GSMA

Industry 4.0 (I4.0) Brownfield Evolution Framework

A reference framework for starting your digital transformation journey

April 2023

The GSMA is a global organisation unifying the mobile ecosystem to discover, develop and deliver innovation foundational to positive business environments and societal change. Our vision is to unlock the full power of connectivity so that people, industry and society thrive. Representing mobile operators and organisations across the mobile ecosystem and adjacent industries, the GSMA delivers for its members across three broad pillars: Connectivity for Good, Industry Services and Solutions, and Outreach.

This activity includes advancing policy, tackling today's biggest societal challenges, underpinning the technology and interoperability that make mobile work, and providing the world's largest platform to convene the mobile ecosystem at the MWC and M360 series of events.

Verizon Communications Inc. (NYSE, Nasdaq: VZ) was formed in June 2000 and is one of the world's leading providers of technology and communications services. Headquartered in New York City and with a presence around the world, Verizon generated revenues of $136.8 billion in 2022.

The company offers voice, data and video services and solutions on its award-winning networks and platforms, delivering on customers' demand for mobility, reliable network connectivity, security and control.

Verizon was the first company in the world to launch commercial 5G for mobility, fixed wireless and mobile edge computing. The company's operating structure focuses on two customer-facing areas: Consumer and Business. Citizen Verizon is the company's responsible business plan for economic, environmental and social advancement.

GSMA Digital Industries is a community of network operators, industrial organisations and the wider ecosystem working together to advance the adoption of mobile technologies in the industrial and manufacturing sector. As the industrial revolution continues towards digitalisation and connected intelligence, the community explores all aspects of the industrial value chain from raw material extraction, to refining, supply chain, component production, assembly, and smart warehousing.

Through a series of forums, activity work streams and events including MWC, the GSMA Digital Industries community aims to:

- Understand the business and operational needs required from across the industrial value chain.
- Identify new kinds of innovative opportunities and collaborations to develop stronger solutions and propositions that harness the benefits of 5G disruptive technologies; AI, Telco Edge Cloud, computer vision, robotics, AR/ VR and digital twins.
- Unlock and address barriers to digital transformation in the sector.
- Share key knowledge including new implementations, successful use cases, achievements and commercial propositions from global leaders.
- Drive new relationships with the wider ecosystem to achieve success.

Find our more and how to get involved at:
gsma.com/iot/digital-industries

Follow the GSMA IoT on LinkedIn:
linkedin.com/showcase/gsma-internet-of-things

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Executive Summary

The terms Industry 4.0 (I4.0) and Digital Transformation (Dx) are well known and have been documented by industry experts. However, the challenge expressed by potential adopters to this day is how to get started when looking to transform their existing industrial networks and operations (i.e. brownfield deployments). As such, the goal of this white paper is to share a brownfield evolution framework exemplifying how to assess and embark on the digital transformation journey to enable Industry 4.0 outcomes. GSMA Digital Industries expresses thanks to Verizon for submitting this contribution as part of Verizon's commitment to driving thought leadership, innovation and wider adoption of Next Generation Industrial Networks. The aim is to share this work with GSMA members, industry leaders and the wider ecosystem to drive discussion and spur greater adoption across many related industries.

Introduction

Document goals and purpose

One of the challenges with any new technology is understanding the complexities and dependencies involved in operationalising it. In the case of Industry 4.0 (I4.0), the technology stack is deep (device to cloud) and the vendor landscape is changing, with roles blurring between traditional operational technology (OT), information technology (IT), OEMs, cloud, communication service providers. Couple that with the challenges of integrating legacy systems, processes and culture, and the task can seem overwhelming.

The goal of this document is not to reintroduce the concept of industry 4.0. There have already been plenty of works done in this vein. However, we will provide the I4.0 context as it applies to this paper. Our objective is to introduce a reference Brownfield Evolution Framework that may be leveraged for assessing and planning the adoption of I4.0 use cases. We will apply this framework based on our learnings and experiences from our own implementation of a digital transformation case study of industrial use cases. We will explain the tenets of the framework, the different phases and dimensions, as well as how to use it as a valuable tool for assessing your starting and destination points along the digital transformation journey.

