Industry IoT Consortium

Digital Transformation in Practice: Learning from IIC Deployments

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1 INTRODUCTION

Achieving success with digital transformation is a challenge to businesses. Many factors come into play from business objectives to technology readiness, organizational goals and alignment. How can an organization begin to understand the issues and aspects associated with achieving positive outcomes? One way is to take learnings from practice to provide meaningful guidance.

Industry IoT Consortium (IIC) members partner to put theory to practice. They experiment, assess, and pilot new technology, solutions and business models in testbeds and test drives. Results from testbeds and test drives inform members' go-to-market strategies and offer guidance to industry about how to solve real-world problems. Learnings can be shared with industry to help businesses form and fulfil their transformational goals. Industry guidance is extracted and applied leading to less risk and more rapid deployments.

Testbeds are platforms for experimentation and innovation. They explore the technology and business models that enable a trustworthy industrial IoT. Each testbed is deployed outside the lab, in a real-world environment where the testbed faces a different set of challenges. Facing these real-world challenges builds insight and knowledge about how the testbed technology and business model perform. This leads to meaningful guidance and an impact in the marketplace.

Testbeds produce technology and new learnings, but they are not solutions to be deployed as operable solutions. Test drives do that. Test drives are solutions created for deployment as pilots. Test drives leverage technology from testbeds and industry to the benefit of technology users and their businesses. Test drives enable technology users to take technology for a test drive, similar to how a prospective automobile purchaser may do the same. Test drives that achieve digital transformation outcomes result in learnings that inform industry about what works.

Learnings that affect success factors for IIoT projects were documented in the IIC white paper, "*A Compilation of Testbed Results: Toward Best Practices for Developing and Deploying IIoT Solutions*"[1]. This current report describes a set of IIC testbed and test drive deployments and extracts learnings from them pertaining to *digital transformation*. It makes observations to inform and guide digital transformation initiatives generally.

Learnings from practice create meaningful guidance for businesses and teams engaged in or considering digital transformation initiatives. While testbed and test drive deployments may be constrained in their size and scope, each is deployed into a real-world environment and faces real-world challenges. As a result, learnings from the deployments are credible and extensible, with caution, to full scale projects.

[1] *https://iiconsortium.org/test-beds/testbed-results.htm*

2 METHODOLOGY

Recognizing that testbeds and test drives are not in themselves digital transformation initiatives, we developed a methodology based on the "*Digital Transformation in Industry White Paper*"[2] to extract learnings for typical digital transformation goals and objectives. The aspects of digital transformation initiatives include business goals and key factors influencing the digital transformation journey and underpinning technology that enables achieving transformation.

Each team describes their deployment according to how they address these business goals:

- IT/OT integration and convergence,
- Operational impact,
- Customer experience impact and
- Business model impact.

Each team describes how the deployment addresses the three key factors of an organization's digital transformation journey:

- Business,
- Technology and
- Trustworthiness.

Each team describes the digital transformation technology that underpins the deployment:

- Data center/edge,
- Hyper-connectivity,
- Data security,
- AI & analytics,
- Digital twin,
- Distributed ledger,
- Human-machine interface,
- Data sharing,
- IIoT,
- Autonomous robot systems,
- Innovation at the IT/OT boundary and
- Micropower generation for IIoT end devices–energy harvesting

Refer to the "*Digital Transformation in Industry*" white paper for a thorough description of the business goals, key factors and underpinning technology.

[2] Morrish, J., Zarkout (Ed.) Digital Transformation in Industry White Paper, including B. Morrish, J., Zarkout, B., A. Ferraro, C. Lim, S. Lin as authors, 2020, Boston, Industry IoT Consortium. *https://iiconsortium.org/pdf/Digital_Transformation_in_Industry_Whitepaper_2020-07-23.pdf*

The deployments described in the following sections each have learnings that can be applied to digital transformation initiatives. Each description includes an overview, a comparison against digital transformation business goals, key factors and underpinning technology.

3 Smart Factory Web Testbed

Smart Factory Web was approved in 2016 with the primary goals to:

- Achieve a flexible adaptation of production capabilities and sharing of resources and assets in a web of Smart Factories to improve order fulfillment and
- Provide the technical basis for new business models with flexible assignment and sharing of production resources.

It was initiated by Fraunhofer IOSB and the Korea Electronics Technology Institute (KETI). Subsequently Microsoft and SAP have joined the testbed team to leverage commercial business cases and additional technologies. The Negotiation Automation Platform led by NEC applies Smart Factory Web for the registration and search for matching manufacturing resources.

Smart Factory Web forms a strategic ecosystem of projects in which concepts and technologies of IIC, Plattform Industrie 4.0 and the International Data Spaces Association are tested, evaluated and developed further. More detailed information can be found in Usländer et al[3] and Watson et al[4].

3.1 Business Goals

IT/OT integration and convergence: The Smart Factory Web Testbed makes extensive use of the standards OPC UA, AutomationML (AML) and the Asset Administration Shell (AAS) of Platform Industrie 4.0. These standards provide the framework for the integration of OT assets (factories, machines and devices) with IT. Asset descriptions, capabilities and data variables can then be fully accessed in the IT world as an essential step towards digital transformation of a factory and the networking of its production equipment. New applications can be deployed without the constraints and limitations of the traditional OT world dictated by proprietary software environment and device interfaces. Assets are registered in Smart Factory Web with a description of their capabilities. Selected factory data can be exploited in Smart Factory Web via standard interfaces to support a range of use cases, for example monitoring of overall production status.

