Smart Factory Applications in Discrete Manufacturing

An Industrial Internet Consortium White Paper

Authored by the Smart Factory Task Group

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1 EXECUTIVE SUMMARY

As the world of traditional manufacturing fuses with information technology, organizations are tapping into a level of technical orchestration never attainable before. Symphonies of systems facilitate real-time interactions of people, machines, assets, systems, and things. This is the Smart Factory; the factory ecosystem of the future. It is an application of the Industrial Internet of Things (IIoT) built with sets of hardware and software that collectively enable processes to govern themselves through machine learning and cognitive computing.

The result is a level of lean operations that was previously impossible to achieve. Downtime is predicted and prevented, waste and defects are eliminated, surplus production is minimized, machine behavior is optimized as conditions change, and systems can make context-based 'next best' actions. Connected devices in the factory report their status, giving operations personnel and decision-makers access to real time, actionable information. Wearable technology tracks employee location and status in case of emergency. A global ecosystem of partners ensures that specific parts are replenished based on automated, real time needs analysis. The list of applications goes on. But significant challenges remain in assessing, implementing, and operating IIoT systems.

All incremental value of a Smart Factory system is based on your ability to accomplish three objectives:

1. **Aggregate** a broad array of data from your equipment, as well as relevant internal and external systems.
2. **Analyze** the data to generate information that can be used to inform operational and business decisions.
3. **Act** on your new insight by automating processes, optimizing systems, and informing business strategy.

The development of powerful yet affordable edge and cloud computing technologies provides companies with the storage and processing capabilities to aggregate, analyze, and act on data. Scalable clouds aggregate the flow of big data. Meanwhile, analytics is increasingly performed on the edge in gateways, inside controllers or in miniature data centers located in facilities. Analytics software cross-analyzes diverse data streams to generate actionable information and unanticipated insight. And the results are shared from the cloud and edge processors to operators, equipment, and enterprise software to drive action.

Industrial Internet Consortium (IIC) member companies such as Bosch, National Instruments, Cisco, and TechMahindra are deploying Smart Factory solutions to help companies realize these benefits:

- **Increased Shop Floor Visibility:** Greater insight into the production floor enables issues to be identified and addressed before they occur to improve quality control, equipment uptime, and maintenance scheduling.
- **Intelligent Supply Chain Management:** Sensors, such as radio frequency identification (RFID) tags, allow inventory monitoring and process automation.
- **Decreased Total Cost of Ownership:** Smart grid technology predicts and optimizes power consumption, IoT-enabled heating, ventilation and air conditioning (HVAC), and load balancing.
- **Streamlined Human Resources:** Continuous data means continuous analysis, risk assessment, and process coordination resulting in fewer field service calls, remote monitoring and diagnostics, and proactive equipment maintenance. Reducing routine work allows your teams to refocus on value adding activities.
- **Reduced Environmental Impact:** Sensor networks and machine learning enable factories to improve efficiencies of energy and material inputs, while better monitoring outputs to ensure regulatory compliance.
- **Increased Profitability:** Together Smart Factory optimizations are leading to better operational results, new business opportunities, cost savings, and increased revenues for early adopters.

The Smart Factory is an elaborate, calculated composition that has been years in the making and that will continue to evolve over the coming decades. Members of the Industrial Internet Consortium are delivering manufacturing-centric testbeds to prove out collaborative innovations developed across industries and functions. This whitepaper explores some of the key challenges and best practices that you should consider as you evolve your Smart Factories.

This white paper was written with mid-sized brownfield operations in mind. Greenfield planning is (relatively) simple. But what if you have a traditional factory with old machinery? In previous decades, only industrial giants were able to invest in connecting sensors, controllers, and data analytics. Today, the cost of sensors, connectivity, and analytics software has plummeted, making it possible for every operation to upgrade, retrofit, and prepare for digital automation. The process to becoming a Smart Factory is a journey. Companies that delay may find themselves out-competed, out-classed, and out of business.

The Internet of Things (IoT) has become everyday jargon, but how does it relate to Smart Factories? It’s simple – the first three industrial revolutions were powered by steam, electric energy, and electronics. Today’s Industrial Revolution is powered by data. And that data comes from the “things” that fill your factories and supply chains. Sensors, controllers, edge-computing nodes, and devices all talk to one another and to the cloud in order to turn data into insight and insight into action. These “things” possess varying levels of processing functionality, ranging from simple sensing and actuating, to control, optimization, and full autonomous operation.

The Smart Factory is one aspect of a Smart Enterprise managed by connected assets and humans operating in conjunction through "systems of systems." Importantly, the systems that impact your Smart Factory will not all be internal. External systems from weather networks, suppliers, logistics partners, and technology providers share data with internal systems to drive insight and to coordinate action. System linkages rely on standardized Internet and network protocols that enable secure access to information over cloud and fog platforms. Systems that do not communicate in a standardized language cannot share data to create business value.

2 Industrial Applications – Where is the Business Value?

IoT technologies do not impact factories in isolation. They also impact manufacturers' customers, suppliers, value chain partners, competitors, and employees. Customer expectations regarding product, warranty, payment, and service are changing rapidly. Suppliers and partners create, deliver, and capture value in new ways. New competitors from seemingly unrelated fields may enter your markets with innovative value propositions. And the skill sets of your employees must evolve to match your business transformation.

These and other changes have created challenges as well as opportunities for manufacturers. Several challenges are now, more than ever, on the minds of manufacturing organization executives:

1. *Customer expectations* for increasingly complex and customized products and services
2. *Business model disruptions* like "Manufacturing-as-a-Service" changing the value chain
3. *Rapid change* from accelerating innovation cycles and time-to-market expectations
4. *Productivity plateaus* in developed economies due to the lack of young, skilled labor
5. *Regulatory pressure* driving energy efficiency and pollution-reduction targets
6. *Rising input costs* as population growth drives up labor, land, and raw material costs
7. *Globalization* resulting in factories, vendors, and customers distributed across borders

IIoT technologies are not a miracle solution for all challenges facing manufacturers. In fact, many of the core technologies have been in use for decades. However, falling hardware and connectivity costs, coupled with rapidly improving data analytics, is enabling a broad array of use cases that were previously impossible or unaffordable. Consider, for example, dynamic industries like consumer electronics where a delayed product release can significantly reduce sales and margins. The "sashimi theory," coined by Yun Jong Yong, former CEO of Samsung Electronics, notes that fresh raw fish can be sold at a premium in an expensive restaurant; the next day, the fish can be sold for half the price at a second-tier restaurant; on the third day, the fish sells for one-quarter of the original price; and after that it is cat food.[1]

[1] Pete Engardio and Moon Ihlwan, Business Week, Samsung's Sashimi Theory of Success

Consumers are unwilling to pay premium prices for a product that lost its fresh appeal. To avoid commodity pricing, industries from fashion to frozen food are innovating and launching products faster. There are several ways in which the IIoT can shorten time-to-market and help companies maintain competitiveness, for example:

1. **Cross-disciplinary collaboration:** Improving data flow between plant systems and business applications enables cross-disciplinary collaboration. Product development teams can access production line data to design in manufacturability. And manufacturing engineering can digitally pre-test production line processes to reduce error and accelerate time to market.

2. **Iterative improvement:** Adding connectivity to products enables manufacturers to release a product with a basic feature set and iteratively add advanced features through firmware updates. For example, every new Tesla is capable of driving itself.[2] Full roll out of autonomous driving features may remain years off. But as soon as both regulations and the software are ready, Tesla can make the capability available immediately through over-the-air updates.

We have identified nine areas where the IIoT is delivering bottom line business value today. Some applications, such as System-Wide Visibility, can provide value in a broad range of situations. Others, such as Mass Customization, describe a specific but very significant use case. Each application is exemplified by an IIC testbed. Testbeds are real projects, implemented collaboratively by member companies to increase our collective understanding of the technical and business aspects of the IIoT.

2.1 System-wide Visibility – Data Flow from the Shop Floor to the Top Floor

Manufacturing is typically characterized by a hierarchical structure. In this "automation pyramid" sensor and actuator data are inputs to local control loops governed by a Programmable Logic Controller (PLC), Micro-Controller (MC), or Industrial PC (IPC). Supervisory Control and Data Acquisition (SCADA) networks, Manufacturing Execution System (MES), and Enterprise Resource Planning (ERP) systems in the different layers of the automation pyramid govern the local control loops. The sensors and actuators in the manufacturing system are capable of generating massive amounts of data, of which only a fraction is used by the PLC/MC/IPC to manage the control loop's automation task. Transferring those comprehensive data from the operational technology (OT) systems in the shop floor to the information technology (IT) systems at the top floor would enable a variety of Smart Factory use cases supported by analytics of big datasets aggregated from multiple sources. Figure 1 illustrates the integration of IT and OT systems through IIoT enablement.