Target Audience

- Industry Leaders in Operational Technology, Informational Technology and Communications Service Providers
- Device Manufacturers
- Industrial Customers and Systems Integrators
- Technologist at Large

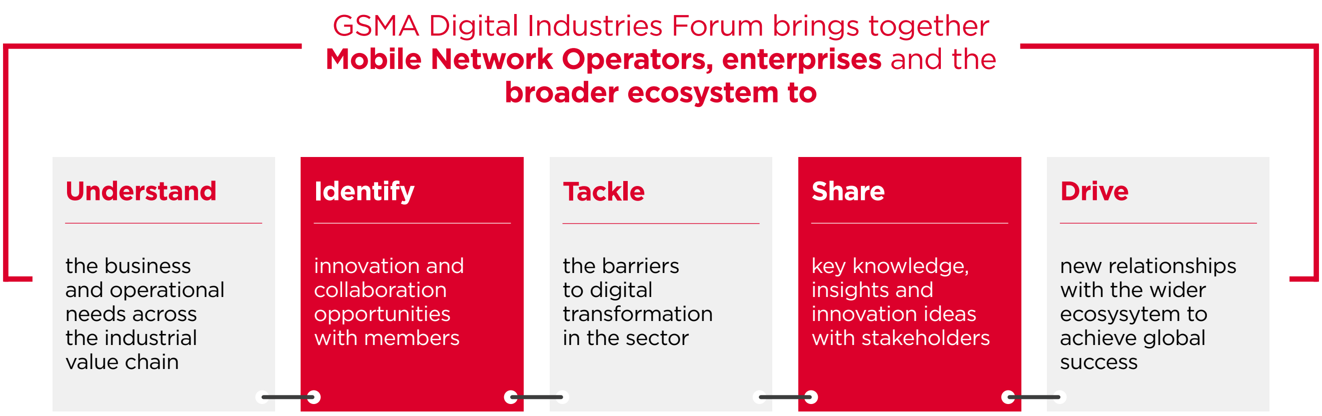
Origin and stakeholders

GSMA Digital Industries is a community of network operators, industrial organisations and the wider ecosystem which is working together to advance the adoption of mobile technologies in the industrial and manufacturing sectors.

Through collaboration and shared objectives, the forum aims to understand the business and operational needs across the industrial value chain, identify innovation and collaboration opportunities with members, tackle the barriers to digital transformation in the sector, share key knowledge, insights and innovation ideas with stakeholders and drive new relationships with the wider ecosystem to achieve global success.

Acknowledging that it is still early days for the road to Industry 4.0, members of the GSMA Digital Industries forum recognised that making the decision to transform from a legacy or brownfield infrastructure to a digital operation and planning for that transition is a large undertaking. As an attempt to address that barrier, this paper was conceived to assist any organisation with decision-making and planning.

Figure 1 | Aims of the GSMA Digital Industries Forum



Source: GSMA

Background

Industry 4.0 Levelset

Industry 4.0 (I4.0), or the Fourth Industrial Revolution, has been studied and written about for years with various nuanced perspectives and definitions. I4.0 can apply to healthcare, retail, logistics and many other verticals that stand to benefit from being connected, optimised, transparent, proactive, and flexible. Many of these industries are being challenged by labour and skills shortages, supply chain issues, cost and revenue pressures and want to unlock I4.0 outcomes to address these pain points. For the purposes of this document, we will subscribe to the GSMA's definition, which states:

> "The Fourth Industrial Revolution or Industry 4.0 describes the exponential changes to the way we live, work and relate to one another due to the adoption of cyber-physical systems, the Internet of Things (IoT) and the Internet of Systems (IoS)."[1]

This definition is intentionally broad, yet it gets at the heart of what makes I4.0 different from its predecessor. Industry 3.0 (I3.0) leveraged computers and industrial ethernets (e.g. EtherCAT, EtherNet/IP, PROFINET, CC-Link IE and Modbus TCP) to provide low latency and determinism for large-scale automation and digital process control in order to make existing processes better and faster. I4.0 looks to create cyber-physical representations of things, processes and operations in order to enable data-driven, near-real-time decision-making.

