Framework for connected supply chain based on Internet of Things and cloud services

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***Abstract*—With the power to enable greater visibility and control, the use of Internet of Things (IoT) technology in the supply chain offers new possibilities to improve processes and operations. However, due to supply chain complexity, implementing IoT solutions effectively can be very challenging project, and it requires forethought, strategy, platform and models. In this paper, we discuss opportunities for employing IoT systems in supply chain management (SCM) along with literature review and state of the art background research. We introduce the six-step framework for implementing more agile and intelligent IoT connected SCM systems. Finally, based on the proposed framework, we present and-to-end solution for connected factory which utilizes various IoT, data management and analytical cloud services in order to enhance visibility and responsiveness, increase efficiency, lower costs, and improve decision making.**

I. Introduction

The speed of current technological breakthroughs and the exponential pace of disruptive innovation now bring about a fourth industrial revolution, known as Industry4.0—characterized by unprecedented processing power, storage, access to knowledge and the blurring of lines between physical, digital, and human space.

As the collaboration between suppliers, manufacturers and customers is crucial to increase the transparency of all the steps from when the order is dispatched until the end of the life cycle of the product, it is therefore necessary to analyze the impact of Industry 4.0 on the supply chain as a whole [1].

At the heart of supply chain digital transformation efforts are a combination of cloud- and edge-based technologies, including high-performance computing, IoT, and advanced analytics. These technologies enable companies to digitally connect and model process, physical assets or products – creating "digital twins" that replicate the physical world and enable sophisticated analysis and advanced simulation.

The IoT presents unprecedented opportunities to digitally enable the supply chain, and to create solutions that combine digital and physical products and services. Connected sensors, devices, and intelligent operations can transform traditional supply chain management and enable new growth opportunities, better efficiency, process improvements and competitive advantage.

ERP (Enterprise Resource Planning) and SCM systems have gone together for quite some time, but the IoT revolution will allow companies to enhance those solutions by intelligently connecting people, processes, data, and things via devices and sensors. Now, companies can access, analyze, and use previously untapped data to automate business processes and trigger automatic alerts and actions, helping to increase efficiencies and decrease costs.

Surveys show that IoT is among top three digital supply chain initiatives for past several years.

Worldwide spending on the Internet of Things will reach $800 billion, growing 16.7% year-over-year in 2018 [2]. In terms of industry, manufacturing, transportation and utilities currently lead the charge in terms of total spending on IoT. The largest use cases for IoT currently exist in the supply chain: the manufacturing operations segment is forecast to spend $105 billion this year; freight monitoring will invest $50 billion; and production asset management will spend $45 billion [3].

II. Background Research

Supply chains are increasingly complex in this globalized world. Connecting people, processes, data and products is incredibly difficult, which is why the IoT is tipped to cause big changes in how supply chains operate.

One of the surveys shows that a thirty-fold increase in Internet-connected physical devices by the year 2020 will significantly alter how the supply chain operates [4]. Specifically, the impact will relate to how supply chain companies collect and process large volumes of data, perform analytics and automate decision making and actions.

While we're still in the early days of IoT solving these challenges, organizations need to start mapping out the opportunities, barriers and strategies for moving forward now or risk being left behind by more agile, efficient and flexible competitors. From improved data capture and demand planning to leveraging data analytics, there are many use cases that are particularly exciting for the supply chain that can directly drive operational process improvements and cost savings [5]:

- Manufacturing Maintenance - One area where supply chain IoT progress can be seen is within production facilities that integrate sensor networks into machinery to increase up-times, reduce operational cost and improve overall quality of service.
- Inventory Forecasting - IoT data provides critical information to change the way manufacturing and distribution companies understand procurement operations.
- Asset Tracking - From manufacturing to production, IoT capabilities are also applicable to warehouse operations, where new replenishment models help monitor inventory and stock levels for distribution.

- Logistics - Key to in-transit visibility are cloud-based GPS and Radio Frequency Identification (RFID) technologies, which provide identity, location, and other tracking information.

These examples demonstrate that the new wave of IoT technology, including its integration into the likes of virtual reality, predictive analytics, cloud, business intelligence, and demand planning, are changing the way supply chain operations interact with both customers and partners. IoT provides companies deeper supply chain visibility through a network that helps cut down on lost margins and prepare for expansion, both of which are critical to market success.