[2] Jack Stewart, Wired, Elon Musk Says Every New Tesla Can Drive Itself

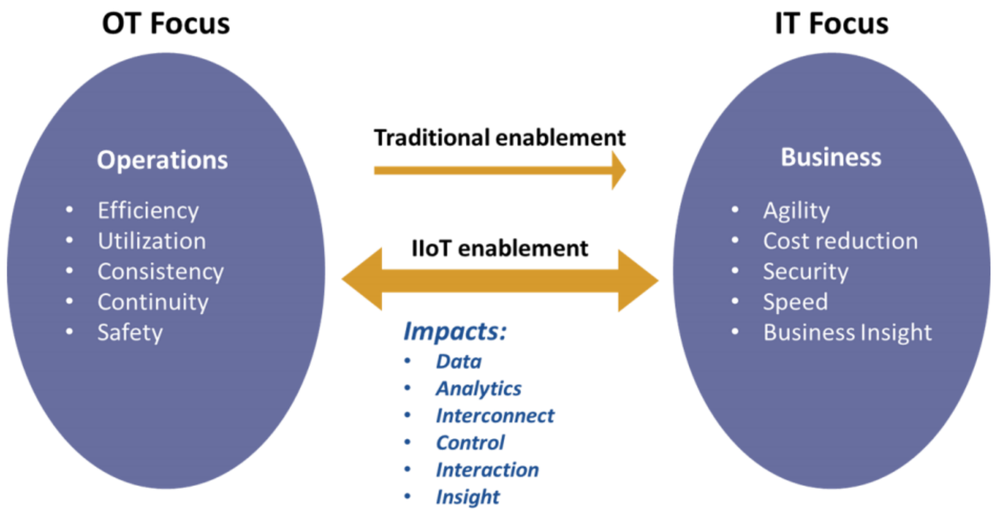


Figure 1: Current IT/OT state and transformational potential[3]

There are three approaches to establishing the "shop floor to top floor" connectivity required to make all sensor and actuator data available to IT systems in near real-time:

1. **Direct Communication:** Each sensor and actuator is equipped with active communication modules enabling a direct connection to the IT system.

2. **OT Upgrade:** The PLC/IPC is (re-)programmed to deliver all data to the IT system in addition to performing its traditional automation task.

3. **Gateway Aggregator**: An aggregation point inside the control loop (e.g., an IO module) is connected with a gateway. This integrated device extracts the data from the real-time system and provides them to the IT system without the need to reprogram the PLC/IPC.

A facility operator will select one of these three options depending on the benefits and costs of providing the equipment with IoT capabilities. Generally, the OT Upgrade approach is suited for greenfield installations where an appropriate PLC/IPC can be chosen. In brown-field situations, PLCs/IPCs are seldom capable of performing the additional data transport task. Reprogramming a PLC entails significant costs and downtime, so the Gateway Aggregator solution is usually preferred. The Direct Communication approach is an alternative for targeted, high-value brownfield upgrades. However, this approach does not scale well and can be very costly if many sensors are equipped with communication capabilities.

[3] Industrial Internet Consortium, Volume B01: Business Strategy and Innovation Framework

System-wide visibility can be expanded to cover the entire value chain, from Research and Development to Production to Customer Service. It can also be distributed globally to facilitate coordination and benchmarking. Figure 2 illustrates IT-OT connectivity across the organization to enable system-wise visibility. The IT-OT boundary will likely be blurred as the IIoT develops and connectivity is widely integrated into operations.

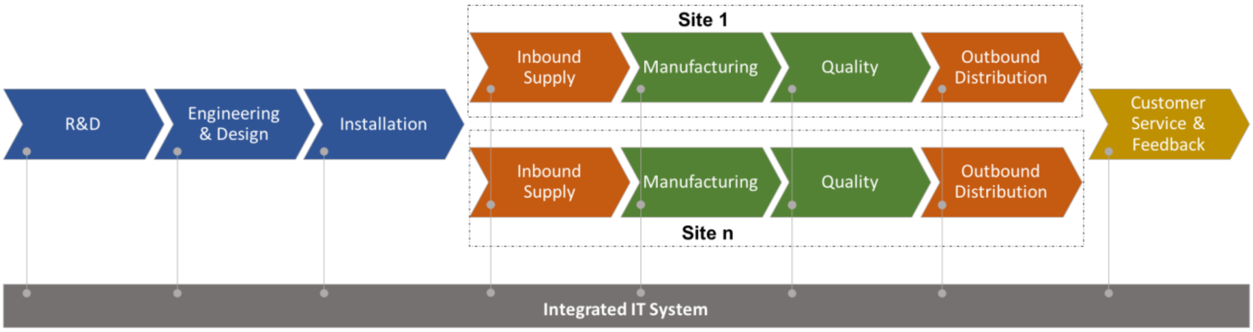


Figure 2: The Connected Enterprise[4]

End-to-end system visibility is not possible without the seamless transfer of data between business systems and operations systems. To imagine the range of opportunities simply ask yourself: "Where would additional data allow better decision making?" For example, Product Development departments typically use surveys and market studies to guide new product development. They must rely on end consumers to answer questions honestly and accurately. And they rely on dealers or customer service representatives to relay feedback. There is significant room for human error to result in bad data.

IIoT solutions use sensors fitted into finished goods to track usage patterns and allow engineers to view exactly how end consumers use the product. Engineers assess real usage data – which features are used, how frequently, when, by whom, for how long, in what order, when do parts break – and derive insight to improve product design by identifying, feature gaps, non-value-adding features, use-case segments, and engineering weaknesses. Improved design contributes to increased customer satisfaction and brand recognition, while reducing non-value-adding features and product defects.

Manufacturers operating multiple factory sites to manufacture similar products catering to global customers can also set up a "Central Operation Center" and compare quality parameters across sites in near real-time. Centralized visibility provides management with a macro view and enables standardization of global quality metrics. This is accomplished by retrofitting factory equipment with sensors to track operating parameters. This data is analyzed to identify the root cause of quality deviations.

[4] Peter Klement, XMPro

IIC Factory Operations Visibility and Intelligence Testbed

MARKET SEGMENTS: Manufacturing of complex, composite products (e.g., IT equipment, consumer electronics, network appliances)

CHALLENGE: Most data generated by factories is not currently used to generate actionable insight due to three challenges. Contextual and background data is often stored in various, incompatible formats. Storage and distribution of large amounts of raw data requires considerable computational resources, which are rarely locally available. The cost to install and maintain equipment to collect and distribute data is significant.

SOLUTION: Establish new factory operation visualization scenarios with data upload and simulation capabilities to augment physical factory equipment. Use a cloud-based platform that combines factory sensor and operational data to enhance the visibility and analysis of key manufacturing processes to improve operational efficiency. Capabilities include: support for Manufacturing and Repair process control; extensibility with enhanced visual rendering tools to track process flow, product status, scheduling, and machinery status; plug-in capabilities for analytics and diagnostics software.

COMMERCIAL BENEFITS: In the factory, system-wide visibility enables more timely product manufacturing and shipment, reduced rate of product rejection, faster product repair turnaround, and enhanced production throughput. Other benefits are applicable across the enterprise.

2.2 Production Automation – Fewer Tradeoffs Between Cost, Quality, and Speed

Manufacturing productivity growth has slowed worldwide according to data from the International Labor Comparisons (ILC) program of The Conference Board.[5] More than half of the economies covered in their dataset saw less than 1 percent growth in 2015, and 6 of the countries posted negative productivity growth rates. US Government studies indicate that productivity growth over the period of 2007-15 fell about 50% from 2000-07 levels.[6]

However, despite this global trend of weakening manufacturing growth, the German manufacturing industry expects to see a €90 billion to €150 billion boost in productivity over the next five to ten years. Their estimated productivity improvements will be between 5-8%.[7] The

[5] The Conference Board, Press Release: Manufacturing Productivity Growth Slows to Crawl Worldwide

[6] United States Bureau of Labor Statistics, Labor Productivity and Costs

[7] Boston Consulting Group, Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries

positive forecasts for the German manufacturing sector reflect the expected ROI of pragmatic adoption of IIoT technologies in brownfield scenarios by mid-sized manufacturers.

Time Sensitive Networks (TSN) are one solution being used to enhance production automation. The goals of a TSN is to achieve real-time control and synchronization of high performance machines over standard Ethernet. TSN enables high performance in latency sensitive applications and provides for the integration of edge-cloud control systems into IIoT infrastructure and applications.

IIoT systems such as TSN are required for advanced automation of process and machine controls where latency is critical to meeting closed loop control requirements. Flexible processing lines with multiple integrated control systems and peer-to-peer communication are needed to reduce the tradeoff between cost, quality, and speed. They also enable low-volume-high-mix manufacturing with the use of reconfigurable robotics.