Above all of the machines, devices and sensors is an interconnection of systems that monitor and control business processes, referred to as the Internet of Systems (IoS). The IoS network supports the exchange of data and insights and the coordination of activities that allows these systems to work together both seamlessly and efficiently.

The goal is to harvest data from all aspects of the operation in an intelligent, flexible and orchestrated way, allowing industries to totally reimagine the way things are done. Why? Because by having data-driven, near-real-time agile adaptations and optimisations to production, companies could improve quality, safety, output and time to market. At the same time, they could reduce downtime, materials waste and cost. It could also enhance the experience for partners, suppliers and, ultimately, the customer. The following chart summarises the characteristics and key elements of I4.0:

1 gsma.com/asia-pacific/wp-content/uploads/2021/02/Industry-4.0-Report-FINAL.pdf

Figure 2 | Industry 4.0: Definition

	Characteristics	Key Elements
	Interconnected Merging of physical and digital The ability to merge the physical and digital components of all connected things. It is the ability of machines, devices, sensors and systems to connect and communicate. This characteristic is where the GSMA definition is focused, but there are other salient characteristics to also consider.	• 5G Private Network • Public Network • IoT/IIOT • IoS
	Transparent Massive amounts of data transparently shared and accessible I4.0 includes massive amounts of data being transparently shared and made accessible to influence decision-making, process and supply chain improvements, customer experiences etc.	• Security • Management • Visualisation
	Augmented AI/ML, robotics and simulations heavily assisting problem solving I4.0 can also be characterised by the heavy use of artificial intelligence (AI), machine learning (ML), robotics, simulations (e.g. digital twins) and extended reality (XR) that augment human capabilities to improve decision-making, problem-solving and actions.	• Robots • Digital Twins • AI/ML
	Decentralised Distributed but coordinated decision-making The ability of systems and nodes within systems to act autonomously and to coordinate with each other to make decisions and take actions, both within the business and across the ecosystem.	• Edge (MEC) • Edge Orchestration • Edge Analytics

Source: Original Verizon graphic

Existing wired and wireless technologies will be challenged to meet the security, latency, bandwidth and reliability needed to satisfy this vision. This means that ubiquitous, industrial-grade cellular connectivity will be required to support the convergence of business and operational systems, the collection and processing of all generated data, and the operational flexibility and resiliency required both in and out of the shop floor. ABI Research confirms the following:

> "…a recent survey undertaken by ABI Research between industrial manufacturers suggests that 88% of manufacturers looking into deploying cellular connectivity on their factory floor look into deploying their own private network (either operated by themselves or by a service provider)."[2]

The good news is that early adopters could start to receive incremental value by planning and developing strategies that will drive their infrastructure and processes towards their specific goals. Materially, these efforts could drive mass sensorisation, the 'IT-fication' of operational technology (OT), and position advanced AI/ML and cellular connectivity as critical enablers for the next-generation technologies that are transforming the way we live, work and communicate. Some of these technologies include collaborative and automated mobile robots (AMRs), augmented reality (AR) and virtual reality (VR), computer vision, industrial IoT devices and more.

Challenges

When it comes to challenges, each I4.0 vertical will have its own set of unique pain points but may still share common themes. Given that the manufacturing segment represents the largest opportunity and has a very high level of technical complexity and strict requirements for digitally transforming its operations, we will use it as a proxy to explore these challenges. From an operations standpoint, disparate and non-standardised systems create data and operational silos that impede optimisation because there is no visibility of the end-to-end operation. These systems often require different skill sets to operate and maintain, sometimes leading to many cycles of troubleshooting. Alternatively, companies are left to rely on vendors to resolve issues in their proprietary systems. This activity leaves little time for innovation and data enablement, putting operations in a reactive, largely manual problem-solving mode. This has a direct effect on the business due to impacts on human resources, production, safety, overall equipment effectiveness (OEE), materials waste and increased costs.

Undoubtedly, one key challenge is directly tied to the projected shortage of skilled workers. For example, Deloitte[3] cites that US manufacturing is expected to have a 2.1 million shortfall of unfilled jobs by 2030. In fact, they highlight that manufacturing executives surveyed believe that finding the right talent is now 36% harder than it was in 2018. Technologies like automation, collaborative robots and digital twins are addressing some of the labour shortfall, while creating opportunities for upskilling.