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[3] Usländer, T.; Schöppenthau, F.; Schnebel, B.; Heymann, S.; Stojanovic, L.; Watson, K.; Nam, S.; Morinaga, S. Smart Factory Web—A Blueprint Architecture for Open Marketplaces for Industrial Production. Appl. Sci. 2021, 11, 6585. *https://doi.org/10.3390/app11146585*

[4] Watson, K.; Becker, K.; Heymann, S.; Okon, M.; Schnebel, B.; Schöppenthau, F.; Stojanovic, L. Usage of Standards in the Smart Factory Web Testbed: An Industry IoT Consortium White Paper. *https://www.iiconsortium.org/pdf/Usage_of_Standards_in_Smart_Factory_Web_TB_White_Paper_2020-06-29.pdf*

Operational impact: The application of the standards allows plug-and-work for new machines and devices, ease of configuration and adaption of the production process. Plug-and-work refers to the insertion of a machine or device into a production system and its automatic configuration in the operational software, similar to a USB device in a PC. The plug and work architecture of the Smart Factory Web testbed is explained in Heymann et al[5].

Customer experience impact: ease of integration of best-of-class applications from multiple suppliers. The flexibility and cost-effectiveness of modern IT becomes available to the OT arena, thus adding the digital world experience to OT. A simple, but compelling illustration is the display of current production data on the factory manager's smart phone.

Business model impacts: Smart Factory Web offers new opportunities for finding manufacturers with matching capabilities and offering services in an entire supply chain. This increases market visibility, especially for small to medium-sized companies. Easy selection and IT integration of assets enables cost-effective production even of small lot sizes.

3.2 Key Factors

Business: Smart Factory Web is a blueprint platform to create an ecosystem of competing and cooperating players in a manufacturing supply chain. The platform has a technology-independent open architecture based upon international standards. This enables both manufacturing as a service (MaaS) on a web platform as in Figure 1, and a federation of marketplaces with well-defined interfaces in an industrial ecosystem[6]. For example, the Negotiation Automation Platform (NAP) led by NEC can search Smart Factory Web for registered assets to initiate a negotiation between candidate suppliers of manufacturing and logistics services.

The negotiation process considers terms and conditions (such as price, quantity, available production capacity and schedule) in a multi-party environment with both competition and cooperation. AI methods support the solution of this multi-constraint, multi-objective optimization problem. Most products depend on a complex supply chain for their components. A supply chain can be evaluated and adapted more easily by involving new alternative partners to respond to risks. Smart Factory Web incorporates a search function for complete supply chains by considering the input and output products of individual factory assets, their capabilities and

[5] Heymann, S.; Stojanovic, L.; Watson, K.; Nam, S.; Song, B.; Gschossmann, H.; Schriegel, S.; Jasperneite, J. Cloud-based Plug and Work Architecture of the IIC Testbed Smart Factory Web. 2018 IEEE 23rd International Conference on Emerging Technologies and Factory Automation (ETFA), 2018, pp. 187-194, doi: 10.1109/ETFA.2018.8502645. *https://ieeexplore.ieee.org/document/8502645*

[6] Usländer, T.; Schöppenthau, F.; Schnebel, B.; Heymann, S.; Stojanovic, L.; Watson, K.; Nam, S.; Morinaga, S. Smart Factory Web—A Blueprint Architecture for Open Marketplaces for Industrial Production. Appl. Sci. 2021, 11, 6585. *https://doi.org/10.3390/app11146585*

which combinations of assets can be linked to form the required supply chain for a given target product[7].

Technology: The standards OPC UA, AAS, AML and OGC SensorThings API are used in Smart Factory Web. These provide the basis for several supporting technologies such as the generation of OPC UA servers from AML descriptions or the import of asset descriptions from AAS. From a strategic perspective, these standards protect investments in IT systems, enable new technologies to emerge and evolve in an open system of systems and eliminate vendor lock-in. A digital transformation can be implemented step by step, thus greatly reducing the risk of failure and allowing important requirements to be recognized following experience in the first phases.

Trustworthiness: The trusted connector of the International Data Spaces association (IDS) is applied to ensure that any data transferred between a factory and Smart Factory Web is subject to defined access and usage constraints. This is an essential requirement to gain acceptance for digital transformation involving critical factory data or process information.

3.3 UNDERPINNING TECHNOLOGY

Data center/edge: the standards OPC UA, AML, SensorThingsAPI.

Data security: Usage control with the IDS connector.

Digital twin: An AAS of an asset can be imported into Smart Factory Web to register the asset on Smart Factory Web. This AAS contains the description of the asset capabilities and key data variables and is, in this sense, a digital twin of the asset.

Human-machine interface: Intelligent web-based data importers allow a user to map their asset data on to the concepts in Smart Factory Web in a controlled way.

Data sharing: Asset and supply chain data can be used in a controlled way.

IIoT: Sensors with additional data relevant to the production in a factory or the execution of an entire supply chain can be integrated in Smart Factory Web with the aid of standards such as OGC SensorThings API. This can be done independently of the manufacturing execution systems (MES) and enterprise resource planning (ERP) systems.

Servitization: Smart Factory Web enables supporting services, such as whether the product specifications can be achieved (a manufacturability check) and assessment of supply chain risks. Again, the standardized IT interfaces are a key enabler for new services.

[7] Usländer, T.; Schöppenthau, F.; Schnebel, B.; Heymann, S.; Stojanovic, L.; Watson, K.; Nam, S.; Morinaga, S. Smart Factory Web—A Blueprint Architecture for Open Marketplaces for Industrial Production. Appl. Sci. 2021, 11, 6585. *https://doi.org/10.3390/app11146585*

Technical platforms for new business models and payment methods: quoting, price and terms negotiation can be realized on federated platforms.