IIC Time Sensitive Networking Testbed

MARKET SEGMENTS: Manufacturing, Utilities, Oil and Gas

CHALLENGE: Manufacturing operations require tight coordination of sensing and actuation to safely and efficiently perform closed loop control. Typically, these systems have been deployed using non-standard network infrastructure or air-gapped (unconnected) standard networks. This approach leaves devices and data much harder to access and creates a technical barrier to IIoT, which is predicated on the ability to consume data anywhere throughout the infrastructure.

SOLUTION: To address these needs of IIoT all the way to the control system, the IEEE organization has been working to update the standards for Ethernet and wireless (IEEE 802) to support time sensitive networking. The technology will be used to support real-time control and synchronization of high performance machines over a single, standard Ethernet network, supporting multi-vendor interoperability and integration.

COMMERCIAL BENEFITS: TSN will open up critical control applications such as robot control, drive control and vision systems to the Industrial Internet. This connectivity then enables customers, suppliers and vendors to more readily access data from these systems and to apply preventative maintenance and optimization routines to these systems.

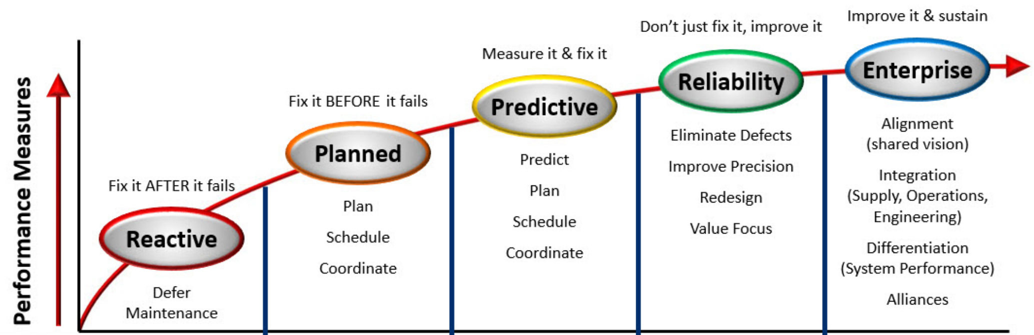
2.3 Predictive Maintenance – Machine Downtime Visibility and Reduction

Predictive Maintenance is the application of predictive analytical algorithms against real-time observed data to proactively identify potential concerns before they arise and to make guided recommendations to address the issue. A recent study on Asset Efficiency maturity from Infosys and the Institute for Industrial Management (FIR) at Aachen University revealed that 85 percent of manufacturing companies globally are aware of asset efficiency, but only 15 percent have implemented it at a systematic level.[8]

Using machine learning to develop strong predictive algorithms requires broad historical datasets that are analyzed in centralized datacenters due to the large computational requirements. However, algorithms can be applied on site with embedded hardware. Currently, measurements are often manually performed by an aging skilled labor force leading to inconsistent analysis and poor coverage. Adding connected sensors to the asset enables continuous online measurements of early wear indicators and the utilization of human expertise globally via cloud applications. Automated analysis and maintenance scheduling also enables a new quality of predictive maintenance for critical assets.

Maintenance of enterprise assets is evolving rapidly as new technologies allow organizations to move from reactive to preventative models. Figure 3 illustrates the maturity continuum across seven EAM elements. Predictive IIoT technologies must be implemented before an organization can graduate from Planned Maintenance (stage 2) to Predictive Maintenance (stage 3). Advanced machine learning is then necessary to achieve Reliability (stage 4).

[8] Infosys, Industry 4.0: The State Of The Nations



EAM Elements	Reactive	Planned	Predictive	Reliability	Enterprise
CMMS Functionality & Utilization	CMMS PM Management	CMMS Planning & Inventory Management	CMMS Scheduling & Robust Reporting	CMMS Automated Work Generation	CMMS Lifecycle Cost Tracking
Inventory Management	Limited Inventory Control	Basic Inventory Management	Cycle Counts & Inventory Turns	Point of Use Storage	Inventory Lifecycle Management
Metrics & Performance Improvement	Minimal Performance Tracking	Lagging Indicators	Leading & Lagging Indicators	Continual Improvement Efforts	Organizational Metrics Aligned
Maintenance & Reliability Strategy	Limited PM Effectiveness	Asset Criticality Ranking	Predictive Technologies	PM Optimization	Total Productive Maintenance
Organizational Readiness	"Fire Fighting" Heroes	Overlapping Responsibilities	Senior Facility Leadership Involvement	Documented Senior Staff Knowledge	Master Plan Implementation
Planning & Scheduling	Planning on the Fly	Planning Materials	Kitting Materials & Scheduling Technicians	Detailed CM Job Plans	Proactive Planning & Scheduling
Work Management	Limited Work Management	Effective Work Request Review & Approval	Process Management System Utilization	Monitoring Technician Work Execution	Optimized Work Package Quality
Assessment Score	0.0 – 3.0	>3.0 – 5.0	>5.0 – 7.0	>7.0 – 9.0	>9.0 – 10.0

Figure 3: Maintenance Maturity Continuum[9]

IIC Asset Efficiency Testbed

MARKET SEGMENTS: High Tech, Discrete and Process Manufacturing, Automotive, Aerospace

CHALLENGE: Challenges include the lack of asset instrumentation, real-time data analytics, and contextual data provided by other systems. The resulting lack of insight prevents companies from holistically managing energy usage, asset utilization, operations, and serviceability to optimize asset efficiency.

SOLUTION: The goal of this testbed is to collect asset information efficiently and accurately in real-time and run analytics to make the right decisions. Use cases include failure mode prediction and modelling of asset performance.

[9] Genesis Solutions, EAM Assessment Methodology – A Graphical Viewpoint

COMMERCIAL BENEFITS: Conditioning monitoring provides a high ROI in many scenarios by improving asset life, reducing asset downtime, maximizing production, and enabling the predictable delivery of services for assets.

2.4 INDUSTRIAL DIGITAL THREAD – LINKING MANUFACTURING AND SERVICE DATA

The Industrial Digital Thread is a complex and comprehensive concept that weaves design, manufacturing, engineering, and supply chain functions together. It provides the capability for design, manufacturing, and service data to be captured, harnessed, and leveraged to enable the analytics that drive advanced manufacturing.

The Industrial Digital Thread addresses three significant challenges faced by manufacturers:

1. Faulty production techniques lead to costly unplanned downtime of industrial assets with root causes that are difficult to determine. The causes of such failures are hidden in manufacturing processes. Careful analysis is required to return assets back to production but field engineers and service teams often lack data and insights needed to troubleshoot the underlying issues. The Digital Thread provides the data and analytics needed to understand root causes.

2. Hundreds of thousands of parts go into large complex product such as aircraft structures. These parts are provided by multiple supplier facilities spread across the globe. Issues regarding the mechanical fit and quality issues often result in expensive returns and reworking. The Digital Thread maintains visibility across the supply chain.

3. Product defects could be the result of a fault in design, material, or supply-chain. Expensive recalls are regular occurrences across industries. The Digital Thread helps to reduce variability and faults, and to trace the cause when they occur.

IIC Industrial Digital Thread Testbed

MARKET SEGMENTS: Industrial Manufacturing, Discrete & Process Manufacturing, Automotive, Aerospace, High Tech

CHALLENGE: Field engineers and service teams often lack data and digital insights needed to assess and troubleshoot large industrial assets when performing corrective and preventative maintenance activities. Quality Assurance engineers need to understand why a particular problem is recurring, or why parts from suppliers are mismatched in assemblies. The root cause is usually hidden in design, manufacturing processes, supply chain logistics, or production planning.

SOLUTION: The Industrial Digital Thread Testbed uses a platform stack that is integrated across the supply chain and manufacturing enterprise. Data is collected from the design of the asset, its assembly structure, production planning, manufacturing, field servicing, and supply chain flow.

COMMERCIAL BENEFITS: The insight generated from the Industrial Digital Thread Testbed improves overall efficiency of manufacturing setup and end product quality, while reducing asset downtime during service.

2.5 Global Supply Chain Integration – Supplier to Factory to Customer and Back

The globalization of markets and supply chains has been a boon for manufacturers over the past decades. However, these opportunities come with their own challenges. Manufacturers require visibility into diverse variables such as input material prices, quality specifications, and supply chain disruptions across regions. Incomplete information can impact cost, quality, and the timely delivery of finished goods.

Access to new markets also requires adherence to a broader range of specifications and increased customization to meet the requirements of a diverse customer base. Many manufacturers have attempted to solve this challenge with regional factories. However, regionalization complicates operations such as enforcing quality standards, coordinating group sourcing, and addressing operating inefficiencies.

