Enhancing Supply Chain Operations Using IoT and Digital Twin

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CONTENTS

FIGURES

1 ABSTRACT

This paper will discuss how to enhance the supply chain operations using IoT and digital twin. Connected supply chain operations provide better visibility and tracking, and using IoT systems such data can be used as the foundation for building the process digital twins.

Supply chains often involve a complex network of interconnected systems leading to the movement of goods and services from suppliers to customers. In recent years, the supply chain has become increasingly digitalized, using IoT and digital twins. IoT sensors data such as location of goods in transit and the temperature of refrigerated goods can be used to identify potential quality issues as well as improve the design, operation and performance of the supply chain processes.

Overall, IoT and digital twins of supply chains can help to improve efficiency, reduce costs, and improve customer satisfaction.

2 INTRODUCTION

Well-designed SCM systems are complex operational networks that enable the timely and efficient movement of products and services from suppliers to customers. SCM systems involve many different stakeholders working together, which include manufacturers, distributors, transportation providers, warehouses, retailers and both b2b and b2c consumers.

Coordinating these interconnected systems of SCM is critical but often not an easy task. In many cases, these supply chains may span global distances, e.g. a car being manufactured overseas. Even small inefficiencies can cascade into major disruptions in supply chain operations.

As an example, the blocking of the Suez Canal by the Ever Given container ship in March 2021 paralyzed this critical trade route and caused major disruptions to global supply chains. Here is the overview of this incident that aggravated a global supply chain operations crisis:

- The Suez Canal is one of the world's most important trade routes that is used by about 50 ships daily. It provides the shortest sea link between Asia and Europe.
- When the 200,000 ton Ever Given ran aground and blocked the canal on March 23, 2021, marine traffic came to a standstill in both directions.
- Over 360 ships ended up stuck waiting days or weeks to traverse the canal, stopping the flow of raw materials, intermediate goods, and finished products.
- The timing was especially bad as shipments of manufactured goods, commodities, and energy products were already facing strains after the pandemic.

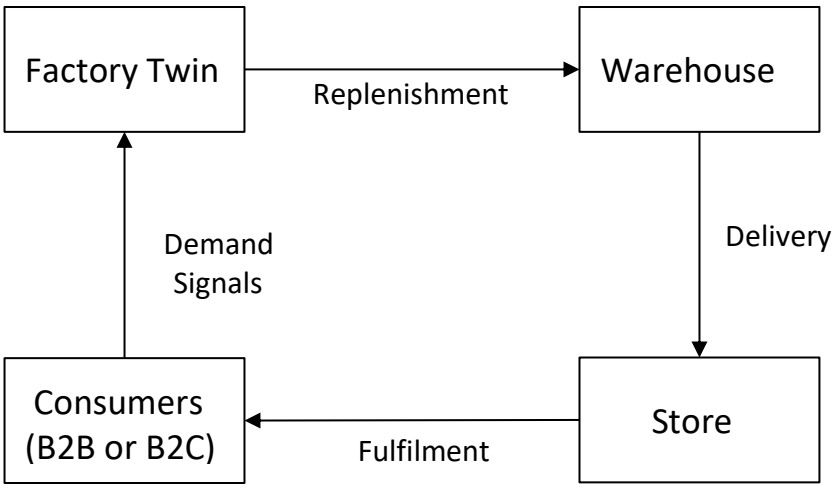
- Supply chains around the world felt ripple effects. Automakers could not get parts, leading to production halts. Europe faced delays in seafood, fruits, and oil deliveries from Asia.
- Even after Ever Given was freed on March 29th, the backlog of ships took over a week to clear as congestion persisted.
- Economists estimate that the blocking of the canal cost global trade over $9 billion with higher shipping rates and inventory shortages lasting months after.
- The crisis highlighted the vulnerability of supply chains and their dependency on single points of failure like the Suez Canal. It accelerated talks of alternate trade routes.

Even in the age of technological advances, this short-term Suez Canal obstruction led to severe consequences by paralyzing the interconnected flow of global commerce and underscoring the fragility of modern supply chains.

We need to harness the technologies available to us today, to prevent such supply chain disruptions in future. In recent years, there has been a growing interest in using IoT and digital twin technology to enhance supply chain operations. IoT involves a network of internet-connected smart sensors that can monitor almost any kind of activity or condition in the physical world. Such systems are enhanced by weather monitoring as well as weather predictions and other similar external data. Digital twins are virtual representations of physical assets or processes such as supply chain and logistics operations. By integrating IoT data flows into digital twin models, supply chains gain unprecedented visibility, responsiveness, and coordination.