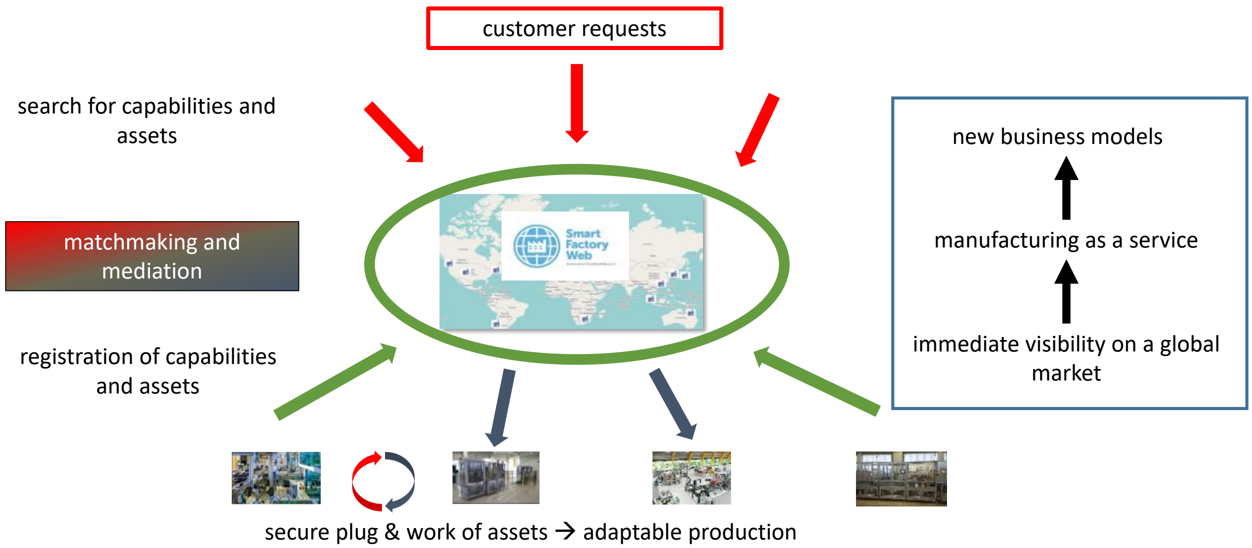

Figure 1 The Smart Factory Web vision for new business models with flexible production

3.3.1 Bottom Line

The Smart Factory Web Testbed defines a blueprint architecture for open marketplaces that network stakeholders in industrial-production ecosystems. Factory integration into a marketplace and functions of the platform economy such as "production as a service" all follow international standards, especially those of IEC, IIC, Plattform Industrie 4.0 and IDSA. This open, strategic approach is designed to smooth the digital transformation journey of a company wanting to implement new business models at minimum risk.

4 Time-Sensitive Networking

The Time-Sensitive Networking (TSN) Testbed was established in 2015 to accelerate the development and adoption of TSN to facilitate the digitalization in the manufacturing industry and related markets through early prototyping, interoperability testing and close cooperation with standardization organizations.

More than 30 companies are actively participating and almost 20 in-person plugfest events have been conducted. The testbed is hosted by the ISW, University of Stuttgart in Europe since 2018 and Vanderbilt University in the US since 2020.

The TSN testbed is focused on evolving TSN as a base technology rather than a single use case.

4.1 Business Goals

IT/OT integration and convergence: Communication and connectivity are key factors for successful IT/OT convergence. OT systems often require deterministic real time communication, not provided by traditional IT communication. TSN combines the connectivity of IT networks with the deterministic guarantees required by OT.

Operational impact: TSN-based converged networks impact the communication infrastructure. A single network serving all applications is required, instead of many parallel networks. IT/OT integration poses new challenges and opportunities in its operation and management.

Customer experience impact: The direct customers of TSN are solution providers integrating digital value in traditional OT systems. Their customers benefit from a new connectivity and data accessibility and a simplified communication architecture.

Business model impacts: TSN infrastructure, hardware and software solutions for endpoints and services are a highly relevant market. Even larger is the market for digital solutions for OT systems enabled by TSN.

4.2 Key Factors

Business: A single converged network instead of many parallel systems allows companies to focus on their business rather than being caught up in technology. This accelerates adoption of digital solutions. The unified infrastructure also allows the development and deployment of software products and services in an OT environment without having to provide hardware and devices.

Technology: TSN is a base technology for wired communication, and the base for other trending technologies such as 5G, DetNet, deterministic Wi-Fi or OPC UA on the higher layers of the communication stack.

Trustworthiness: Trustworthiness of OT networks and systems used to be achieved by airgaps or proprietary solutions, often of questionable quality. Connecting OT systems to the IT world exposes them to more threats, so we require solutions. A single, well-designed converged infrastructure enables a clear approach for trustworthiness relying on well-established solutions known from IT instead of many combined proprietary technologies with no interoperability.

4.3 Underpinning Technology

Data center/edge: TSN-based converged networks connect field-level devices with IT networks and edge and cloud data center solutions. Various platforms were tested in the testbed.

Hyper-connectivity: Converged networks allow a single infrastructure to be used for multiple applications, protocols and services –real-time and non-real-time.

AI & analytics: Data access is a requirement for most AI and analytics methods. TSN enables the required connectivity and can adjust parameters of the acquisition to the needs of the methods.

Digital twin: Connectivity between the real and the digital world is a requirement for many approaches in the field of digital twins.

Human-machine interface: A connectivity from user devices down to field devices allows a new data and information accessibility and therefore new quality for HMIs.

Data sharing: TSN provides the required connectivity for data sharing between any devices.

IIoT: Connectivity is a requirement of an IIoT-based system. TSN provides connectivity and fulfills the real-time requirements of the connected systems and thereby enables many new use cases.