IIoT solutions provide manufacturers with centralized visibility into supply chains, distribution networks, output quality, operating parameters, and business systems. Business and engineering teams based in headquarters can troubleshoot local emergencies without flying across the globe. Your factories may be distributed globally, but your data and management talent do not have to be isolated into regional silos.

Real-time visibility into logistics routes and material flow across the supply chain increases the efficiency of your production and inventory management. Benefits of IIoT-enabled integration of supply chain and factory systems include:

- Error-proofing automated processes that stretch across multiple facilities.
- Increasing visibility at each stage of an end-to-end production process.
- Increasing throughput of assembly lines by addressing pain-points related to the availability of materials and spare parts.
- Improving inventory and production status visibility for customers and supply chain planners.
- Optimizing production dynamically by adjusting output based on supply and demand.

IIC Track and Trace Testbed

MARKET SEGMENTS: Industrial Manufacturing, Power Tools, Fleet Management

CHALLENGE: The production of many industrial and consumer goods requires exacting work - down to the precise force used to tighten a screw. However, misuse of tools can result in serious accident or injury, especially in fine, repetitive actions.

SOLUTION: Tracking technology will enable factory systems to detect the location of a tool within a meter. Smart, hand-held tools used in manufacturing, maintenance, and industrial environments will be connected to enable precise automation. Asset management and work management will be integrated with factory manufacturing systems.

COMMERCIAL BENEFITS: This technology will enable the "Tools-as-a-Service" business model for equipment vendors. It will also provide manufacturers with enhanced productivity, production quality, and work safety.

2.6 Resource Efficiency – Management of Input Costs and Environmental Impact

Between 2004 and 2014, manufacturing costs increased in most of the top 25 exporting countries around the world.[10] Population growth and environmental regulations will continue to impact land and raw material prices. Meanwhile, the cost of labor increased between 1.9 to 2.6 percent in year 2015, globally.[11]

Globally, manufacturers are also under mounting pressure from governments to improve energy efficiency and reduce carbon emissions. In a 2016 survey of US manufacturers, three-quarters of respondents considered regulatory burdens to be one of the main challenges facing their sector.[12] Initiatives like the European Union's Energy Savings Opportunity Scheme (ESOS), the US government's Better Plants program and the ISO 50001 certification have made this an issue that manufacturers can no longer ignore.

The US Environmental Protection Agency has stepped up monitoring after the Volkswagen AG emissions scandal in 2015. In October 2016, a US automotive manufacturer settled a $28.5 million claim with the EPA for violating the Clean Air Act. Manufacturers cannot afford to identify regulatory infringements after the fact. They must anticipate and prevent costly violations.

[10] Boston Consulting Group, The Shifting Economics of Global Manufacturing
[11] United States Bureau of Labor Statistics, Economic News Release: Employment Cost Index Summary
[12] Carolyn Lee, Shopfloor, Tax and Regulatory Burdens Still Top of Manufacturers' Minds

The impact of IIoT technologies on regulatory compliance can be summed up by Peter Drucker's insight, "What gets measured, gets managed." Low-cost sensors can monitor gas emissions, energy usage, temperatures, and water contamination to provide real-time alerts. Analyzing data flows with machine learning algorithms enables you to predict when you are likely to exceed regulations with sufficient lead time to prevent critical events from happening.

The cost of inputs and fines is unlikely to shift downward in the near term. But pragmatic adoption of IIoT solutions in brownfield environments will help manufacturers stay competitive by reducing waste.

Next generation machines are using integrated sensors to measure and optimize energy consumption based on their usage patterns. Today energy metering capabilities can be added to any existing automation-system without impacting the system itself. Meters with embedded Ethernet connectivity enables cloud-based systems that dramatically reduce the cost of data storage, visualization, and analytics. Combining operating data with external data, like weather forecasts, energy prices, and production schedules can be used to automate processes, inform business decisions, and optimize operational parameters to manage costs.

IIC Smart Energy Management Testbed

MARKET SEGMENTS: Local Government, Critical Infrastructure, Organizations with Large Campuses, Emerging Markets

CHALLENGE: Energy costs continue to increase globally, driven by the depletion of fossil fuels, geopolitical instability and disruptions in the global supply chain. At the same time, organizations are constantly thriving to reduce overheads and minimize the cost of the operations. Current challenges include lack of instrumentation to get the energy consumption details and lack of tools to visualize and analyze the energy consumption patterns. This hinders stakeholders from taking any meaningful action to optimize energy consumption and reduce the overall energy cost.

SOLUTION: Commercial buildings and equipment will be instrumented to measure the electricity and provide tools to monitor, visualize, analyze and optimize energy consumption within the organization. The testbed will provide IT tools such as alarms, notifications, workflows, a ticketing system and augmented reality to improve the operations.

COMMERCIAL BENEFITS: The testbed will result in 5 to 10 percent year over year reduction in energy consumption. It will also provide tools to plan the expansion of operations and to achieve sustainability objectives. Overall energy utilization will be normalized and equipment will run optimally resulting in the reduction of operating expenses.

2.7 Human-machine Collaboration – Improved Safety and Productivity

Human-machine collaboration can be segmented into mobile Human-Machine Interfaces (HMI) and Human-Machine Collaborative Systems (HMCS). HMI technologies such as smartphones, tablets and wearables, combined with Internet access to data and information (analytics and augmented reality) will transform the way machine operators and factory floor engineers work. Personnel no longer need to be in close proximity to the main operator panel in order to monitor or manage performance. Portable wireless devices also expand operator capabilities by providing ready access to product documentation and maintenance manuals using QR-codes or augmented reality headsets to identify an asset.

Today, most operators only have access to information from automation systems. Augmented operators can now access information from all of the needed enterprise systems. Meanwhile, the relationship between the operator and the system (machine) through HMI is evolving from detailed operations to mission-control. Systems are increasingly able to detect and address issues automatically and to alert operators only when human intervention is necessary.

HMCS technologies are intended to provide flexible robotics for small lot manufacturers with rapidly changing assembly lines and the need to augment, not replace, legacy equipment. They provide collaborative robot systems in which humans work directly with robots in dynamic environments. Common capabilities of HMCS include object recognition and action sequence analysis. Object recognition is useful for a range of quality control situations in which human assessment is error prone. A robot can be trained to flag products with specific unwanted characteristics, such as a solar panel with imperfections on more than 0.5% of surface area. Action sequence analysis enables robots to dynamically learn new tasks, such as assembling a new product. The learning sequence involves repetition, rather than programing, and can be completed by a line worker with no IT training.

IIC Edge Intelligence Testbed

MARKET SEGMENTS: Vertical industry testbeds

CHALLENGE: Many emerging industrial IoT applications call for coordinated, real-time analytics at the "edge," using algorithms that require a scale of computation and data volume/velocity previously seen only in the data center. Frequently, the networks connecting these machines do not provide sufficient capability, bandwidth, reliability, or cost structure to enable analytics-based control or coordination algorithms to run in a separate location from the machines.

SOLUTION: The Edge Intelligence Testbed will significantly accelerate the development of edge architectures and algorithms by removing the barriers that many developers face: access to a wide variety of advanced hardware and software configurable to directly resemble state-of-the-art edge systems at very low cost to the tester/developer.

COMMERCIAL BENEFITS: More rapid development of testbeds and IIoT innovation. Having the right work instructions directly on the mobile device will not only improve the productivity but also the safety of the operator.

2.8 Mass Customization – Dynamic Manufacturing Processes

Customers expect an increasingly high level of customization in an increasingly short delivery window. The rigid, high volume production lines of Industry 3.0 are under pressure as the “lot size of one, delivered to the customer’s door in days” is becoming the new standard. There has always been a tradeoff between customization and scale. The Industrial Internet of Things (IIoT) is now enabling manufacturing environments that provide customization at mass market scale.

Small batch and batch of one customization is enabled by system of system interaction between e-commerce, supply chain, productions, and logistics systems. The underlying trends driving this innovation are the falling costs of bandwidth and embedded processing which simplify the management of complex supply chains and production processes. A static, preprogrammed product line cannot accommodate customization due to the cost of retooling and changing material inputs.

The IIoT enhances just-in-time manufacturing to enable single-piece workflow by single units to be tracked through the supply chain and production line in real time. New management models and operational architectures are required. To seize this opportunity, companies must master new ways of operating and collaborate more closely with IT and IoT platform vendors to achieve a tighter integration of OT and IT solutions across their internal and external supply chains.

The twin requirements of customization and delivery times are forcing manufacturers to rethink inventory, production planning, machine retooling, and overall manufacturing processes. Companies that meet these expectations will satisfy customers and grow market share. Manufacturers that fail to improve flexibility and service levels will be under pressure as customers’ options increase.