However, many companies have yet to integrate and/or replace existing legacy systems with new technology advancements. Common barriers to adoption include expertise, confidence or budget concerns. Additionally, a basic lack of understanding of multitude of technologies, scalability needs, cost and management requirements stand in the way of IoT-implementation [6]. On the other hand, most of the existing research and studies have focused on conceptualizing the impact of IoT with limited analytical models and empirical studies. In addition, most studies have focused on the delivery supply chain process and the food and manufacturing supply chains [7].

In this paper, we introduce the six-step framework for designing and developing IoT supply chain systems and provide concrete IoT cloud solution for realizing smart factory concept.

III. Connected Supply Chain Operations

A. *Framewrk for Connected SCM*

The world of supply chain operations is forever changing with the help of IoT devices, which are enabling visibility and real-time insights that can lead to new revenue and business opportunities. IoT use cases in supply chain management and manufacturing are expanding at a rapid pace.

Here, we present a phased approach that helps companies start quickly, gain rapid insights, and expand according to business needs. While each IoT project is unique to specific supply chain, this approach offers a unified methodology which encompasses all the steps needed to design, develop and implement IoT solutions:

1. Determine supply chain digitization objectives - In addition to understanding the possibilities, it is important to determine target business objectives. This helps provide the foundation for a business case and serves as a benchmark for proving value. It is also important to start small and identify a specific place to start.
2. Experiment with data sources - Experimenting with a solution that allows for simulation gives companies a no-risk way to see what digitization can accomplish. Simulations don’t require connecting any of actual equipment and won’t impact real operations.
3. Connect equipment without disruption - Digitization does not have to be accomplished all at once. Connecting a specific set of equipment enables experimenting on a small scale and at own pace, all without disrupting operations. This creates a foundation companies can build on and scale out across supply chain when ready.
4. Contextualize and visualize manufacturing performance - With connected equipment comes greater visibility into operational status, anomalies, trends, and other performance insights. This visibility is the foundation for making a wide array of operational improvements.
5. Make operational changes based on data - The visibility gained by connecting equipment adds value when those insights drive operational changes. Better visibility and insight makes it possible to identify issues and respond faster, make better decisions, and enact other operational changes.
6. Enable new scenarios and scale - As companies enable new scenarios and scale, the key is to continue experimentation using a phased approach, and to continue fine-tuning as business needs and environment evolve.

B. *Solution for Connected Manufacturing*

In order to demonstrate the effectiveness and applicability of the proposed framework, we have designed and developed an end-to-end IoT smart factory solution that implements common industrial scenario using various cloud services such as IoT gateways, event hubs, stream analytics, storage and web portals. It has been designed as a preconfigured cloud solution (with reusable assets such as servers, containers, jobs, analytical models, dashboards, etc.) which can be used as a starting point for specific implementation or customized in order to meet specific supply chain requirements [8].

In this simulated scenario, several factories connected to the solution report the data values required to compute overall equipment efficiency (OEE) and key performance indicators (KPIs). The web portal dashboard enables companies to:

- Monitor factory, production lines, station OEE, and KPI values.
- Analyze the telemetry data generated from these devices using time series machine learning cloud service.
- Act on alarms to fix issues.

Each factory has production lines that consist of three stations each. Each station is a real OPC UA server with a specific role:

- Assembly station
- Test station
- Packaging station

These OPC UA servers have OPC UA nodes and OPC Publisher sends the values of these nodes to the cloud. This includes:

- Current operational status such as current power consumption.
- Production information such as the number of products produced.

The logical components of the solution accelerator are shown in Figure 1.