Autonomous robot systems: Autonomous robots can benefit from interconnection with remote systems, IT-based or other robots. A reliable, deterministic communication infrastructure is required, which is provided by TSN and related wireless technologies.

Innovation at the IT/OT boundary: TSN creates convergence at the IT/OT boundary by enabling seamless connectivity. IT and OT systems will share the same communication infrastructure, thereby removing this connectivity boundary and allowing for easier development of cross-IT/OT solutions and services.

4.4 Bottom Line

Connectivity is a key requirement for digital transformation and TSN is the enabling technology to connect OT and IT systems. The TSN testbed is a contribution to the success and adoption of TSN by providing a space for early adoption and interoperability testing as well as providing the foundation for development and testing of innovative real-time applications.

5 Smart Mold Test Drive

The Smart Mold project was approved in 2020. The major goals are to:

- optimize injection recipe operation by applying smart mold to the injection process,
- solve on-site problems quickly as the process is run by AI solutions and
- allow users to upload their data onto the AI platform and receive optimized injection recipe operation from the service.

This IIC test drive was initiated by Hanguk Mold (manufacturer) and Inter X (AI platform service provider). Based on positive results from the test drive experiences, Inter X plans to launch a testbed molding business.

5.1 Business Goals

IT/OT integration and convergence: The smart mold test drive makes extensive use of data standards from various injection machine companies, automated machine learning solutions, standards of OPC UA and a standard database to collect data. These standards let users attach their injection machines and IoT sensors. The platform is a framework for the integration of various OT assets such as injection machines and IoT devices with IT assets such as predictive AI solutions and optimization AI solutions. Any molding industry participant can enjoy AI solutions by plugging in their injection machines and IoT devices to the platform. Because the data standards are pre-defined, new IT solutions such as novel machine learning or deep learning algorithms can easily be deployed. Smart mold technology enables *digital transformation in the molding business*. This is because AI technology reduces quality costs, inspection costs and maintenance costs by replacing human labor. The business may then reallocate resources. Improved quality also affects customer satisfaction, and potentially alters the business model.

Operational impact: Through the smart mold platform and related AI solutions, the molding business participants can attach their IoT devices as well as their injection machines and enjoy several benefits offered by the platform.

Customer experience impact: The platform allows customers to detect the causes of the defects and provide quality prediction for customers autonomously. The customer can analyze the non-operational loss and instantaneously change the work settings when a defect occurs. The customer can also conduct production recipe analysis. The AI service analyzes the factors related to production and develops the optimal recipe from it. Customers can also do the cost analysis. The solution analyzes the phenomena and causes of costs incurred by production losses and suggests effective solutions to overcome the problems related to the cost issues.

Business model impacts: The test drive offers new opportunities for molding manufacturers with enhancing their productivity and the quality of the molding. Thus, the AI solution service provided to the customers would increase the market profitability.

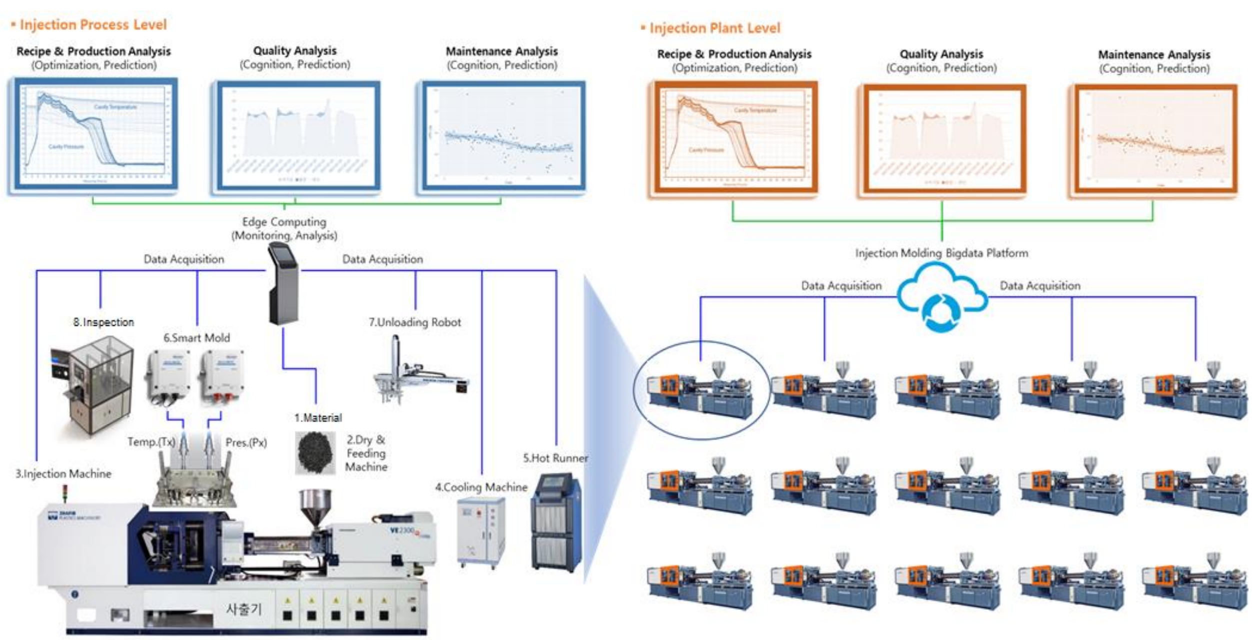

Figure 2 AI platform service diagram

5.2 KEY FACTORS

Business: Smart mold is an AI platform service that helps molding businesses reduce their defect costs and improve productivity. The service includes several machines and IIoT devices connected to the architecture, based on domestic and international standards. The platform contributes to digital transformation by impacting the molding business, customers, and the business model.

