Internet of Things and Edge Cloud Computing Roadmap for Manufacturing

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The industrial Internet or Internet of Things (IoT) for manufacturing is a new Internet evolution. It involves integrating potentially billions of sensors, cameras, industrial machines, displays, smartphones, and other smart communicating devices (collectively referred to as "things"[1,2]) into cloud datacenters, and processing their data in a timely fashion on elastic and virtualized cloud resources for automating an end-to-end manufacturing lifecycle. Industry consortiums around the world are making significant efforts to develop and advocate an open, standards-driven smart manufacturing factory supported by the Industry 4.0 vision (the fourth industrial revolution).[3] As defined in Wikipedia, Industry 4.0 "is embracing a number of contemporary automation, data exchange and manufacturing technologies."

At the end of 2015, Gartner forecasted that 6.4 billion IoT devices would be in use worldwide in 2016 (up 30 percent from 2015), and that their number would reach 20.8 billion by 2020 (in other words, in 2016, 5.5 million new IoT devices would be connected every day).[4] In addition, the IoT market will support service spending of US$235 billion in 2016 (up 22 percent from 2015). In terms of hardware spending, consumer applications will amount to US$546 billion in 2016, whereas smart services and other applications using connected things in the enterprise will bring US$868 billion in 2016. Gartner also projects that by 2020, these numbers will reach US$1.534 and US$1.477 billion, respectively. Estimates from other sources are more ambitious.[5]

The relatively recent rise of the IoT is driven by the increased availability of omnipresent, ever-shrinking, low-cost devices (such as sensors, smartphones, and wearables); ubiquitous Internet connectivity and cloud computing services; and the pressure on industry to innovate faster to maintain competitive advantage. These IoT developments have impacted application domains such as transport, healthcare, disaster management, and utility grids.

IoT and cloud computing are particularly important for the manufacturing sector, as illustrated in several recent studies reporting IoT-based productivity gains in manufacturing plants. For example, Cisco recently reported productivity improvements via IoT-based cloud solutions in power tools manufacturing plants.[6]

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Business Value of the IoT and Cloud in Manufacturing

Currently, many manufacturing plants employ machines, sensors, and handheld devices for data acquisition and supervisory control. However, direct, real-time, and bidirectional communication between these machines and devices is daunting because of the restrictions imposed by the variety and incompatibility of their interfaces and communication protocols. Although some proprietary solutions exist, they're expensive, rarely open, and don't allow real-time plant data analysis and delivery of high-value information for instantaneous decision support. In contrast, the IoT provides standards and solutions that are Internet-based, open, and bridge the gap in collecting data from any plant machine or device. More importantly, it supports bidirectional machine-to-machine communication in the plant or anywhere on the Internet. The IoT, when combined optimally with cloud services, allows for real-time computation and delivery of high-value information anywhere. For example, it provides for real-time key performance indicator (KPI) monitoring and prediction delivered to the smartphone of a plant manager or CEO. These advantages are enabling manufacturing plants across the world to gain unprecedented operation effectiveness, increase profits, and reduce costs.

Consider, for example, a recent Cisco survey that captured key production areas where the introduction of IoT and cloud solutions makes manufacturing plants more effective.[6] Figure 1 illustrates the IoT impact in each of these key production areas.

The IoT and cloud services bring important business value to manufacturing. For example, machines, sensors, and handhelds connected through the IoT capture increasingly detailed plant data. Real-time analysis of this data using cloud services results in productivity, quality, and safety insights that drive business and operational transformation, reducing labor and productivity costs and increasing profits. These findings can also support production process improvement and timely delivery of task-related information to workers and plant machines.