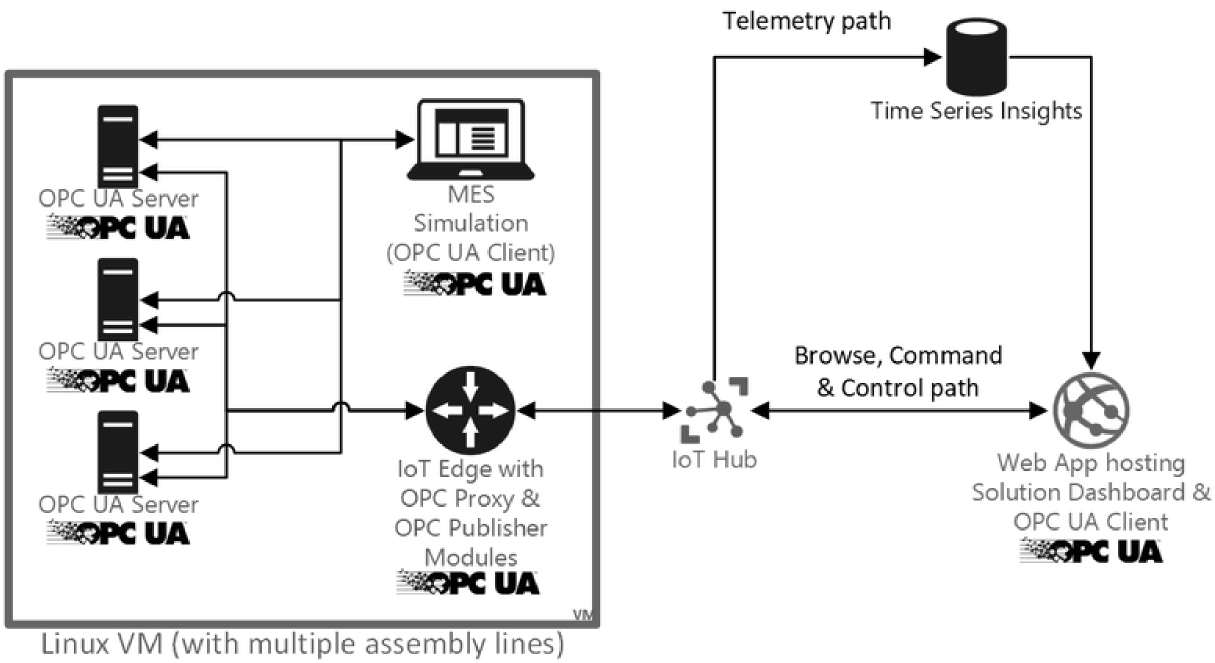

Figure 1. Logical Architecture

The solution uses the OPC UA (Open Protocols Communications Unified Architecture) Pub/Sub specification to send OPC UA telemetry data to IoT Hub in JSON format. The solution uses the OPC Publisher IoT Edge module for this purpose. The system can also connect to both simulated industrial devices running OPC UA servers in simulated factory production lines, and real OPC UA server devices.

The simulated stations and the simulated manufacturing execution systems (MES) make up a factory production line. The OPC Proxy and OPC Publisher are implemented as modules based on IoT Edge. Each simulated production line has a designated gateway attached.

All simulation components run in cloud containers hosted in an Linux virtual machines. The simulation is configured to run eight simulated production lines by default. A production line manufactures parts. It is composed of different stations: an assembly station, a test station, and a packaging station.

The simulation runs and updates the data that is exposed through the OPC UA nodes. All simulated production line stations are orchestrated by the MES through OPC UA.

The MES monitors each station in the production line through OPC UA to detect station status changes. It calls OPC UA methods to control the stations and passes a product from one station to the next until it is complete.

The solution also has an OPC UA client integrated into a web application that can establish connections with on-premises OPC UA servers. The client uses a reverse-proxy and receives help from IoT Hub to make the connection without requiring open ports in the on-premises firewall.

The IoT hub receives data sent from the OPC Publisher Module into the cloud and makes it available to the cloud machine learning time series service.

The Gateway OPC Publisher Module subscribes to OPC UA server nodes to detect change in the data values. If a data change is detected in one of the nodes, this module then sends messages to Azure IoT Hub.

IoT Hub provides an event source to cloud time series service. This service stores data for 30 days based on timestamps attached to the messages. This data includes:

- OPC UA Application Uri
- OPC UA Node ID
- Value of the node
- Source timestamp
- OPC UA DisplayName

To retrieve the data for the OEE and KPI gauges, and the time series charts, data is aggregated by count of events, Sum, Avg, Min, and Max.

The time series are built using a different process. OEE and KPIs are calculated from station base data and rolled up for the topology (production lines, factories, enterprise) in the application.

In order to deliver valuable information and alerts, the cloud analytical web app is designed. The app is dashboard-based, and it enables:

- The visualization of OEE and KPI figures for each layer in the topology.
- The visualization of current values of OPC UA nodes in the stations.
- The aggregation of the OEE and KPI figures from the station level to the global level.
- The visualization of alerts and actions to perform if values reach specific thresholds.