Technology: The data standards of various injection machine companies, OPC UA and IoT devices are used in the test drive. It also largely follows IIC's *"Industrial Internet Analytics Framework",*[8] which facilitates easier evaluation, and systematic and effective resolution of stakeholder concerns. The test drive has its own solution to validate the quality of the data.

Trustworthiness: Only trusted enterprises can join the smart mold platform. All injection machine data is stored in the data center and internal servers located at the service provider. To ensure that the data is trustworthy, the test drive tests the validity of the data by checking the completeness and uniqueness of the primary variables. If and only if the quality of the data meets the standard, AI service is provided.

5.3 UNDERPINNING TECHNOLOGY

Data center/edge: All AI solutions including predictive machine learning models and deep learning models are operated at the data center. This enables users to train and test the models quickly. Users can check the status of the developed AI services through the edge computer installed at the factory.

Data security: Inter X has its own physical servers where user's data is securely stored. The company also partners with several local computer antivirus software companies such as V3.

AI & analytics: The test drive has its own AI library where the library contains various machine learning and deep learning models that could be easily tested.

Human-machine interface: Since the AI models can make mistakes, the test drive has a tablet PC near the injection machine where the user can update the model if the suggested result is not correct. By updating the model, the accuracy of the overall AI will increase.

Data sharing: The test drive prohibits data sharing among platform users for data security purposes, but it does allow transferring learning within the factory. A developed AI model on an injection machine could be transferred to other injection machine. This is useful when the amount of the training data from new injection machine is not enough to make the model.

IIoT: Smart mold included four temperature sensors and two pressure sensors.

[8] *https://www.iiconsortium.org/pdf/IIC_Industrial_Analytics_Framework_Oct_2017.pdf*

5.4 BOTTOM LINE

Offering an AI service platform for the digital transformation in the molding business is important. The contribution of Smart Mold test drive is clear. We showed that employing AI service platform into molding business can reduce defect ratio, inspection cost while increase productivity. We believe that the benefit would be greater on a larger-scale digital transformation journey.

6 AUTOMOTIVE AND OVER-THE-AIR UPDATE TESTBED

Automotive and over-the-air (OTA) testbed was approved in 2021. The goals are to:

- demonstrate how software can be managed on a fleet of vehicles remotely. Software can be deployed, inspected, updated, and replaced. A microservices architecture provides maximum functional improvement with a minimum of software change,
- show how a system needs to be conceived for software over-the-air update (OTA) to reach its full potential. (Pushing software over the network is already done to some extent, with limited benefit. A proper solution requires a component-based full life-cycle management for software on the vehicle.)
- showcase Li-Fi for OTA updates and V2X communication to address the challenges associated with RF, such as signal interference, jamming, and limited bandwidth and
- illustrate how manufacturers can manage the entire DevOps cycle of an automobile, from development, to testing, to deployment, and to operations, mitigating cybersecurity risks inherent in the integration of IT and OT.

The IIC Automotive and OTA Testbed was initiated by AASA and aicas. Other current participants are Linaro and Bosch.

OTA is a result of industries digitally transforming towards software and artificial intelligence—both of which require the solution providers to reimagine the entire dev-ops cycle. A key component is bridging the IT/OT gap. OTA helps; doing so smartly is key to product success.

The testbed has yet to be completed. We welcome the addition of 5G as communication method, and applying OTA to other industries such as health IT and industrial applications.

6.1 BUSINESS GOALS

The testbed addresses digital transformation business goals. Integrating networking technology into the vehicle for OTA forces the vehicle to become part of the IT infrastructure, as well as continuing to be an OT system. This has an operational impact, drastically changes requirements for achieving trustworthiness and affects the customer and the business model of the vehicle.

Connecting the car to the internet requires *IT/OT integration* and convergence. The purpose of the testbed is to come as near as possible to a full automotive proof-of-concept for OTA. This means covering as many of the concerns of modern electrified, autonomous vehicles as possible. New services can be offered that change the way vehicles work. They can be integrated into systems beyond the vehicle, improving efficiency and providing features to drivers and passengers that stretch into the world outside. But all the security concerns of being connected must be considered so as not to affect running the vehicle. For example, a denial-of-service attack should never change the drivability of the vehicle. And real-time data collection and response with limited resources goes well beyond what most IT systems can do. Only by combining techniques from both worlds will a successful OTA be possible.

The *operational impact* is immense. A vehicle may no longer be viewed as a build-once system, where maintenance is the concern of the vehicle owner, focused on managing physical wear and tear. Once the vehicle becomes part of a wider IT system, OTA becomes mandatory, if only to provide periodic security updates for maintaining the trustworthiness of the vehicle. The vehicle OEM must remain connected to the vehicle over its lifetime. Currently, consumer devices, such as mobile phones and internet routers, are provided with updates for around four to five years, while a vehicle might have a service lifetime of 20 ~ 30 years and electric vehicles may last longer. Adding functionality to the vehicle over time might become a new revenue stream. Access to operational data from the vehicle will revolutionize vehicle maintenance.

The successful implementation of the testbed will have the following operational advantages on the automotive OTA update process:

- Limiting updates to what is required,
- Understanding the current software version for each component for updates,
- Ensuring that only the systems where the update is authorized are updated,
- Being able to update any vehicle (most) anywhere,
- Reverting any update without exception,
- Being able to update, within reason (safety), a running system,
- Ensuring that only authorized software can be deployed,
- No compromise to security, safety, integrity, resilience, or robustness of the system and
- Use Li-Fi for OTA updates and V2X communication to address the challenges associated with RF such as signal interference/jamming and limited capacity.