IoT sensors data such as location of goods in transit and the temperature of refrigerated goods can be used to identify potential quality issues as well as improve the design, operation and performance of the supply chain processes. Overall, the synergy between IoT and digital twin can help to improve supply chain operations efficiency, reduce costs, and improve overall customer satisfaction. Here are some ways:

- Location Tracking for Real-time visibility: IoT sensors could be used to track the location and condition of goods in transit. This would provide real-time visibility into the supply chain, which could help to identify and resolve problems early on.
- Supply Chain Process Models: Digital twins can provide virtual representations of the supply chain processes. They can be used to simulate the behavior of the logistics operations and movement of goods, and to test different scenarios. This could be used to test different routing and scheduling options, and to identify potential bottlenecks in the supply chain.



Supply Chain Process Twin

Figure 2-1: Simplified process digital twin.

Figure 2-1 shows a simplified view of the digital twin of the supply chain process. The process twin may be composed of the digital twins of the sub-processes such as the manufacturing process, replenishment of inventory process, order delivery process and fulfillment process to the business or end consumer. To close the loop, this leads to demand signals back to the production systems in the factory.

Let as look at how technology can be harnessed to reduce the chances of recurrence of Ever Given like crisis in future:

- This issue was caused by high winds and sandstorm that reduced the visibility and prevented the ship to stay on a straight course. Better use of weather predictions and enhanced navigational devices to assist the ship's captain would have reduced the chances of the ship getting stuck. Integration of such leading weather predictions, to the safety and transit simulation model, based on the digital twin of the Suez Canal and its traffic operations, could be one plausible solution in future.
- While it is not always possible to have a second human co-pilot, an equivalent of the ship's Captain using generative AI-based technologies can provide the captain with a second opinion for navigation and risk avoidance in such cases.
- In future, alerting the ship's crew and the Suez Canal traffic operations about using tugboats proactively in marginal weather conditions or holding and pacing the other ships, can be a recommendation from the SCM process digital twins.
- Finally, advising the enterprise shippers to not put all their "eggs in one basket" when possible and split their shipments into two different ships or modes of transportation, to

reduce chances of larger amounts of inventory getting stuck in transit. Such advisories can be generated based on weather predictions, seasonality and traffic volumes.

In this example, if the inventory is tracked by the shipper, then the delay in the replenishment or the delivery can also be tracked. This can be achieved by inputting tracking data into the process digital twin, which in turn can be used to run scenario analysis to decide if alternate shipment, such as air shipment for electronics or expensive merchandise, should be initiated to prevent fulfillment defaults. Likewise, simulations can be done using the process twins to figure out how production orders in the factory should be altered to deal with a crisis.

Using a related example from Peloton, the home-gym equipment company who experienced massive demands in early 2020. Due to the pandemic, which had forced gyms to close, Peloton CEO John Foley said they were flying parts from all over the world in 2020 to meet massive demands. While the cost of flying gym equipment parts is very high, it met their needs due to high customer demand for their premium end products.

The connected Peloton products provide leading indicators of actual use and user satisfaction and the expected demands from the customers. This proves that advisories and recommendations from the forecasting and simulation systems based on data from connected products and operations when coupled with appropriate sourcing strategies, can help to optimize the SCM systems. This is one way to reduce the adverse impact of the global supply chain crisis.

3 CHALLENGES

One of the biggest challenges in supply chain operations is the lack of real-time visibility and tracking of inventory and assets as they travel through the network. This can lead to problems such as stockouts, late deliveries, and product damage. The lack of real-time data creates opportunities for instrumentation of the shipments, operations, manufacturing facilities and in some cases the end products, as well.

Another challenge in supply chain management is the need to optimize routing and scheduling. This can be a complex task, as it involves taking into account factors such as traffic conditions, weather, and the availability of transportation resources such as trucks, trains and ships. IoT sensors and weather information can help to optimize routing and scheduling by providing real-time data on traffic conditions and the location of assets. The purchase of The Weather Company in 2015, for $2.9 billion, by IBM is supporting evidence, when IBM started investing in development of IoT solutions.