2 Private Cellular Forecasts 1Q 2023, ABI Research, 2023.
3 www2.deloitte.com/us/en/insights/industry/manufacturing/manufacturing-industry-diversity.html

Device/Network Commercialisation Delays

Another major challenge is the lack of commercial availability of network features and devices needed to support large-scale production grade deployments[4]. Manufacturers of chipsets, modems, user equipment (UE) and other connectivity devices are holding off on adding new capabilities like ultra reliable low latency communications (URLLC) and time-sensitive networking (TSN) until they see others do it first. It is the proverbial chicken and egg problem.

Security/Governance

Security and governance present another set of challenges for I4.0 deployments. The regulatory and privacy requirements for the types of data created, distributed and stored will vary by vertical, business entity, location and customer. These can include encryption, data privacy and IP protection. I4.0 solutions need to account for these often-complex challenges in order to be approved for production, which may include the data never leaving the premises.

Beyond the above aspects of security, the OT side of the house needs to also account for uptime, worker/visitor/public safety, environmental and biological hazards among other factors. This is one of the main reasons that IT systems have historically been kept separate from OT systems. Maintaining strict oversight, control and surveillance are therefore key operational considerations and this is why private 5G networks are a good fit for industrial environments. Private 5G deployments can natively support secure and ubiquitous connectivity with authenticated devices/gateways and full management and monitoring of the network. Zero Trust architectures and edge-based security further elevate the security profile, while allowing customers to decide the level of access and breadth for all data generated in the network. Although this paper does not do a deep dive into the specific security requirements of I4.0, it should be noted that security is a critical success factor for I4.0 adoption.

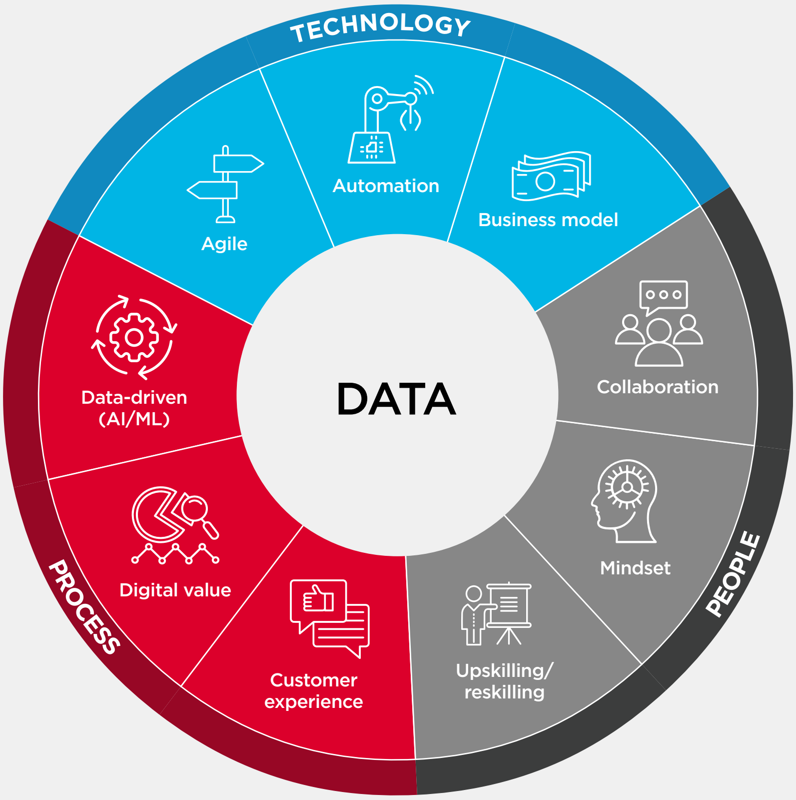
Culture and Process Mindshifts

Beyond the stated technical and resource challenges above, there is a historical divide between the operations and IT teams. The culture, budgets and systems have traditionally been mutually exclusive. However, the digitisation of operations is creating new business and operational models. Having a holistic view of the entire operation from order to delivery is forcing this collaboration and convergence of both systems and networks in order to stay competitive and be ready to deliver value in a demanding digital economy.