Opportunities for Introducing IoT Solutions to Manufacturing Plants

This section outlines several opportunities for improving productivity, quality, and safety in manufacturing

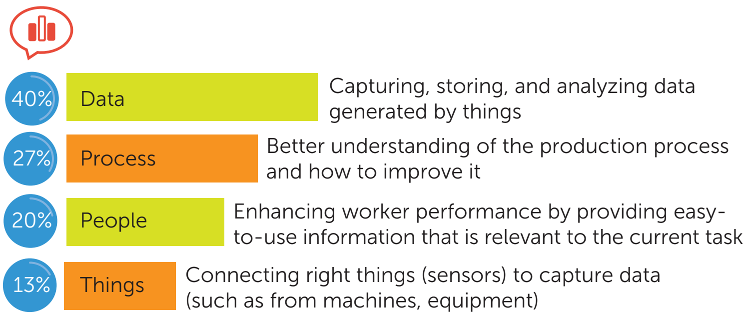

FIGURE 1. Key production areas where the introduction of IoT and cloud solutions makes manufacturing plants more effective.

plants identified through extensive consultations with manufacturing industry professionals. The first opportunity, real-time monitoring of production KPIs and KPI-driven production process assessment and improvement, involves

- automatically computing and visualizing KPIs in real time;
- providing personalized KPI visualizations and alerts to plant management and personnel that are relevant to their responsibilities and needs; and
- capturing and analyzing the production process to identify opportunities for improvement.

A second opportunity, smart inventory management, includes electronically tagging products to enable tracking and identifying them both while they're in the plant and as they move from plant to consumer. Smart inventory management also includes optimizing product inventory operations to reduce labor cost and time. This involves either automation via robotic transportation of products to and from storage to fill customer orders (which is expensive and more suitable for large plants), or optimization of manual inventory tasks via smartphones or other IoT tracking devices that monitor and direct manual picking and storing activities (which is inexpensive and more appropriate for smaller plants).

A third opportunity is the automation of complex activities for assessing product quality using specialized camera systems or wearable technologies. IoT solutions can also help make worker training more efficient by electronically monitoring and mentoring workers while they're working in production lines or performing specialized manufacturing tasks. Finally,

(a) (b)

FIGURE 2. Examples of sensors used in the Internet of Things: (a) SensorTags and (b) iBeacon. These inexpensive sensors include numerous on-board sensors and communicate via Bluetooth or Zigbee. (SensorTags courtesy Estimote, Inc.; iBeacon courtesy Texas Instruments)

FIGURE 3. Epson Moverio Smart Glasses (BT-200) for better augmented-reality experience. (Courtesy Epson)

these solutions can improve plant safety through real-time monitoring (for example, using RFID or proximity sensors) of how workers use their protective equipment, operate machines, and gain access to restricted work areas.

Advancements in the IoT Device Ecosystem

Because the IoT is Internet based, its basic infrastructure (National Broadband Network, Wi-Fi, 3G/4G, and so on) is already in place worldwide. IoT devices and their data are becoming common, cheap, and easily accessible. For example, RFID tags currently cost about US$0.15 each, making them practical for tracking low- to medium-value assets. Low-cost sensors, such as the SensorTag and iBeacon (Figure 2), which are manufactured in massive numbers, include a multitude of on-board sensors, and can communicate via low-energy Bluetooth or Zigbee. They're available on Amazon for around US$20–$30 per device and purchasing large quantities can bring the cost to down to US$10 per device.

In the wearable IoT technology space, Epson glasses (see Figure 3) are available off the shelf for less than US$700. Cheaper and more capable wearable IoT devices come to the market every month; within 12 months such products will likely cost about half the current price.

Such IoT devices offer simple plug-and-play functionality and don't require skilled technicians to install or maintain, hence they can be easily integrated into existing manufacturing plants. Moreover, their batteries allow continuous operation for several months—in some cases, up to two years. Battery life is also improving rapidly.