Supply chains are also vulnerable to disruptions. These disruptions can be caused by natural disasters, accidents, cyberattacks, or even human error. In May 2021, a ransomware attack on Colonial Pipeline caused a massive fuel crisis in the eastern parts of the United States. The attack forced Colonial to shut down its entire pipeline system. This system delivers about 45% of the fuel consumed in the Eastern US IoT systems in combination with Digital Twin of Twins can be

used in such complex scenarios. The Twin of Twins is a concept where the net digital twin consists of multiple digital twins, each focusing on a specific domain. In this case a cyber security digital twin would help to capture the leading indicator of security vulnerability and feed to the aggregate digital twin.

Such Twin of Twins can help to mitigate or reduce the impact of disruptions by providing early warning of potential problems and evaluating different scenarios to overcome the impact after the fact. The airline industry often has to recover from massive flight disruptions when blizzards lead to flight cancellations during a busy holiday. Such solutions, which focus on restoring flights to minimize the overall impact to thousands of stuck airline passengers, can be repurposed to apply to recover from SCM crises such as those posed by Ever Given or Colonial Pipeline.

While the technology ingredients such as platforms and tools are available, designing and deploying solutions in real-world scenarios is challenging and requires an ecosystem approach. The work done by consortia like Industry IoT Consortium (IIC) and Digital Twin Consortium (DTC) is commendable in bringing the different stakeholders together, to solve such problems collectively. We recommend looking at the below related IIC testbeds:

- Industrial Digital Thread Testbed
- FOVI Testbed
- Track and Trace Testbed

The above testbeds provide the building blocks that can be used to build the supply chain process solution using IoT and digital twins.[1]

4 SOLUTION APPROACH

Another example to illustrate the power of IoT and digital twin in supply chains is the aviation industry, first from the passengers and airline perspective and then tracing it to the aviation manufacturers and the associated supply chain system. Supply chain operations are critical in that industry where aircraft require extremely high levels of reliability. Any unscheduled downtime in the airline industry results in a high cost and disturbance to flight schedules causing disruptions to passenger journeys and plans.

One of the largest aircraft manufacturers in the world, Boeing, uses digital threads to connect and streamline data throughout the entire life cycle of its aircraft. Digital threads could be created by combining the digital twins at the different stages of the lifecycle of a product such as an aircraft. By integrating sensors across their factories, Boeing gains near real-time insights into inventory requirements and operational bottlenecks. Furthermore, they leverage artificial

[1] *https://www.iiconsortium.org/test-beds/*

intelligence (AI) across the data from the IT (Information Technology) and OT (Operational Technology) systems to continually search for further enhancements in supply chain operations.

The Industrial Digital Thread Testbed by IIC, is an example where the digital thread is used to help resolve a supply chain issue that was causing quality issues in the jet engines. It is important to note that the aircraft manufacturers rely on hundreds of suppliers for the components and sub-assemblies in the aircraft. Hence, use of digital threads that try to model the complex supply chain operation, from factory to flight, can be key to further optimizations in the aviation industry.[2]

The advantages of this technology-driven approach to improve supply chain operations are substantial. It enables companies to enhance the dependability and resilience of their supply chains while reducing the need for costly investments in physical infrastructure such as additional inventory, capacity or suppliers. For instance, employing sensing and analytics tools allows for early identification of potential issues, reducing the necessity to diversify existing supply chains.

Technological advancements empower supply chains to be more flexible, as organizations can better anticipate demand and adjust to address potential challenges that could impact inventory, service, compliance, or other critical aspects. Additionally, agile supply chains not only mitigate risks but also position organizations to react quickly and seize new opportunities for growth.

4.1 IoT for Enhanced Data Collection

The proliferation of low-cost IoT sensors, power technologies, connectivity, and cloud data storage has created new opportunities to digitize supply chains by leveraging the IoT Platforms and applications. IoT sensors can be used to collect data on a wide range of factors, such as the location of assets, the environment, the condition of products, and the performance of equipment. This data can then be used to improve visibility, optimize operations, and mitigate risks. In the context of the airline industry, the jet engine is the most expensive and critical part of the aircraft.

New jet engines have around 300 sensors built into them to record the temperature, pressure, vibration during the taxi, take-off, cruise, descent and landing of the aircraft. During the flight, such information from the engine along with other aircraft body data is collected and stored in the Flight Data Recorder (FDR). Older aircraft and engines are often retrofitted with the essential sensors, during their shop visits for maintenance.

This FDR data, often referred to as the full flight data, is a treasure trove when it comes to enhanced data collection for IoT. Such data allows building hi-fidelity digital twins of the airline operations and provide resiliency to occurrence of maintenance impacts. It also prepares the supplier ecosystem of aircraft components by providing the leading indicators of parts demand.