This transformation will not happen all at once and will require the entire ecosystem to help drive this evolution. This means cultural mindshifts, reimagined processes, systems and heterogenous networks will be incrementally and strategically upgraded towards that vision. The chart below shows a holistic view of the transformation required across people, processes and technology in order to realise the full potential of I4.0. This paper will not delve further into this topic, but it is important to recognise that this is not strictly a technology problem.

4 www.fiercewireless.com/private-wireless/chips-are-holding-back-5g-private-wireless

Figure 3 | Industry 4.0 Transformation Requirements



- From 5G, IoT and blockchain to AI and data lakes, the raw potential of emerging technologies is enormous and critical.
- But the transformation is more than just a technology challenge.
- Everything a business does is built on processes, which are run by people.
- These emerging technologies will unlock data-driven processes that fuel growth and upend the customer experience including new touchpoints.
- This will equip employees with digital toolkit that will drive a leap in productivity and safety.
- The full transformation potential is dependent on tearing down silos: organisational (e.g. OT/IT) and use cases (smoke stack)

Source: Airbus

Innovation Horizon

As we learn more about what it takes to deliver industrial-grade over-the-air networks and begin to assimilate technologies into production deployments, we must continue to innovate to simplify the installation, management, upgradeability and interoperability of the infrastructure and help drive down cost. This will be important as new generations of networks and devices will demand more collaboration that will extend beyond the factory floor. Opportunities for new delivery and service models enabled by platform services will foster innovation by both incumbents and disruptors alike, disrupting the ecosystem and rules of engagement.

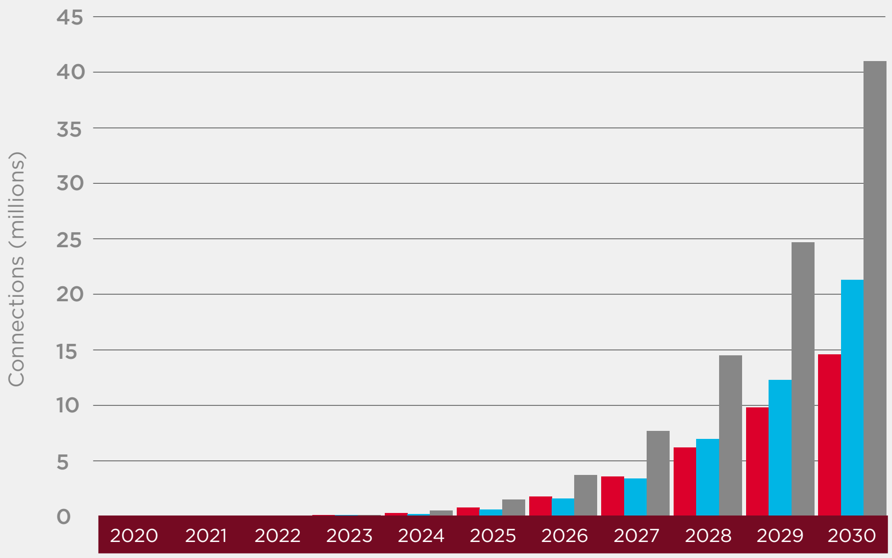
State of Industry 4.0

The general consensus from industry analysts is that manufacturers are the early I4.0 adopters, beginning their digital transformation journeys for targeted use cases. However, manufacturers also want their investments to be extensible and future-proof to allow for the addition of more complex and concurrent use cases. Advanced network capabilities like ultra-reliable low-latency communications (URLLC) and time-sensitive networking (TSN) could afford industrial customers the latitude to grow and modernise their operations by enabling the convergence of IT and OT on an advanced 5G network fabric that can yield full end-to-end view and control of the entire operation.

Acknowledging the incremental value from specific point solutions, many industry analysts also believe that convergence is actually what enables the maximum benefit of I4.0 and when the most ROI is realised.

According to ABI Research[5], the number of URLLC connections will grow exponentially starting in 2024-2025 and take off significantly by 2027. They are expected to exceed both enhanced mobile broadband (eMMB) and massive machine type communications (mMTC), making it the leading connectivity type for I4.0 market. This further reinforces the trend towards IT/OT convergence.