IoT devices can capture, bidirectionally communicate via the Internet and cloud services, and analyze data about any activity or resource involved in a manufacturing plant's production processes. IoT-based solutions can process data in real time to instantaneously monitor and predict KPIs, and discover opportunities for reducing the utilization of plant resources, such as labor, energy, and water. Wearable IoT devices such as Epson glasses create a new opportunity to provide task-related information, KPIs, and training or mentoring to production line workers. Sensors, such as SensorTags, attached to workers' clothing and protective equipment allow plant managers to monitor workers' use of safety equipment and can generate alerts in real time if they detect a serious safety risk.

Advancement in Edge Cloud Computing Datacenters

Collecting and analyzing information in real time while avoiding excessive data transfer and data processing delays is at the heart of smart manufacturing in the digital age. Cloud services today are hosted in, and offered from, large datacenters operated by companies such as Amazon, Apple, Google, Microsoft, and Facebook. Using various service-provisioning paradigms, such as platform as a service and infrastructure as a service, hardware and software services in datacenters are virtualized, and these virtualized resources are then rented out on a pay-as-you-go model.

Cloud datacenters have traditionally been used to process IoT data since they provide cheaper and virtually unlimited computing power. However, with the challenges imposed by the rapidly growing IoT ecosystem, current assumptions that the intelligence and resource capacity necessary for IoT data processing reside predominantly in the cloud datacenter are being challenged.

The burden of uploading data to remote cloud datacenters is on the resource-constrained IoT devices, leading to inefficient uses of their bandwidth and energy. A store-and-process-later approach might generate some savings. This, however, undermines real-time decision making, which has been the mantra behind IoT. Highly time-sensitive IoT applications in manufacturing and other domains require immediate analysis of, or response to, the sensed data. For example, they could warn of roof collapse, air quality, temperature, and humidity in underground mines and indoor manufacturing plants; identify workers who don't have the appropriate gear or adequate training for a particular machine; or prevent unauthorized workers from entering restricted areas.

Hence, traditional cloud-centric IoT approaches (such as Amazon IoT and Google Cloud Dataflow) must undergo a paradigm shift toward a distributed model so they can take advantage of smart and programmable cloud services at the network edge, such as smart gateways (Raspberry Pi 3, UDOO board, ESP8266, and so on) and network function virtualization solutions (Cisco IOx, HP OpenFlow, and Middlebox Technologies, for example). These cloud services on the network edge can offer computing and storage capabilities on a smaller scale (often referred to as an *edge datacenter*) to support traditional cloud datacenters in tackling real-time data processing challenges. Moving IoT data processing activity closer to IoT data sources or data sinks has two clear benefits:

- It saves energy for the resource-constrained edge devices, which under the current resource management model must continuously upload data to the cloud datacenter.
- It saves unnecessary network bandwidth consumption.

Edge datacenters support smart manufacturing plants (SMPs) by providing increased processing and storage capacity as an extension of available IoT devices, but without needing to move data or processing to a centralized cloud datacenter. This reduces communication delays and the overall size of the data that needs to be migrated across the Internet and public and private datacenters. Edge datacenters can employ a set of mechanisms to process data on behalf of the IoT device, effectively sending data to the remote cloud datacenter only when more complex analysis is required and the processing capacity is available at the edge.

Roadmap to the Smart Manufacturing Plant

We expect that the roadmap to an SMP starts with the implementation of one or more IoT-based solutions that address the immediate opportunities identified earlier. However, we also envision the establishment of an SMP forum initiative (described later) that will allow the industry to share IoT experiences and solutions, permit third-party vendors to contribute IoT solutions for industry to try, and encourage the industry to jointly develop or adopt IoT solutions, industry-specific interfaces, and standards, as well as identify and use free and open source IoT software infrastructure for developing them.

We outline our recommendations for achieving these opportunities and highlight the benefits a IoT-based solution will help deliver for improved business outcomes. The solutions described next are underpinned by cloud and edge services that provide the necessary networking, storage, real-time data analytics, and information delivery capabilities.