[2] *https://hub.iiconsortium.org/industrial-digital-thread*

In future, instrumenting cargo ships like Ever Given and the associated logistics can make the global shipping industry more robust.

4.2 Building a Digital Twin

Once IoT sensors are implemented across the supply chain to collect useful data, the next step is aggregating and integrating that data to create a digital twin model of the physical assets such as the aircraft or the product being manufactured as well as of the end-to-end supply chain. A digital twin is a virtual representation of a physical asset or process. It can be used to simulate the behavior of the asset or process, and to test different scenarios. A few examples of the public cloud services for building such IoT and digital twin solutions for supply chain are:

- Microsoft Azure IoT and Azure Digital Twins[3]
- Amazon AWS IoT Twinmaker[4]
- Google Supply Chain Twin and Pulse[5] as shown in Figure 4-1

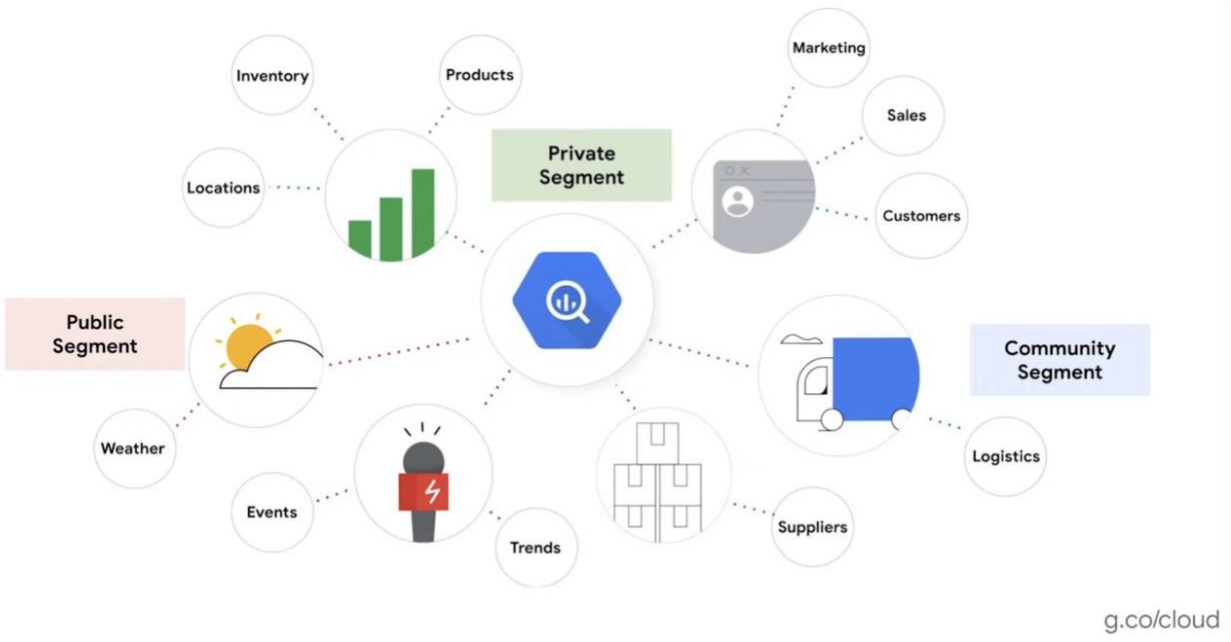


Figure 4-1: Supply Chain Twin and Pulse by Google.

There are other commercial digital twin solutions by General Electric, Bentley and some specialized providers as well. Digital twins can be used to improve supply chain operations in a number of ways. For example, they can be used to:

- Identify inefficiencies in the supply chain.
- Test different routing and scheduling scenarios.

[3] *https://azure.microsoft.com/en-us/products/digital-twins*
[4] *https://aws.amazon.com/iot-twinmaker/*
[5] *https://cloud.google.com/solutions/supply-chain-twin*

- Predict the impact of disruptions.
- Improve the accuracy of inventory forecasts.