The impact on *customer experience* will not be any less. OTA is a key factor in making autonomous driving systems trustworthy. The AI models behind autonomous driving will evolve as the body of knowledge of the environmental impact on driving improves and as the environment, both physical and legal, evolves. New features can be added at the touch of a screen. In fact, the driver may no longer configure the car in the car, but rather from any browser or smartphone. The customer will be able to buy services, prepare trips and schedule maintenance online.

None of this can happen with the current *business models* for vehicles. The OEM will need a reliable revenue stream to keep software updated. Some of this might come from selling new features to the car owner, but this may not suffice. Vehicle service will become more accurate and less time consuming, so other revenue streams will be needed. Driver monitoring for insurance and fleet management will become more efficient as a new source of revenue. A new model for OEMs might become necessary. Vehicles might need to be able to use third-party software like app stores for smartphones.

The OTA-testbed can have a larger impact beyond the vehicle market. The technology can be used in other market segments such as healthcare (medical devices) and manufacturing (industrial machines).

6.2 Key Factors

This testbed addresses the three key factors of an organization's digital transformation journey: business, technology, and trustworthiness. It demonstrates the technology behind OTA, and provides insights into the business impact and the trustworthiness of the resulting systems.

Effective OTA changes the *business* of producing vehicles, especially as we change from internal combustion engines to electric motors. The value of engine technology is rapidly decreasing as the value of software increases. OTA is a contributor to this software value and helps increase the value of electrification through integration in the larger power grid. This change lowers the hurdle for entering the vehicle market, so traditional OEMs need to embrace OTA to be successful in the future. The more a vehicle can do on its own, the more flexible the transportation market becomes. What happens to the Uber model, when no driver is necessary?

OTA is dependent on *technology* and system architecture. OTA is built around a telematics unit (TU) to manage the connection to the external network. Currently, the TU is also the HMI unit, but they can be separated. The TU also has connections to internal busses: ethernet and CAN. On the TU and other larger ECUs, a real-time OSGi framework with resource enforcement manages the software. Each instance can track its own software within its own sandboxes, as well as external software, even in external containers, running as a separate process, in an FPGA, on a GPU or on a microcontroller. An MQTT messaging service is used to connect to known servers. Standard key mechanisms are used to validate the vehicle to the server and *vice versa*. This reduces the risk of hostile penetration.

The testbed focuses on system *trustworthiness*: security, safety, integrity, privacy, and resilience. The OTA testbed provides the means of maintaining trustworthiness over time by only allowing applications to be installed that have been fully vetted and by only using secure communication channels for getting software and transporting data. Moreover, there are components for threat analysis and ranking of apps, hardware, communication, networking, and cloud connections.

6.3 Underpinning Technology

Data center/edge: MQTT message server provides secure connection to the data center.

Hyper-connectivity: 5G keeps the vehicle optimally connected. Li-Fi for OTA updates and V2X communication addresses challenges associated with RF such as signal interference/jamming and limited capacity.

Data security: State-of-the-art encryption and validation protects data and software.

AI & analytics: Standard model formats to enhance edge updatability.

Digital twin: The data provided from the vehicle can be used for building digital twins.

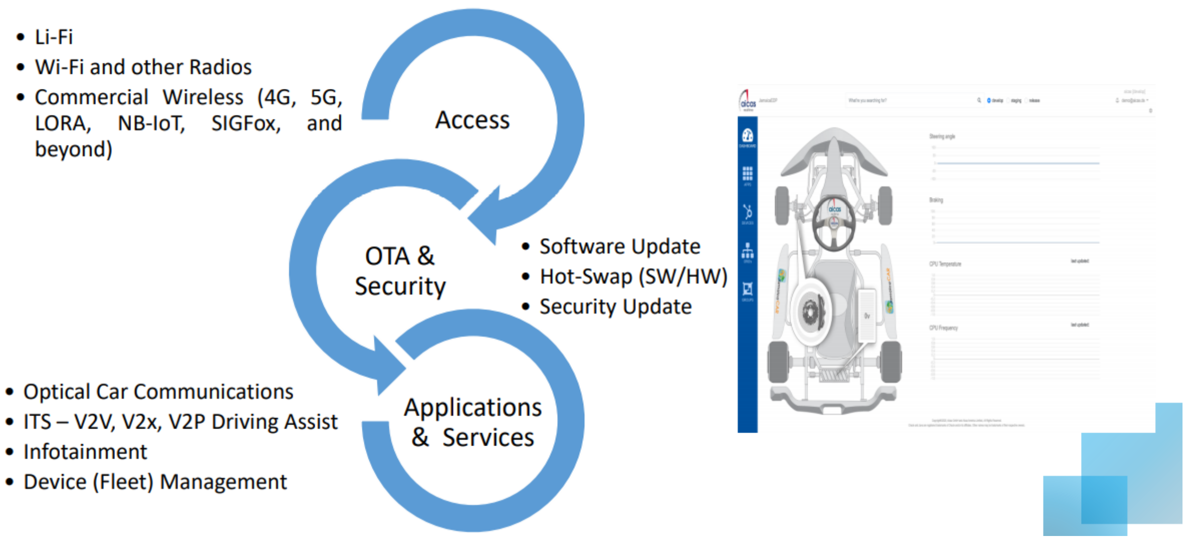

Figure 3 Solution overview

Human-machine interface: Seamless vehicle management provided from browser and internally via in the vehicle displays.

Data sharing: Vehicle data can be used, but only as permitted.

Autonomous robot systems: Robotics technology drives the vehicle of the future.

Innovation at the IT/OT boundary: the testbed adapts IT technology for OT requirements.

6.4 Bottom Line

Connecting a vehicle to the internet is just the beginning of digital transformation. This testbed demonstrates how connectivity can be used for effective data collection and remote software maintenance. Keeping the cloud-to-vehicle connection secure is essential for this transformation.