Monitoring Plant KPIs in Real Time

From our consultations with the manufacturing industry, it was evident that the major drivers for manufacturing businesses are cost and quality. Cost and quality KPIs originate from major customers and are mapped to corresponding manufacturing plant operations and inventory management and supply chain operations. Therefore, we can broadly classify processing KPIs as

- *Customer-driven KPIs* include KPIs that are set to satisfy customer requirements such as product quality (for example, mean time between failures), unit cost, consumer safety, consumer preferences, and the development and market trial of new products.

- *Plant operations KPIs* aim to track and improve plant and supply chain productivity, maintain plant/worker safety and related personnel training, and measure and forecast product demand.

One of the most important directions for the manufacturing industry is develop IoT solutions for real-time KPI monitoring and assessment of the plant's production process from the perspectives of productivity, product quality, and safety. Such an IoT-based solution should perform automatic real-time computation, visualization, and prediction of plant KPIs, as well as real-time delivery of personalized KPIs to management and supervisors via any IoT device. In addition, such an IoT-based solution might provide personalized KPI dashboards in real time that are appropriate for the scope of each employee's responsibilities. For example, IoT can combine real-time production data from IoT devices with existing plant databases and graphically display performance KPIs tailored to the employee's role and responsibilities. This IoT solution can help workers and management instantaneously assess and quickly respond to customer and operational KPIs, for example, by making informed decisions about productivity, product quality, and safety dynamically.

Improving Productivity

Current industry KPIs are mainly based on

- *input*—raw materials or externally produced parts processed in the plant each day;
- *output*—the number, type, and quality of products produced, and orders filled per day; and
- *resources*—labor and other resources, such as electricity, water, and machine maintenance costs, used to convert plant inputs to outputs.

To improve productivity, product quality, and safety, manufacturers could use IoT devices to capture higher-fidelity production process data—that is, more detailed data about each activity and subactivity, instead of only capturing the data needed for existing KPIs. IoT devices can similarly monitor plant machines to determine their operation versus idle time, the quality of the parts they produce, and reliability.

Directions manufacturers could take to achieve these improvements include breaking down plant processes to finer activities, for example, by considering not only how many people and machines are on the job and how many products they produce, but also how much time they spend in less productive activities that could be eliminated, reduced, or replaced. Another direction is to electronically detect and monitor activities and subactivities in the production process, including their input/output and the resources they use. (IoT is ideal for this purpose because it can use existing RFIDs, new low-cost sensors, and "bring your own" smartphones, and put this data on the Internet for KPI computation and alerts.) Manufacturers might also compute higher-fidelity productivity, quality, and safety KPIs from monitoring such activities and resources (in real time). Other possible directions are improving the production process to include more productive and fewer unproductive activities and periodically repeating IoT-based production process improvement steps.

Optimizing Inventory Management

Manufacturers could use smartphones or IoT wearable devices to collect information from manual inventory management operations, and use this information to optimize and automatically guide workers' picking and packing activities based on product weight, age, and quality. In particular, IoT-based solutions that dynamically track, optimize, and guide picking and packing activities could improve plant's productivity by reducing labor costs and the time involved in moving and finding the appropriate products stored in warehouses. This solution will also allow plants to minimize product inventory, storage, and/or heating and chilling capacity to the minimal level needed to fill customer orders. IoT-based solutions could also improve a manufacturer's ability to track, find, and store products based on quality and weight, and enhance production line agility to accommodate multiple customer orders concurrently.

Smart mobile devices are widely available, and ubiquitous IoT tracking devices are cheap and easy to install and maintain. An IoT-based solution can readily leverage any smart mobile or IoT tracking device. The IoT also provides standards (for example, the W3C's Semantic Sensor Networks, www.w3.org/2005/Incubator/ssn[7]) and open source cloud-based platforms[8] (such as the Open Source Project for the Internet of Things, https://github.com/

OpenIotOrg/openiot) for integrating such devices and their data and supports real-time processing of data streams.[9] By including an evolutionary learning component to process such data streams in real-time on edge servers, an IoT-based solution (supported by corresponding cloud services) can generate optimized path for storing, picking, packing, and transporting products based on product features such as model, weight, quality, age, and customer order. An IoT-based inventory management solution should perform real-time tracking of workers, and also deliver corresponding personalized directions to workers via their smartphones or IoT wearable device for optimized inventory management.

