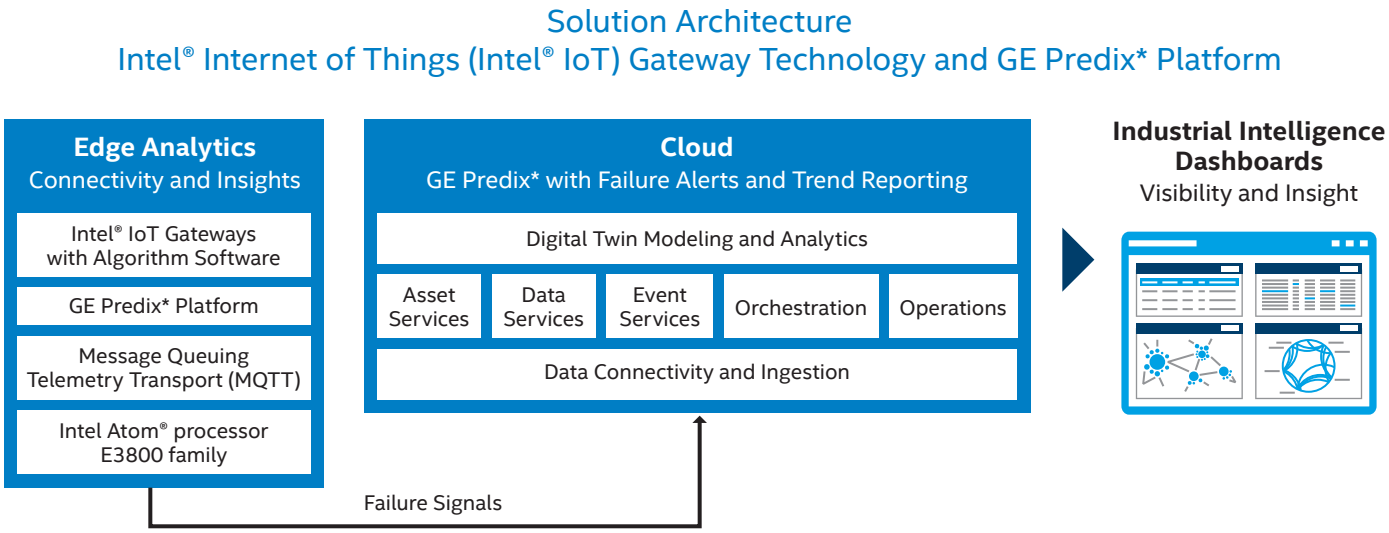


Figure 3. Intel® Internet of Things (Intel® IoT) Gateways and GE's Predix* platform solution provide scalability, security, interoperability, and performance at the edge.

Next Steps

The scalable, interoperable framework we developed for the FFU process creates a foundation that can be used in a variety of other IIoT use cases in the factory. For example, we plan to scale this solution to include detecting anomalies in electro-mechanical devices and other manufacturing processes. Additionally, Intel is now partnering with GE to work with OEMs and suppliers to learn how a partnership approach, along with external domain expertise, can further enhance the value of this IIoT solution across Intel's supply chain.

As Intel looks to scale globally, we will explore leveraging Predix* Asset Performance Management (Predix* APM) solutions to centrally view and manage our tools and assets.

Conclusion

When Intel created a new use case to monitor the FFUs and better predict health trends before failure, we needed a solution that maintains a high degree of security, performs analytics at the edge, and minimizes the amount of data transmitted across the network. We were able to achieve these goals by using Intel IoT Gateways and GE's Predix platform.

Selecting FFUs as our first cloud-based predictive-maintenance solution also allowed us to demonstrate ROI with a single, ubiquitous process. Through data standardization, partnering with industry experts, and setting measurable goals, our FFU IIoT solution has allowed us to develop a foundation for edge-to-cloud IIoT computing that can scale to other processes and tools in the factory. This new solution has helped us experience a 300 percent decrease in unscheduled downtime over manual FFU monitoring, improving productivity and optimizing operations.

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For more information about the partnership with GE, visit **intel.com/GE**.

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