7 Valuable-asset Tracking for Healthcare Networks Test Drive

Valuable-Asset Tracking (VAT) for Healthcare Networks was approved as a test drive in 2021. The goals of VAT are:

- To build a trusted and transparent asset tracking by combining three technical components, namely secure edge-devices, blockchain and standardized supply-chain data format and
- Facilitate collaboration among supply chain stakeholders, improve supply-chain efficiency and user experience, and achieve substantial cost savings.

This test drive was initiated by IoTeX (blockchain & IoT solution provider) and is being integrated and evaluated by a medical-supply-chain startup. See the description for more information.[9]

7.1 Business Goals

IT/OT integration and convergence: The VAT test drive brings together different data silos to form a unified view of the end-to-end supply chain using secure edge devices, blockchain, and a standardized supply chain data format. This is necessary for achieving great cost and competitive advantages through collaboration among stakeholders.

Operational impact: The VAT test drive uses blockchain to ensure all the stakeholders share the same view regarding the status of physical assets, which increases asset tracking transparency and eliminates disputes and tedious reconciliations among stakeholders. Smart contracts that execute service-level agreements automate payments and improve administrative efficiency.

Customer experience impact: The VAT test drive allows customers to track status (e.g., location, temperature, humidity, movement, handling) of their physical assets on a user-friendly web portal in a timely manner, which improves the customer experience significantly. Moreover, the combination of secure edge devices and blockchain ensures trustworthiness of supply-chain data, thereby giving customers peace of mind.

Business model impacts: The combination of secure edge devices, blockchain and standardized supply-chain data format creates trust among stakeholders in asset-tracking applications. In addition, the increasing need to eliminate intermediaries and automate supply chain operations are expected to provide growth opportunities for blockchain-empowered asset-tracking solutions, making the VAT test drive is crucial for gaining competitive advantage.

7.2 Key Factors

Business: The VAT test drive creates a trusted and transparent asset tracking platform across multiple tiers of the supply chain. It addresses a number of challenges in supply-chain asset tracking such as poor quality-control across the value chain, low administrative efficiency, long and tedious reconciliations among stakeholders. It is expected to help organizations reduce the overall cost of products, improve customer satisfaction, and unlock new business opportunities.

[9] Valuable Asset Tracking for Healthcare Networks detailed description *https://www.iiconsortium.org/test-drives.htm*.

Technology: The VAT test drive involves a wide range of advanced security, wireless communication, and distributed computing technologies, including, but not limited to, Arm TrustZone-enabled low-power microcontrollers, low-power wide area network (i.e. NB-IoT/LTE-M), blockchain, etc. These state-of-the-art technologies are essential for organizations protecting their digital assets securely and cost-effectively. By evaluating the benefits and limitations of the new technologies, organizations are able to gradually integrate them into their existing systems and workflows for realizing their digital transformation journey smoothly.

Trustworthiness: The security-by-design methodology was extensively applied to the system design of the VAT test drive. Multiple security technologies (e.g., Arm TrustZone, hardware-based root-of-trust, transportation layer security (TLS), blockchain) are employed to ensure trustworthiness of data collection, transmission, and processing in asset tracking applications, which removes barriers for organizations sharing data and conducting collaborative business.

7.3 Underpinning Technology

Data center/edge: The secure edge devices in the VAT test drive are responsible for collecting real-time information of the attached assets in the healthcare network, including location, temperature, humidity, movement, handling, etc. The collected information can be sent to the data center or other decentralized storage, as specified by users.

Hyper-connectivity: The secure edge devices used in the VAT test drive are low-power cellular IoT devices that connect to the backend service via NB-IoT/LTE-M and support worldwide operations with IoT SIM cards.

Data security: The secure edge devices in the VAT test drive use an Arm TrustZone-enabled microcontroller coupled with a security sub-system to realize strong software and data integrity protection on the devices. IoTeX blockchain is employed to further ensure data immutability.

Digital twin: The trusted data collected by the secure edge devices reflects the real-time status of the attached assets in the healthcare network, which is processed by the smart contract on the blockchain to enforce service level agreements among healthcare network stakeholders.

Distributed ledger: The blockchain platform serves as the single source of truth for documenting business interactions among the healthcare network stakeholders, which simplifies trust establishment and facilitates collaboration of multiple organizations.

Data sharing: The blockchain enables healthcare network stakeholders to reach agreement regarding asset status in the supply chain. Besides the supply-chain data shared on the blockchain, additional information can also be shared between stakeholders through a decentralized identifier (DID)-based data authorization mechanism.

IIoT: The VAT test drive demonstrates how to build a trusted and transparent asset tracking solution for healthcare networks by combining secure edge devices, consortium blockchain and standardized supply chain data format, which can be further extended to support other industrial asset tracking applications as well.