Factories that enable mass customization are often greenfield. However, Harley-Davidson reconfigured their York, Pennsylvania factory to equip all machinery with sensors and location awareness. The factory was already tooled for modest customization. But the reconfiguration reduced the lead time to produce customized motorcycles from 21 days to six hours. Today, each model has over 1,500 configurations and all configurations are produced on the same production line.[13]

IIC Smart Manufacturing Connectivity

MARKET SEGMENTS: Discrete manufacturing

CHALLENGE: The discrete manufacturing domain is characterized by a strictly hierarchical structure of the automation systems, commonly referred to as the automation pyramid. Data acquired by a sensor typically flows through an input/output, IO-module into a PLC which manages the local real-time control system. However, because a PLC was selected to exactly match the requirements of the environment within which it was intended to operate, it often cannot support tasks such as communicating data through additional interfaces.

SOLUTION: This testbed implements an alternative solution by substituting IO-modules that connect the sensors with the real-time automation system by a gateway that extracts the sensor data and transfers them to the IT system through an additional communication channel via OPC Unified Architecture (OPC UA)(IEC 62541). This "Y-Gateway" re-uses existing physical connectivity and supports the easy integration of an IO-Link sensor with the IT by using a common device model based on an open standard and thus enables the remote configuration of the sensor.

COMMERCIAL BENEFITS: The testbed enables retrofit-able hardware solutions that reduce the costs of the physical installation. Easy access to a high volume of near real-time data enables the improvement of current analytics and the development of innovative applications.

2.9 Business Model Evolution – Monetize Data and Shift to Services

The Smart Factory is as much about disruption of business models as it is about operational efficiency. New manufacturing business models are developing at a similar degree of magnitude as when XEROX transformed the office equipment market in 1959 by charging for photocopies made rather than machines. XEROX achieved a 41% compound annual growth rate for 12 years running. But more importantly, their innovation prompted a business model revolution that is now the subject of MBA courses in top business schools.

[13] Richard Howells, SAP, How Harley-Davidson And Other Companies Deliver Individualized Products

Manufacturing business models are being disrupted the same way today by 3D printing, Robots-as-a-Service, and the overall servitization of the manufacturing value chain. The line between products and services is blurred by the growing adoption of value-based pricing.

The pioneering engine manufacturer, Rolls-Royce, is a prime example of how innovative business models can increase revenues and profitability. In 2015, Rolls-Royce used business model innovation to rescue the company from financial struggle. They shifted their focus to providing Outcomes-as-a-Service. In their case, it meant selling "power by the hour" instead of selling new engines as a once-off transaction. This benefits the customer by transferring a large portion of operating risk to the manufacturer. And it benefits the manufacturer because it increases the customer lifetime value and barriers to switching vendors.

Rolls-Royce also used operating data from their engines to increase the value-added services they offer to customers. They've signed contracts to help customers such as Singapore Airlines reduce fuel consumption through data analytics. Their focus on monetizing their data and providing more services contributed to half of the company's £14.6 billion revenue in 2015.[14]

Outcome-based business models give manufacturers like Rolls-Royce the opportunity to turn services into a significant revenue driver. By leveraging data from connected products to provide smarter services, manufacturers can stay ahead in the increasingly competitive business landscape.[15]

IIC Smart Factory Web Testbed

MARKET SEGMENTS: Industrial automation

CHALLENGE: The Smart Factory Web testbed aims to form a network of smart factories with flexible adaptation of production capabilities and sharing of resources and assets to improve order fulfillment. Key challenges include: exchanging data between connected factories reliably, providing information securely at the right granularity to authorized partners, and adapting production capabilities quickly and efficiently in response to orders.

SOLUTION: The Smart Factory Web applies a dual plane 3-tier implementation architecture with IIoT technologies on both planes. The upper plane comprises the Smart Factory Web portal to handle cross-factory interactions through gateways to the individual smart factories. The lower

[14] Margi Murphy, Computerworld, Singapore Airlines inks 5-year deal with Rolls Royce for fuel efficiency data analytics

[15] World Economic Forum, Unleashing the Potential of Connected Products and Services

plane is a Smart Factory with a Factory Digital Image to enable secure communication with the Smart Factory Web. Secure Plug & Work techniques based on the standards AutomationML and OPC UA are applied to adapt factories on-the-fly by inserting new manufacturing assets into the factory production with a minimum of engineering effort.

COMMERCIAL BENEFITS: The testbed creates and validates new business models with the flexible assignment of production resources across factory locations. This creates new opportunities for SMEs, allowing them to respond flexibly to manufacturing orders.

3 Core IoT Technologies – What Enables Change?

The technological foundations for the IIoT are not new. Modern manufacturing is the product of continuous technological innovation, from steam engines to assembly lines. In the last 20 years, investment into robots, actuators, sensors, and next generation control systems on the shop floor have laid the foundation for the IIoT. Digitalized "things" are not new in the automation space, but so far they have lacked the "I", Internet connectivity to link equipment and IT systems. Automation systems, sometimes also called OT, were traditionally proprietary systems, isolated from the fast evolving, globally connected world of IT. OT and IT have developed in parallel for many decades. It is their convergence, based on both commercially available and emerging standards for manufacturing processes and technologies, that will transform industries over the next decade.

We are now taking advantage of improvements and cost reductions in Internet connectivity, data analysis, and sensors. Together, these technologies enable use cases that were previously technically or financially impractical across all areas of a manufacturing organization. These emerging use cases are based on aggregating, analyzing, and acting on data.

Data aggregation is a necessary first step in IIoT implementation, whether from existing PLC, SCADA and Distributed Control System (DCS) systems or from newly installed sensors. Cost effective communications technologies are then necessary to move the data. And, most importantly, analytics platforms capable of managing large, diverse datasets are required to extract insight that can be acted on. No technology in itself will disrupt an industry. But the combination of existing and new technologies has created the foundation for significant technology innovation.

However, technology innovation is necessary but not sufficient to disrupt the manufacturing sector. It is necessary to look beyond technology at the people and processes that run your business. Cisco coined the term "Internet of Everything" to draw attention to the interaction between connected "Things" + "Data" + "People" + "Processes." Successful disruption requires evolving an organization's management of people and processes to create value from connected things and abundant data.

Looking outside of a specific company into the value chain technology silos remain common, especially in manufacturing. As in the IT sector, the most impactful disruptions will involve breaking down siloes as value chains evolve to accommodate the dynamic flow of information. Figure 4 illustrates information availability across an industrial cooler's value chain.

Figure 4: Traditional Industrial Cooler Value Chain[16]

Information about the condition and usage of the cooler are of interest to multiple players in the value chain, but the siloed data and systems prevent insights that can enable value chain efficiencies, improve the cooler product, and streamline cooler-related services. It is insufficient to connect sensors to the cooler. The data those sensors produce must be made available to multiple teams within and across organizations.

3.1 Alignment Has Begun – Cost and Capability Drive Feasibility

The building blocks to make the manufacturing value chain more effective and efficient are available and are being used to generate technology and business innovations today. There are two primary drivers that enable new IIoT use cases – cost reductions and capability improvements.

Cost reductions are making long-existing technologies become affordable. For example, sensors are getting cheaper due to improved manufacturing processes for sensor technologies and rapidly growing economies of scale. Costs are also driven down by relatively new technologies. Cloud computing provides affordable, scalable storage and processing capabilities without the risk of investing in fixed assets. The cloud makes big data analytics affordable for risk-adverse small and mid-sized manufacturers. As a result, both manufacturing data and the capacity to store and analyze it are growing in scale and affordability.

[16] Peter Klement, XMPro

Meanwhile, the capabilities of new technologies are increasing rapidly, especially on the IT side of the equation. For example, innovation in machine learning has rapidly increased the intelligence of Apple's Siri and IBM's Watson. Algorithms now have better, and much more rapid, pattern recognition capabilities than humans in many situations.[17] Integrated software-hardware solutions are enabling innovation in the "things space." Consider for example the use of Augmented Reality in asset maintenance, drones to assess damage following natural disasters, and the use of 3D printing to manufacturer stronger, lighter aerospace components.

Interoperability remains an innovation bottleneck and must be addressed in order for diverse IIoT technologies to exchange data. Fortunately, we see standards gaining prevalence on the market. Standardization is progressing in protocols like MQTT (MQ Telemetry Transport) and OPC UA, as well as data formats like HyperCat.

Standardization is a significant challenge and faces many impediments due to the variety of legacy systems and competitive dynamics. Fortunately, forward thinking companies like GE and the aforementioned Rolls Royce have started to sell the data produced by products such as jet engines to generate new revenue streams.[18] This concept of "Product-as-a-Service" provides companies with a means of monetizing data and thus incentivizes further interoperability.