Figure 4 | 5G Connections by Service



	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
eMBB	0.0	0.0	0.0	0.1	0.3	0.8	1.8	3.6	6.2	9.8	14.6
mMTC	0.0	0.0	0.0	0.1	0.2	0.6	1.6	3.4	7.0	12.3	21.3
uRLLC	0.0	0.0	0.0	0.1	0.5	1.5	3.7	7.7	14.5	24.7	41.0

Ultra-reliable low latency communication (URLLC) is forecast to be the dominant use case as manufacturers increasingly deploy robots across their facilities and look to receive real-time data from Programmable Logic Controllers (PLCs) and Human-Machine Interfaces (HMIs).

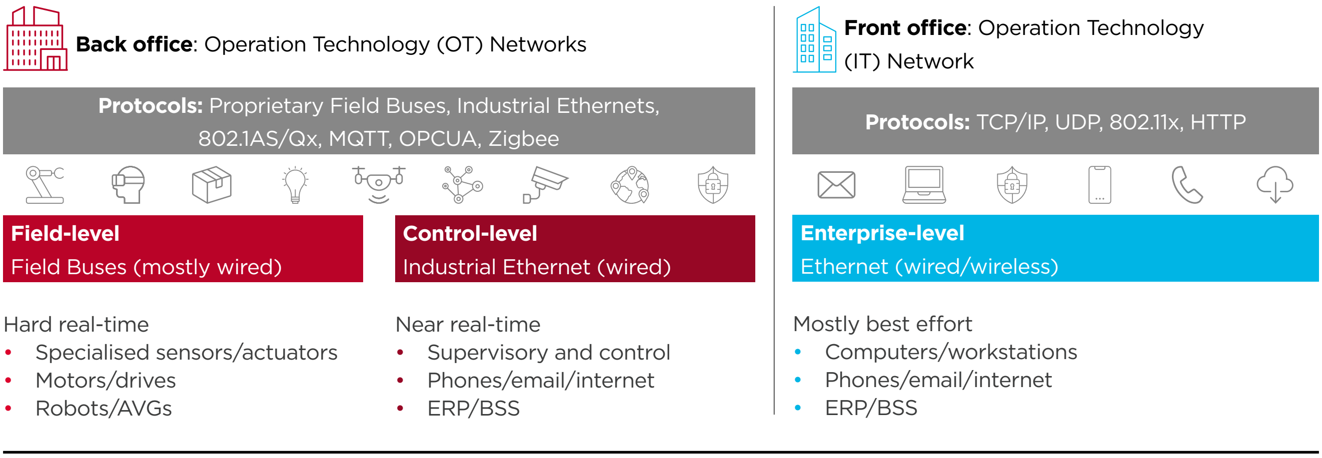
Massive machine type communication (mMTC) will be preferred for monitoring equipment and enhanced mobile broadband (eMBB) for delivering content to and from AR glasses and AMRs.

Source: ABI

Traditionally, the IT and OT domains have been managed, budgeted and maintained by separate networks and by people with different skill sets and priorities. IT typically consists of 'front office' devices like laptops, workstations, phones and servers that communicate over a secure WAN/LAN and run ERP, SCM, billing, HR, cloud and communication applications like email and video conferencing. OT, on the other hand, is typically represented by the 'back office or shop floor' where industrial equipment like sensors, drives, conveyors, pumps, supervisory and control systems communicate on closed, proprietary industrial networks. These require specialised skills to operate and maintain. Any downtime on these systems can translate to millions of dollars in losses.