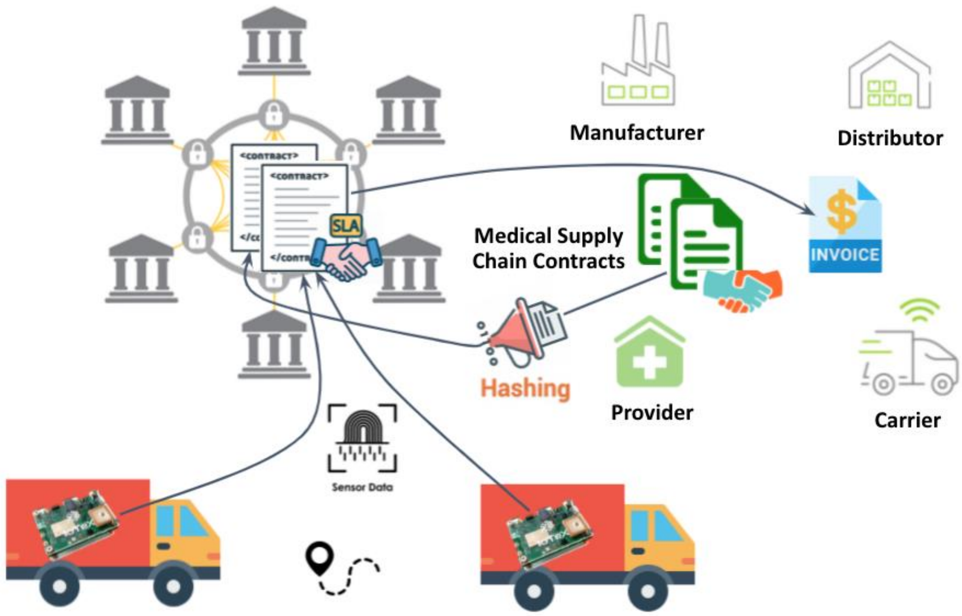

Figure 4 High-level system architecture of the VAT test drive

7.4 Bottom Line

The VAT test drive can improve supply-chain resiliency, traceability, and predictability effectively by creating the trust fabric among all the stakeholders. The innovative and advanced technologies developed in the VAT test drive are critical for an organization ensuring data security and trustworthiness and keeping a competitive advantage during its digital transformation journey.

8 Observations and Conclusions

The digital transformation journey reveals swarms of innovation in business models that could offer transformative value and new services. Business model innovation would be combined with product innovation or process innovation. Because digital transformation in industry is made possible with innovations combining IT and OT, leveraging connected things to transform processes and operations and produce better outcomes[10], a new business model in industries cannot be found through simple efforts of discovering the model. The business models are gradually discovered through complex trial and error of integrating IT and OT and out of efforts to offer new services leveraging connected things.

[10] Morrish, J., Zarkout (Ed.) Digital Transformation in Industry White Paper, including B. Morrish, J., Zarkout, B., A. Ferraro, C. Lim, S. Lin as authors, 2020, Boston, Industry IoT Consortium. *https://iiconsortium.org/pdf/Digital_Transformation_in_Industry_Whitepaper_2020-07-23.pdf*

Testbeds and test drives are therefore helpful for discovering business models that work and technologies that enable them. IIC's testbeds in the manufacturing industry show that testbeds with new services gradually emerge from the previous 'enabling' testbeds. The Negotiation Automation Platform Testbed enables flexible automated negotiation of detailed trading conditions and business counterpart matching across manufacturing supply chains.

The Negotiation Automation Platform can be a platform offering services to firms linked with Smart Factory Web to find negotiation counterparts. Negotiation Automation Platform and Smart Factory Web complement each other in orchestrated supply chains, thus supporting 'manufacturing as a service' in the platform economy[11]. The Smart Mold test drive has an element of new service in the manufacturing industry. Smart Mold testbed for offering service based on smart mold platform is expected to emerge from the smart mold test drive.

These new services and new business models emerge out of efforts to link technological opportunities with business opportunities. The new technologies enable emergence of new services, resulting in new business models. IIC's testbeds and test drives provide an opportunity to observe the feasible technologies that enables new services that can underpin the emergence of business models. These enabling technologies enable other technology-enabled services.

We can observe that the time-sensitive networking testbed verifies technology that enables converged IT/OT networks and therefore a seamless integration of IT-based services with field-level systems. This technology enables a multitude of applications and use cases, for instance asset tracking.

The Valuable-Asset Tracking for Healthcare Networks test drive is deploying "technological-feasibility proven" technology that enables trusted, transparent, and real-time monitoring service of moving objects with a combination of secure edge devices and blockchain technology. Over-the-air technology testbeds aims to demonstrate technology that provide real-time services for updating software without significantly interrupting operation. The OTA technology enables IT-intensive services, where OT domain knowledge is less important. The applicability of the technology is not constrained by features of a specific industry. The technology can also be applied to firms in other industries.

This discovery of new service and business models can be made possible by carrying out experiments such as test beds and test drives. Testbeds and test drives reduce risks and enable finding future partners for new service and business models. This business model discovery journey should not be understood as a journey made possible by technology focused approach.

[11] Usländer, T.; Schöppenthau, F.; Schnebel, B.; Heymann, S.; Stojanovic, L.; Watson, K.; Nam, S.; Morinaga, S. Smart Factory Web—A Blueprint Architecture for Open Marketplaces for Industrial Production. Appl. Sci. 2021, 11, 6585. *https://doi.org/10.3390/app11146585*

Digital transformation business model and service innovations are achieved by taking a customer centric approach[12].

For digital transformation firms' innovation, "test fast, learn fast, scale fast" matters[13], and requires an open approach for overcoming silos between IT and OT organizations[14]. To fuel innovation, testbeds, test drives and other experiments need to be implemented with new 'customer centric, fast and open' innovation process, which IIC calls "BizOps for Digital Transformation in Industries". IIC has been applying the new process by setting up a Business Development Accelerator Team.

Testbeds and test drives reduce risk and enable faster deployments for transformational business outcomes.

9 ACKNOWLEDGEMENTS

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[12] Lim, C., Hackbarth, K., Kordel, K.; Seo, G.; McCann, J., 2021, BizOps for Digital Transformation in Industries. 2021, Boston, Industry IoT Consortium.

[13] Kane, G. C., Philips, A., Copulsky, J., Andrus, G. The Technology Fallacy, 2019, The MIT Press: Cambridge, Massachusetts.

[14] Lim, C., Hackbarth, K., Kordel, K.; Seo, G.; McCann, J., 2021, BizOps for Digital Transformation in Industries. 2021, Boston, Industry IoT Consortium.