3.2 Designing the Smart Factory – Aligning Technical, Market, and Business Value

We have seen that the core technical building blocks for industry disruption are in place. It is now a question of which manufacturers will leverage the windows of opportunity to gain a competitive advantage. From a design thinking point of view, the technical feasibility of the digital transformation of businesses and value chains is a given. The market desirability and business viability of specific use cases needs to be explored further.

Two ongoing developments that appear to meet requirements of technical feasibility, market desirability, and business viability are "Digital Twins" and "Integrated Value Networks." A "Digital Twin" is the digital representation of a physical asset such as a machine on the shop floor or a truck on the street. This requires the physical asset to be equipped with PLCs or sensors that inform about its current state and, if required, allow changing the state of the physical thing via changes to its "Digital Twin." The Sydney Harbour Bridge is an example of a physical asset with a robust "Digital Twin." The physical and digital versions of the bridge are aligned with 2,400 sensors that monitor its physical integrity.[19]

[17] Roger Parloff, Fortune, Why Deep Learning Is Suddenly Changing Your Life
[18] GE Aviation, Digital Services & Data Analytics
[19] P. Runcie, S. Mustapha & T. Rakotoarivelo, National ICT Australia (NICTA), Advances in structural health monitoring system architecture

Traditional value chains imply that the flow of goods and services is sequential between value chain participants. In our increasingly connected world, value chain participants are starting to interact in non-sequential ways. Value chains are becoming value networks. "Integrated Value Networks" rely on the seamless exchange of data, enabled by interoperability technologies and standards. In the example of the cooler manufacturer mentioned above, this transformation to value networks might look like Figure 5.

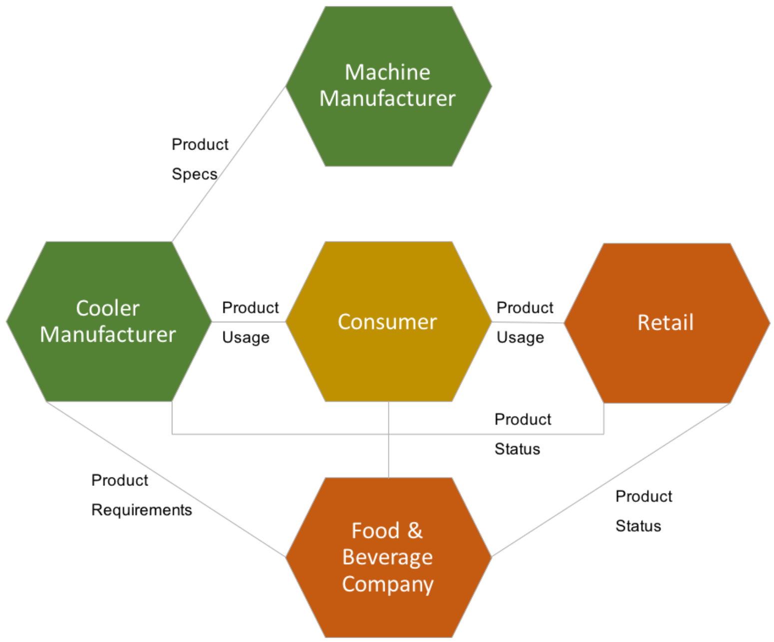


Figure 5. Integrated Value Network in an Industrial Cooler Value Chain[20]

The ability to aggregate, analyze, and act on data requires one or more IoT data management and analytics platforms to be integrated with enterprise systems and external solutions via an IoT integration and orchestration platform. A key selection criterion for any IoT platform is out of the box integration with existing IT and OT systems. "Plug and play" integration will dramatically accelerate implementation and reduce the required investment. Figure 6 illustrates how core IIoT systems integrate with enterprise IT and OT systems from the business process perspective, very similar to a business process management (BPM) system in the IT world. The IIC Industrial Internet Reference Architecture (IIRA) provides further detail into the components of an IIoT System.[21]

[20] Peter Klement, XMPro

[21] Industrial Internet Consortium, Industrial Internet Reference Architecture Technical Report

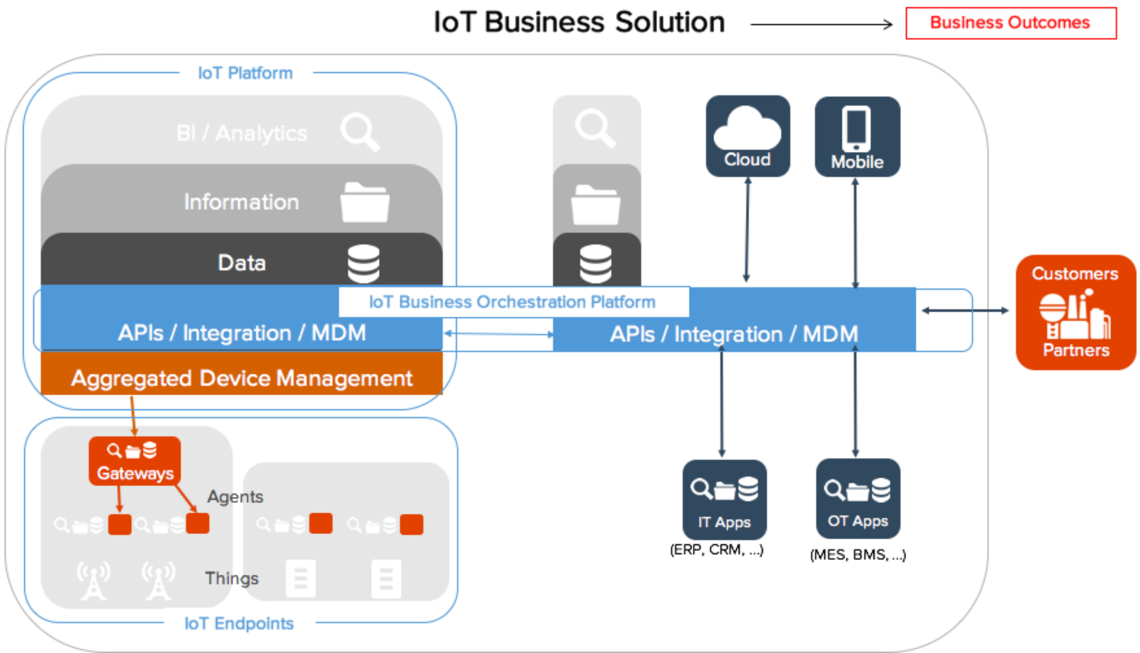


Figure 6: IoT Business Solution Architecture[22]

3.3 The Standards Landscape – Meeting Requirements and Filling Gaps

Standards play a key role in the rate of technology adoption. Standards are required to allow smart connected products, machines, and assets to interact in a transparent fashion. This goes beyond the simple communication protocols, and involves the creation of standard semantics and mechanisms that will allow smart devices to discover each other and interoperate. Standards exist in this area but they are incomplete and do not cover all aspects of manufacturing. [23]

It is important to define both existing and missing standards that fulfill the specific requirements of factory automation. These are primarily related to speed, determinism, and functionality. Basing IIoT platforms on standards enables critical abilities such as scalability, portability, and interoperability. Vendors also follow standards to offer backward compatibility so that their software can be ported to different generations of processors and operating systems. For example, OPC UA remains compatible with the previous OPC 'classic' devices.

It is also important that standards make it possible to recover when a supplier leaves the marketplace, whether due to bankruptcy, discontinuation of a product line, or merger and

[22] Jess Thompson, Gartner, The Hybrid Integration Platform: Foundational Infrastructure for a Digital Business
[23] John Conway, Schneider Electric, The Industrial Internet of Things: An Evolution to a Smart Manufacturing Enterprise

acquisition activity. Standards allow that supplier to be replaced by a direct plug-in provided by an alternative vendor. OT legacy systems have typically been proprietary, and are referred to as de facto standards when they reach a broad level of adoption in the marketplace. They were designed to lock manufactures to a specific vendor, not to provide interoperability between vendors.

This was more acceptable when machines were not connected. However, the connectivity that is core to IIoT systems will not be widely adopted in an environment where communications protocols, data formats, and programming methods are not based on standards. At a minimum proprietary legacy platforms will need to provide a prescribed level of interoperability during the transition to IIoT. True “Smart Factory” solutions will require seamless data flow through multivendor environments.

A classic example is that of deterministic industrial networks. In the 1990’s, Ethernet TCP/IP was quickly recognized as inadequate for machine control because delivery of data packets could not be guaranteed. In response, proprietary networks were developed and still proliferate as ‘flavors’ of Industrial Ethernet today. Connectivity between the enterprise (or cloud) and the facility will become less expensive and closer to ‘real-time’ as we move beyond the need for intermediate systems to communicate between incompatible protocols.