Enabling Plant-to-Customer Traceability

Solutions for SMP-to-consumer traceability permit consumers to track the products they purchase from the plant that produces them, and also enables manufacturers to identify the sources of the product parts.

Such solutions can also help identify product-related issues along the plant-to-consumer supply chain, help provide security against counterfeiters in export markets, and enable the creation of a productive and more incentivized market—for example, high-quality suppliers can earn additional money per product.

The IoT is ideal for providing product traceability from plant to consumer. An IoT solution can track products from their manufacturers to their consumers using a variety of RFID and sensor technologies. The IoT's ability to easily integrate IoT devices, transfer information collected at various steps of the supply chain via the Internet, and store and process such information in a cloud datacenter-based infrastructure that supports information sharing will allow manufacturers to identify suppliers of quality parts. Having such information will ensure that their products meet customer expectations with less risk and cost. An IoT-based solution can also deliver improved product security by raising alerts and providing means to investigate product-related hazards and product counterfeiting. This will allow the industry to maintain its reputation for its products.

Automating Manual Tasks

Current directions in this area include the development of IoT solutions to improve onsite worker safety by attaching low-cost sensors or RFIDs to the worker's protective clothing or gear and the plant equipment. Such safety solutions will alert workers (and in the case of a serious safety risk, relevant floor supervisors) of potential hazardous situations.

In particular, such solutions supported by corresponding edge and cloud services must be able to identify workers who aren't wearing protective gear or aren't wearing it correctly, standing next to machines they aren't qualified to operate, or entering restricted areas they aren't allowed in. They might first send warning alerts to noncomplaint personnel; if noncompliance continues, they can alert the relevant floor supervisors. Finally, these solutions must be smart enough to detect compliance by differentiating between situations such as whether protective equipment is being worn correctly or incorrectly.

Next Steps Toward Smart Manufacturing Plants

LocalGrid's fog computing platform (www.localgridtech.com/smart-manufacturing) exemplifies our SMP vision. The company depicts a manufacturing plant as a collection of IoT solutions supporting the major production activities (or subprocesses) in manufacturing. Such an IoT-based smart plant consists of several IoT solutions interoperating (that is, they use standardized interfaces to exchange data bidirectionally) in real time via the Internet supported by edge and cloud services. Each IoT solution in the plant inputs and outputs products and production data and uses resources such as human labor. IoT-based solutions for manufacturing also compute and predict KPIs, optimize and coordinate activities, and track products and people.

The final direction we envision is for organizations in the manufacturing industry to work together to establish an SMP forum. This forum should aim to support open, joint, and experimental IoT solution innovation across the manufacturing industry. In particular, we envision a forum that

- defines and maintains standardized, open, industry-specific interfaces for developing, using, sharing, and procuring IoT solutions for manufacturing plants;
- lets industry partners share existing IoT solutions and jointly develop new ones to achieve cost sharing and further standardization;