4.3 Key Use Cases and Benefits

IoT and digital twins can transform many aspects of supply chain operations when implemented together. Some of the key use cases and benefits include:

- Inventory management: IoT sensors can be used to track the location and condition of inventory in real time. This information can be used to prevent stockouts, improve planning, and reduce waste.
- Logistics monitoring: IoT sensors can be used to track the location and movement of goods in transit. This information can be used to optimize routing, improve delivery times, and reduce costs.
- Warehouse operations: IoT sensors can be used to monitor the temperature, humidity, and other conditions in warehouses. This information can be used to prevent spoilage, damage, and other problems.
- Quality control: IoT sensors can be used to monitor the condition of products during manufacturing and transportation. This information can be used to identify problems early and prevent defects. The IIC's Industrial Digital Thread is one such example.

We earlier looked at the end-to-end supply chain systems for the aviation industry, where connected systems and enhanced data collection via IoT systems, adds overall efficiency. Such efficiencies and reduced disruption to airline passenger journeys coupled with increased safety of air-travel justify the investments in such IoT and digital twin stems. It allows the aircraft manufacturers and the airlines to communicate why such longer term investments are needed to its stakeholders and investors.

5 Implementation Considerations

While promising, there are key challenges involved in implementing an integrated IoT and digital twin solution across the supply chain. These challenges include:

- Legacy hardware/software integration: Many legacy machines and IT systems are not built to handle new data sources and digital twin integration. APIs and custom programming are required to connect new platforms with old platforms.
- Cybersecurity risks: With billions of new connected devices, expanded attack surfaces and data vulnerabilities need to be managed through cybersecurity best practices for IoT.
- Data standardization: Data from disparate sensors and sources needs to be standardized and contextualized so it can be meaningfully aggregated into supply chain analytics and digital twin models.

- Organizational change management: Adopting new technologies and data-driven processes requires change management and upskilling programs to get organizational buy-in across departments.
- Costs vs benefits: The upfront installation and integration costs associated with implementing IoT/digital twins can seem high at first but are outweighed by the transformational benefits over time as supply chains operate smarter.

Integrating IoT-enabled smart sensors with digital twin simulations offers immense potential to improve the supply chain solutions.

Let us look at one specific example: Deloitte's Project George which is named after George Devol, the inventor of industrial robotics.

Figure 5-1 shows the high-level functional blocks of the solution. It is a classic example of IT-OT (Information Technology-Operations Technology) integration. The sales order typically originates in the CRM system and makes its way to the ERP and manufacturing system. In the case of discrete manufacturing, the sales order drives the manufacturing work order in the factory to produce the specific product or batch of products. The integration of the IoT system such as production monitoring helps to ensure that there is no risk to the order execution. Predictive maintenance and health monitoring reduces factory downtime and risks to the manufacturing and delivery process.

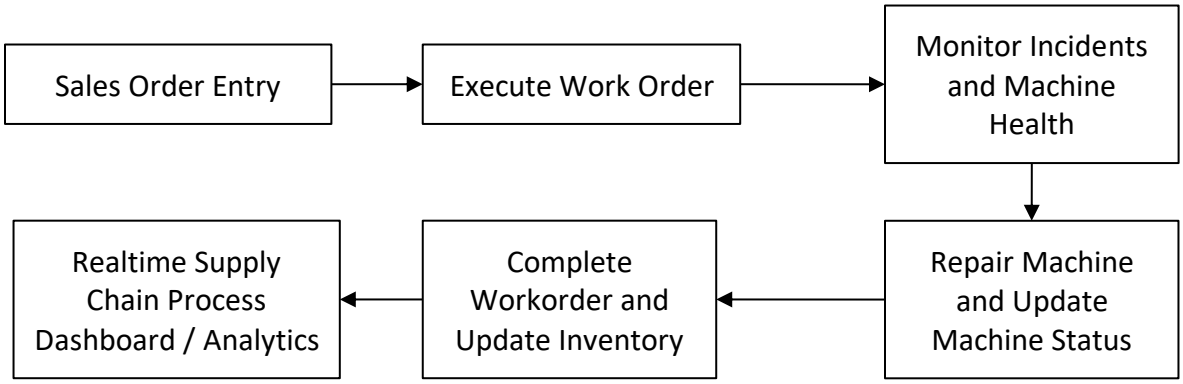


Figure 5-1: Deloitte's Project George for IT-OT integration.

It is important to realize that IoT and digital twin systems eventually become part of the larger IT ecosystem at enterprises, after they are in production use after the stabilization and hyper care state. As a result, the IT-OT integration considerations are key and should be kept as part of the initial architecture and design. Let us look at the architecture components used in Project George in Figure 5-1. Project George focuses on ecosystem collaboration to drive digital supply chain solutions.