Data acquisition, ‘recipe’ downloads, and software updates do not require a deterministic network; however, machine control does. Critical applications that require real-time, deterministic networks include motion control, robotic control, and networked safety across all manner of multi-axis servo controlled machinery, from machine tools to packaging machinery.

In some instances, over 100 servo axes may need to be synchronized at a network update rate in the hundreds of microseconds, with jitter measured in nanoseconds. Each servo axis provides useful feedback data. For example, increased motor current draw suggests mechanical wear that is requiring more force to overcome. The IIoT will put additional pressure on network bandwidth by adding real-time monitoring and adjustment to situations that today are periodically sampled, reviewed, and corrected after the fact, if at all.

Network performance will need to be maintained as node counts and IIoT data volumes increase. Today, networks are typically separated into machine control (highly synchronized), cell or line control and data handling via Ethernet TCP/IP. The vision of the IIoT is to flatten this topology using an (Institute of Electric and Electronics Engineers) IEEE 802 standard protocol. The Time Sensitive Networking Testbed is an IIC initiative studying the feasibility of this approach. This and related determinism use cases will be used to help define architecture specific to the Smart Factory.

The most prominent standardized industrial communications interface is OPC UA. OPC UA is a platform independent industrial machine-to-machine communication standard. The OPC Foundation is a standards organization that is collaborating with both the IIC and complementary standards organizations, such as Object Management Group (OMG), to develop a strategy for the OPC UA and Data Distribution Service (DDS) connectivity standards. While OPC UA is not currently defined as deterministic, it is hoped that developments will lead to OPC UA becoming suitable for highly deterministic machine and line control functions in multivendor environments.

Standardized programming, data handling, state models, event processing, and operating modes also play a key role in the Smart Factory. These standards include Unified Modeling Language (UML), ISA TR88.00.02-2015 (a.k.a., PackML), IEC 61131-3, and MTConnect. The purpose of these standards is to accommodate interoperability and consistent operation and data definitions across different machine types, machine builders, and controls suppliers. This is required for many reasons - more efficient machine operation, reduced total cost of ownership, more direct machine-to-machine communication, cell and line control, production data acquisition, and overall equipment effectiveness implementation, to name a few.

The Smart Factory will rely heavily on data handling, software and communications standards like these to make the connection from machine to cloud as direct as possible, delivering consistent and accurate decision making information in a timely manner.

3.4 STANDARD ADVISORY

The IIC Smart Factory Task Group (SFTG) will make every effort to identify relevant best practices, advisory groups, standards bodies, and manufacturing-specific standards. We welcome both input and enquiries from the readers of this white paper.

Organization	Standards Supported	Notes
A3 - Association for the Advancement of Automation	Various	Umbrella organization for AIA, RIA and MCMA. Focus on vision, robotics, and motion control.
AMT - Association for Manufacturing Technology	MTConnect	Focus on machine tool industry.
ANSI - American National Standards Institute	Various	US government standards body.
DMDII - Digital Manufacturing and Design Innovation Institute	MTConnect	Various government and industry initiatives. Focus on CNC and robotics.
IEC - International Electrotechnical Commission	Various, notably IEC 61131-3	Industrial programming language standard.
IEEE - Institute of Electrical and Electronics Engineers	Various, notably IEEE 802 'dot'	Standards body for Ethernet and TSN.
ISA - International Society of Automation	Various, notably ISA 88, TR88.00.02 (PackML), ISA 95, and ISA 99	Professional organization and standards body corresponding to IEC and ISO in Europe.
ISO - International Standards Organization	Various, notably MQTT (ISO/IEC PRF 20922)	Non-governmental standards body based in Europe.
Modelica Association	FMI (Functional Mockup Interface)	Standard for model exchange and simulation.
MT Connect Institute	MTConnect	Develops open standards to access machine device data.
NIST - National Institute of Standards and Technology	Various	US Dept. of Commerce agency to promote US innovation and industrial competitiveness.
OASIS - Organization for the Advancement of Structured Information Standards	MQTT	MQTT is a lightweight messaging protocol used on top of TCP/IP protocol.
OMAC - Organization for Machine Automation and Control	ISA TR88.00.02 (PackML), MTConnect, and STEP NC	Packaging and Manufacturing Workgroups advance best practices in industrial automation.
OMG - Object Management Group	Various, notably CORBA, DDS, and UML	OMG manages the Industrial Internet Consortium.
OPC Foundation	OPC UA (Open Platform Communications Unified Architecture)	Interoperability standard for data exchange in industrial automation.
OpX Leadership Network	Various, notably OEE, FAT, RFP, TCO	Comprised largely of consumer goods manufacturers responsible for OT.
PLCopen	IEC 61131-3	Supports and expands on the IEC programming language standard.

4 IoT Adoption Barriers in Manufacturers – What Prevents Change?

Several barriers will need to be overcome before next generation IIoT systems are widely adopted across the manufacturing sector. Three of the most pressing challenges include retrofitting legacy assets, accommodating rapid data growth, and protecting sensitive assets and systems from cyber-attacks.

4.1 Legacy Assets

Perhaps the foremost hindrance to IIoT adoption in manufacturing is the nature of capital equipment, which is often expected to perform for a decade or longer, frequently with no upgrades to the original hardware and software. As OT and IT systems become more tightly integrated, OT will become the limiting factor for productivity and capability improvements due to the inability for hardware to evolve at the rate of software. Technology that would be considered obsolete in an IT department soldiers on in manufacturing. And reliability trumps innovation and performance as the operational priority. Despite the importance of a modern OT platform, one in four manufacturers report that they do not have a specific annual productivity improvement objective.[24]

The chronic productivity declines reported by The Wall Street Journal and other news sources can be laid to a large extent at the feet of legacy factories and supply chains. Compare brownfield factories in the United States with greenfield factories in China that are equipped with the most advanced European manufacturing technologies. China's relative pricing advantage is shifting from labor costs to equipment efficiency in its most mature industries. Manufacturers in advanced economies must replace or augment their legacy assets with advanced manufacturing technologies to maintain competitiveness as their equipment ages. IIoT analytics will provide the basis for making those investments.

There is a longstanding complaint among manufacturing professionals that manufacturing is considered a 'necessary evil' in the c-suite and an overhead cost rather than a competitive advantage. This truism may be facing a reversal due to the development of leading edge technologies like mass customization and additive manufacturing. These technologies will place advanced manufacturing at the center of business strategy by enabling new pricing models and product-service offerings. They entail step changes in capability, not incremental improvements in efficiency.

[24] Kronos Corporation and IndustryWeek, The Future of Manufacturing: 2020 and Beyond

4.2 DATA OVERLOAD – EXCESS DATA, INSUFFICIENT INSIGHT

Data is at the heart of every IIoT system. An IDG Research Survey reported that 64% of senior executives felt that integrating data from disparate sources and formats in order to extract business value from that data is the single biggest challenge the IIoT presents.[25] In a typical factory, more than 99% of data is discarded without attempting to derive insight due to high storage and transport costs. There are relatively few organizations worldwide that are truly good at managing data. Google, Amazon, and Facebook come to mind. Data is their business. For most manufacturers, data is a byproduct of production. They lack the knowledge and capabilities to manage it efficiently.

A Smart Factory requires collecting, analyzing, transporting, and storing vast amounts of data. The data must be filtered and processed to extract meaning and value, either at the edge or in the cloud. New systems are required to handle the challenges posed by the volume, velocity and variety of these data sets. Solution vendors must either improve data management capacity or develop algorithms that are better at extracting insight from small samples of data. Until this challenge is addressed, the IIoT will be typified by vast data lakes that are siloed, unstructured, and temporary.

A third way to reduce the manufacturer's data management burden is by turning the data into a revenue stream to offset the cost. Data has value to many organizations. Companies should assess the feasibility of monetizing their data by selling it to third parties such as investors or equipment vendors. This requires an honest assessment of the risks of sharing particular data points. In the past, manufacturers have largely been conservative regarding data sharing. Management typically lacks IT expertise and is thus unable to accurately assess the potential risks. In this environment of uncertainty, the default is to silo or delete data.

4.3 SECURING INDUSTRIAL INTERNET SOLUTIONS

Part of the IIC's mission is to bring together different viewpoints to share information and find common ground for progress. Frankly, the SFTG has not encountered a topic more polarizing than cybersecurity. But we believe that understanding the different business and technical drivers behind OT and IT is essential to creating a best practices security framework that will benefit industrial enterprises. This topic is the domain of the IIC's Security Working Group and IT / OT Task Group, which can be contacted to discuss the issue in greater depth.