5 Private 5G Networks in Manufacturing Market Update: 2022, ABI Research, 2022.

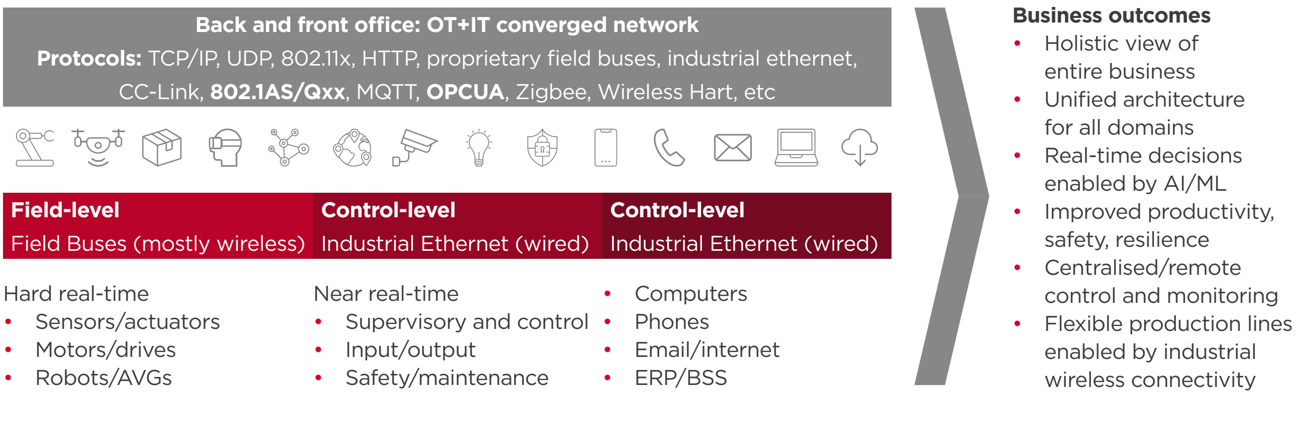
Figure 5 | Traditional industrial and enterprise network domains



Source: Verizon Original

The digitisation of operations and the availability of new technologies like 5G and multi access edge computing (MEC) are creating new business and operational models. Having a holistic view of the entire operation by leveraging a converged network fabric is enabling this collaboration and convergence of IT and OT domains in order to stay competitive. This fabric can leverage open platform communications unified architecture (OPC UA) and message queuing telemetry transport (MQTT) brokers to connect disparate devices, processes and tools of various technologies and protocols to deliver significant business outcomes, which include:

Figure 6 | Single converged network for all domains



Source: Verizon Original

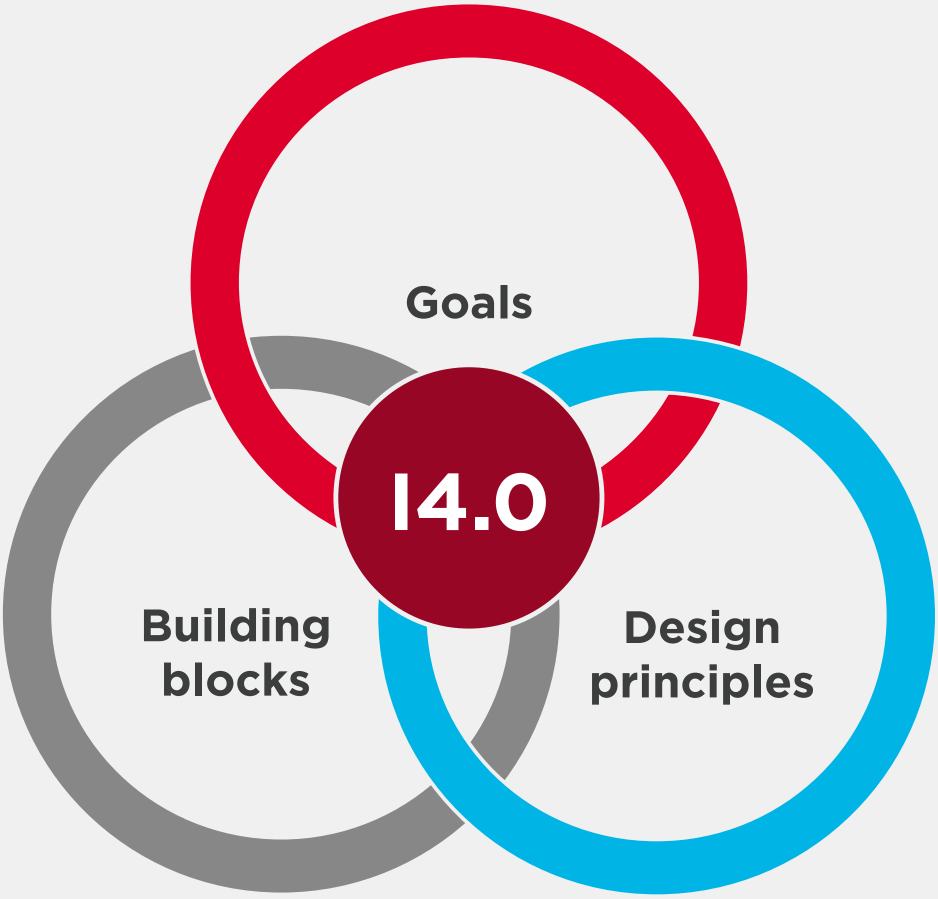
Following up on the convergence theme introduced above, it is important to acknowledge that the evolution towards this vision will take time and iterations throughout the digital transformation journey. It will not be a complete rip-and-replace approach for brownfield operations, but rather a systematic uplift of existing processes and a combination of tactical and strategic decisions along the way.