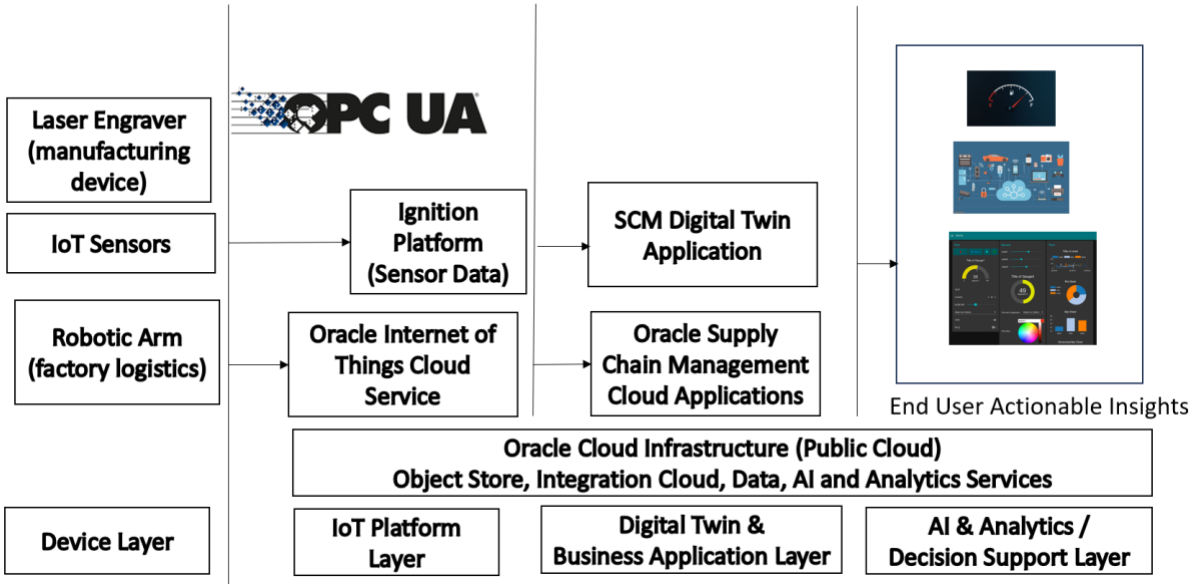


Figure 5-2: Project George high-level IT–OT application integration.

Figure 5-2 shows the high-level application landscape and how the device and sensor data is incorporated into the IoT Platform using the Ignition Platform. This in turn feeds the data into the digital twin and business applications in the business applications tier. The SCM process digital twin resides in this layer and provides the key intelligence, insights and advisory to the business users and the stakeholders in the Decision Support Layer via dashboards, KPIs, reports and graphs as well as acts like the IoT Command Center to deliver alarms and advisories. Root cause analysis can also be performed by human experts using the system insights and recommendations.

This system facilitates predictive maintenance using the IoT capabilities, to reduce the down time of the manufacturing equipment as well as help to improve the asset optimization and overall throughput. In case of unavoidable downtime, it reroutes the orders to different assembly lines and alerts the operators about the potential impact on the customer sales order and delivery dates. This helps to minimize the customer facing impacts to the order execution. Noble Plastics has implemented a similar solution for its manufacturing facilities using the Oracle stack.

The key to successful adoption and delivery of value in enterprises is the IT-OT integration, as part of the SCM solution design. That allows the existing IT teams that are often under the CIO organization to take over and support such solutions and ensure easy accessibility to the supply chain professionals and related stakeholders. Access to the external supply chain and logistics partners can be enabled in some cases to give higher and near-real time visibility to the operations.

6 CONCLUSION

In conclusion, supply chain management faces several challenges that can impact operational efficiency and customer satisfaction. The lack of real-time visibility, suboptimal routing and scheduling, and vulnerability to disruptions pose significant hurdles for companies. However, the integration of IoT sensors, IoT Platform based applications and use of digital twin and digital thread, provide a promising solution to these challenges.

By harnessing real-time data and leveraging advanced analytics, companies can gain better visibility into their supply chains, optimize routing and scheduling, and effectively mitigate disruptions. Embracing IoT-enabled supply chain systems, powered by digital twins, can lead to improved operational efficiency, cost savings, and enhanced customer service, ultimately positioning companies for success in a rapidly evolving business landscape.

7 ACKNOWLEDGEMENTS

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