IT security is every bit as problematic an issue in the Smart Factory as in IIoT initiatives at large. Industrial networks, which were originally designed to be isolated, are now exposed to continuous attacks of ever-increasing sophistication. Additionally, with the proliferation of connected devices worldwide, there is a need to protect against not only malicious intent but

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[25] Bitstew Systems, CIOs Speak Out on The Real Barriers and Opportunities Presented by the Industrial Internet

also errors and mischance. The IIC believes that these factors combine to create a perfect storm that represents a major threat to safety and security in factories.

In its latest Piracy Study of 2016, the German Engineering Federation, VDMA, revealed that 70% of manufacturing companies surveyed in Germany had been affected by product or know-how piracy, which in turn cost the national GDP an estimated 7.3 billion euro and caused the loss of 34 thousand jobs. The targets for counterfeiters are not just components (62%), but also designs (47%), and entire machines (41%).[26] Globally, WIBU Systems found reverse engineering to be the leading source of counterfeit products

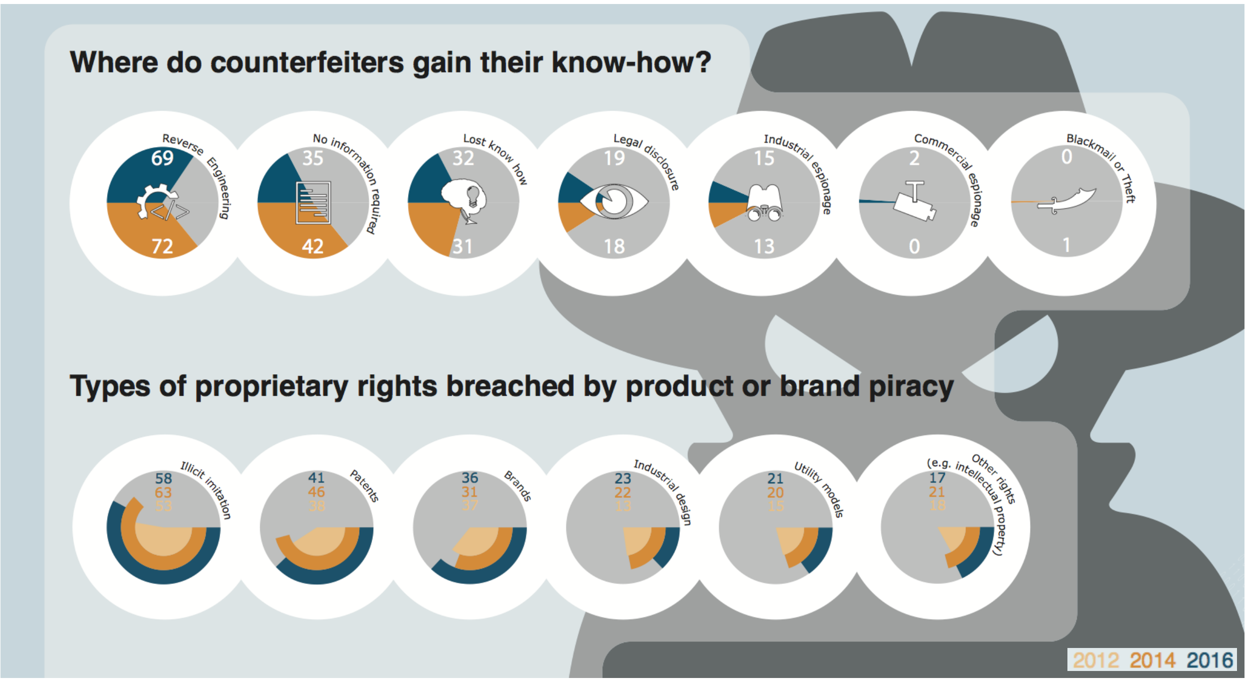

Figure 7: Product Piracy[27]

Each element of the production line, including all connected internal or outsourced modules, should be secured. The most vulnerable component in the chain are the endpoints such as computers, embedded devices, PLCs, and sensors that are collecting, processing, or producing data. By embracing 'Security by Design', some vendors are embedding security technology directly in their new generations of IoT boards, gateways, modules, and systems. Hardware secure elements, in which encryption keys are safely stored, become an intrinsic part of the

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[26] Steffen Zimmermann, VDMA, VDMA Study Product Piracy 2016

[27] Wibu-Systems, Infographics: Product Piracy

architecture and are easy to adopt when retrofitting existing production systems or building new greenfield sites.

The Industrial Internet Security Framework (IISF) evolved naturally from, and builds upon, the IIC's previously published IIRA.[28] This ensures that security is not just bolted onto the architecture, but rather is a fundamental part of it. With its landmark IISF, the Security Working Group has developed a common approach to security and a rigorous methodology to assess security in Industrial Internet systems. It describes the consequences of merging different security fields, provides guidance on how to select and achieve security objectives, and describes how to leverage technologies to overcome cyber-sabotage and cyber-espionage.

The IISF emphasizes five different characteristics of trustworthiness applicable to IIoT systems:

System Characteristic	**Definition**
Security	*Security* is the condition of the system being protected from unintended or unauthorized access, change, or destruction.
Safety	*Safety* is the condition of the system operating without causing unacceptable risk of physical injury or damage to the health of people, either directly or indirectly, as a result of damage to property or to the environment.
Reliability	*Reliability* is the ability of a system or component to perform its required functions under stated conditions for a specified period of time.
Resilience	*Resilience* is the condition of the system being able to avoid, absorb, and/or manage dynamic adversarial conditions, while completing assigned mission(s), and to reconstitute operational capabilities after casualties.
Privacy	*Privacy* is the right of individuals to control or influence what information related to them may be collected and stored, and by whom and to whom that information may be disclosed.

Whether your business is considering, or already in the midst of deploying an IoT strategy, security concerns should be top of mind. As we have learned, the rush to deploy should not overshadow security requirements. Some questions to ask your IT/OT teams:

- What is the best way to keep our facilities and systems secure and our people safe?
- How can you manage the risk of cyber-attacks on our business, or our customer's businesses?
- How do clouds, private clouds and fog change the equation?

[28] Industrial Internet Consortium, Industrial Internet Reference Architecture (IIRA) and Industrial Internet Security Framework (IISF)

The IIC takes all of these concepts a step further with actual testbeds to prove out and optimize the security of real-world IIoT systems. Members contribute to the evolution of the technology, developing improved endpoint protection, communication security, and data protection.

5 CONCLUSION

The Smart Factory is at the heart of the digital transformation that enterprises are currently undergoing. The fusion of OT with IT is allowing manufacturing organizations to tap into a new level of technical orchestration. Systems that were previously siloed are now becoming digitally integrated to enable real-time coordination between people, assets, and things. This emerging Industrial Revolution is driven by our ability to access, aggregate, analyze, and act on data. Some of the foundation technologies, such as sensors, are relatively mature. Others, such as machine learning algorithms, are new to market but advancing rapidly. Together, these IoT technologies will power the next generation of efficiency improvements, business model innovations, and disruptive value chain evolutions.

The factory of the future will use data to drive efficiencies and improve capabilities in three ways. First, connecting people, assets, and things to the internet will enable use cases such as predictive maintenance that reduce operating expenses and improve equipment uptime. Second, integration with non-production departments, such as product development and after-sales service, enables new business insights to drive product and process improvements. Lastly, improved visibility between companies enables collaborative business models such as the Smart Factory Web.

Technological innovation alone is not sufficient to produce change. Business leaders must recognize opportunities, develop new business models, adapt organization structures, and develop people with the right skillsets. The authors hope that this and other documents published by the IIC's Smart Factory Task Group (SFTG) will help to guide business leaders on this journey. We welcome questions, comments and recommendations regarding this white paper or the SFTG in general. Please direct your questions to the SFTG co-chairs at smartfactory@workspace.iiconsortium.org.

6 ABOUT THE INDUSTRIAL INTERNET CONSORTIUM

The Industrial Internet Consortium® (IIC™) is a global, member supported, organization that promotes the accelerated growth of the Industrial Internet of Things by coordinating ecosystem initiatives to securely connect, control and integrate assets and systems of assets with people, processes and data using common architectures, interoperability and open standards to deliver transformational business and societal outcomes across industries and public infrastructure.

The goals of the IIC and its members are to:

- Drive innovation through the creation of new industry use cases and testbeds for real-world applications.
- Define and develop the reference architecture and frameworks necessary for interoperability.
- Influence the global development standards process for internet and industrial systems.
- Facilitate open forums to share and exchange real-world ideas, practices, lessons, and insights.
- Build confidence around new and innovative approaches to security.

The Industrial Internet Consortium is managed by the Object Management Group (OMG). Membership is open to those interested in advancing the adoption of the Industrial Internet. Visit www.iiconsortium.org to learn more.

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- Thomas Nuth – MOXA

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