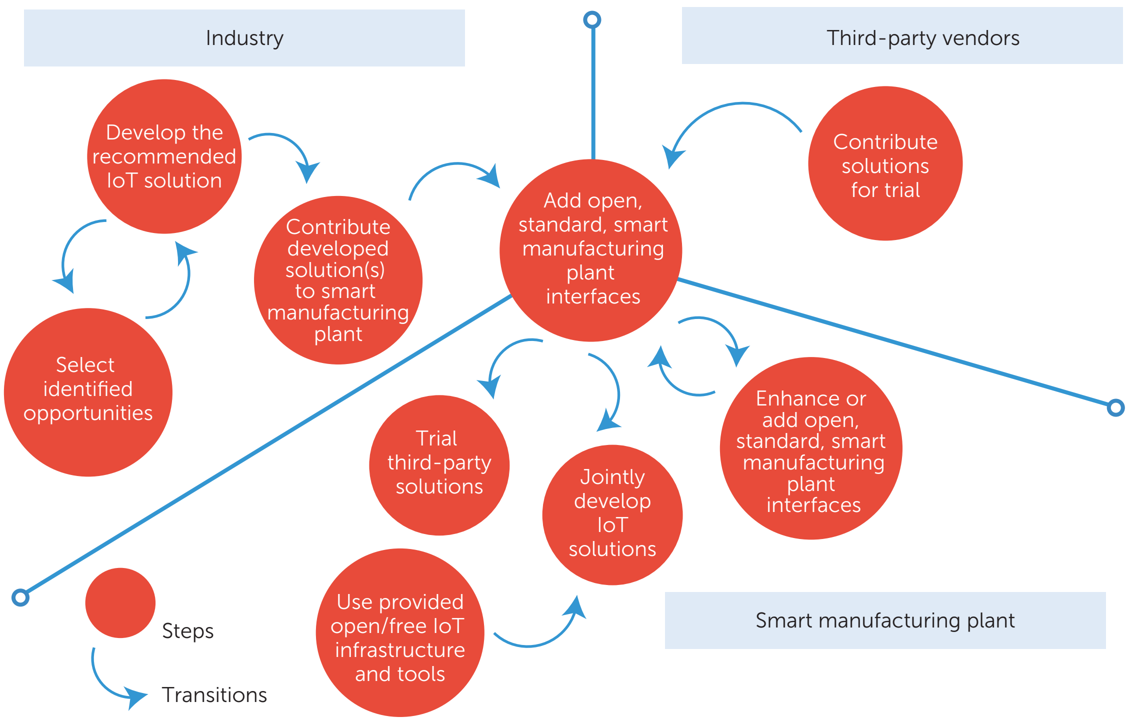

FIGURE 4. Smart manufacturing plant (SMP) roadmap toward an SMP forum for co-innovation.

- permits third-party solution vendors to offer IoT solutions for trial to multiple industry plants, reducing effort and customization costs;
- lets the industry share IoT-related experiences and lessons learned, as well as noncompetitive production and demand information that can support forecasting for the entire industry.

An SMP forum would bring together the collective genius of the manufacturing industry and its vendors to share knowledge and resources to solve common problems. To this end, we put forward an SMP roadmap for co-innovation, which is depicted in Figure 4. The roadmap is based on emerging initiatives, such as Industry 4.0[3]) and ideas from similar forums that have been widely adopted in other industries, such as energy[10] and telecommunications.

As Figure 4 shows, the SMP roadmap recommends establishing an SMP forum that allows manufacturing industry partners to identify immediate opportunities and develop IoT solutions for them based on the directions we've outlined. They can then bring their solutions to the SMP forum, which will involve establishing open standardized interfaces for the contributed solutions. Alternatively, if the SPM forum has already established such interfaces, any contributed IoT solution will need to support them. Supporting such standardized interfaces will allow others to use the existing solutions and share development costs. This roadmap will also let third-party vendors develop and provide solutions to be tested before being integrated in multiple manufacturing plants. In addition to improving IoT solution adoption speed, following this roadmap will reduce vendor costs for producing new IoT solutions and will allow industry partners to jointly procure them.

Many other industries have established and implemented roadmaps when facing similar game-changing technology opportunities. For example, the telecommunications industry has achieved an enormous degree of automation and interoperability through bold visions and initiatives, such as Cable Labs (www.cablelabs.com) and the Telemanagement Forum (www.tmforum.org). These initiatives have allowed the industry to co-innovate and share related risks, while saving billions of dollars in solution development. Although the nature of the manufacturing industry is different, lesson learned in adoption of new technologies from other successful industries support our SMP vision.

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