Figure 2 shows the dashboard page with factory information, map, alarms, OEEs and KPIs.

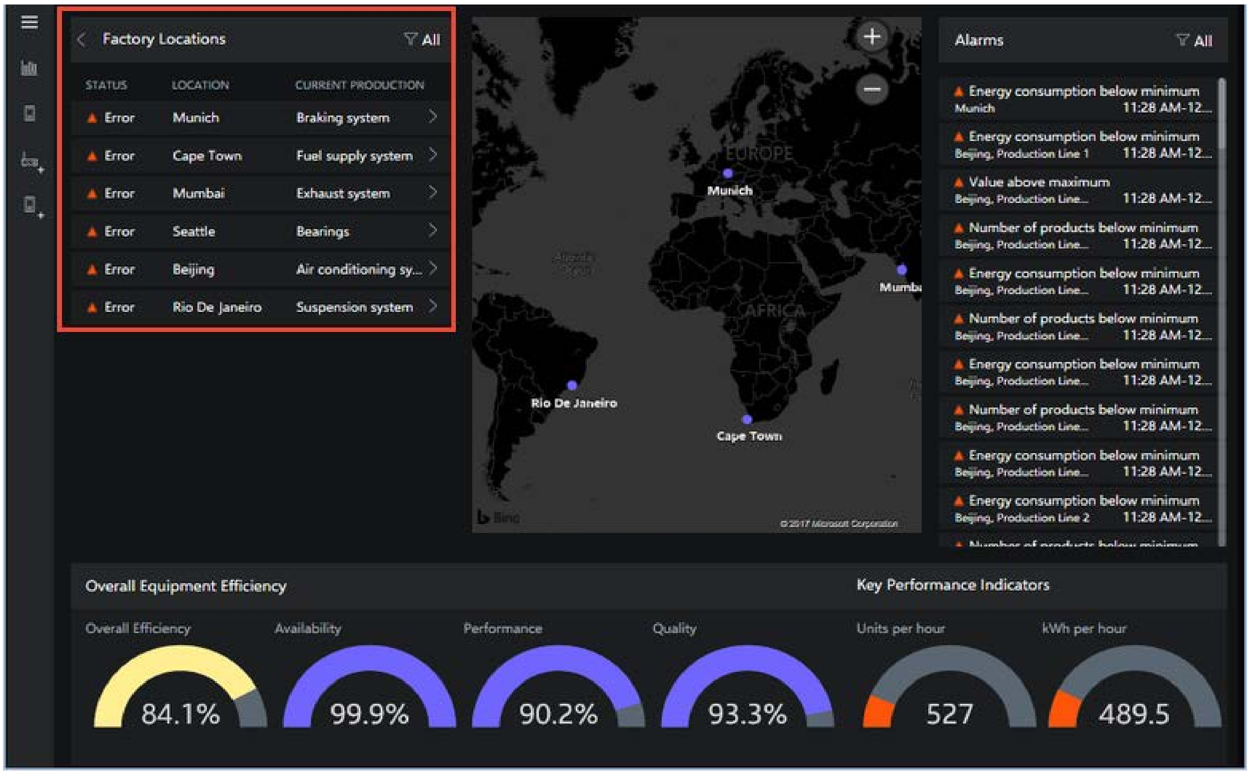

Figure 2. Dasboard analytical page

IV. CONCLUSION

Digital transformation means harnessing various technological capabilities like IoT, cloud and big data to gain insights that companies can use to make their supply chain operation faster, more efficient, and more flexible. This transition process brings many challenges and risks, and it requires careful and systematic planning and implementation.

In this paper, the framework for implementing connected supply chain is presented. It employs a phased approach that encompasses the whole lifecycle from the digitization objectives, all the way to improvement and scaling. This approach provides better effectiveness and success of the projects.

Benefits of the presented connected factory solution can include:

- Improved visibility across manufacturing operations—make more informed decisions with a real-time insight of operational status.
- Improved utilization—maximize asset performance and uptime with the visibility required for central monitoring and management.
- Reduced waste—take faster action to reduce or prevent certain forms of waste, thanks to insight on key production metrics.
- Targeted cost savings—benchmark resource usage and identify inefficiencies to support operational improvements.
- Improved quality—detect and prevent quality problems by finding and addressing equipment issues sooner.

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