These decisions need to consider the long-term operational and business objectives that will enable the re-imagined operations of tomorrow and it all starts with the network. It is at this point when having a framework that can help provide insights into your current and future operations can be valuable. The following sections will provide a deep dive of the proposed Brownfield Evolution Framework being proposed in this paper.

Brownfield Evolution Framework

I4.0 Evolution Tenets

Figure 7 | Industry 4.0: Evolution Tenets



- Digitise and optimise ecosystem
- Real-time decision-making/actions
- Business resiliency and agility
- Enhance UX (connected products)
- Introduce new business models
- Improve safety...

- Interoperability
- Virtualisation
- Decentralisation
- Real-time capability
- Service orientation
- Modularity

Critical drivers	• Intelligence (AI/ML) • Connectivity • Automation
Common threads	• Security • Cloud and edge (MEC) computing • IIoT

Source: Original Verizon graphic

Goals

The initial goal of I4.0 was rooted in improvements to the production process. With maturation, the goals of I4.0 have expanded in other directions, with some goals unique to particular deployments.

For example, in the UK, Verizon deployed a private 5G network in the port of Southampton[6] with the goal of reducing complexity by consolidating data communications onto a reliable, secure network. Automated operations and asset tracking was an initial use case and it saved costs and enabled faster turnaround times. A 28% increase in productivity was realised among 860K+ containers with automated operations and 90% less emergency stops drove significant efficiency improvements7. The longer-term vision is to leverage the reliability, ultra-low latency, security and throughput of private 5G to introduce new technologies, such as near real-time analytics, IIoT and AI/ML[7].

The following goals – while far from an exhaustive list – are frequently referenced in I4.0 discussions.

Optimise the ecosystem
Through smart operations and production processes, along with connected supply chains and products, I4.0 could pave the way for a major disruption in the value chain and ecosystem. Digital ecosystems where a variety of partners manufacture reusable modules and parts, develop reusable software modules and provide specialised services could arise. Each partner can focus on their core competencies and, in concert with one another, form an ecosystem that differentiates itself from competitive ecosystems. A network fabric, APIs, data and insight sharing will form the nexus of these ecosystems.

Real-time decisions
The ability to collect data from sensors and devices and to analyse it in near-real-time will provide the insights needed to support near-real-time decisions and trigger nearly immediate autonomous actions. This requires processing locally, at the edge, where data is produced and used, and a network capable of delivering the latency performance. The networking of the value chain will allow for the sharing of near-real-time data and decisions, which becomes transformative by unlocking an ultra-agile, responsive ecosystem.

Business resiliency and agility
I4.0 will support business resiliency and agility by leveraging AI/ML to monitor operations and productions and quickly responding to any potential issues. The goal is to transition from reactive thinking to a proactive approach that delivers quantifiable ROI by addressing issues before they become problems and by eliminating downtime.

The average automotive manufacturer, for example, loses US$22,000 per minute[8] when the production line stops. Per hour, this equates to more than US$1,000,000. I4.0 can help to minimise or eliminate losses.

6 www.verizon.com/about/news/verizon-european-private-5g-deal-associated-british-ports
7 Remote control: connecting an industrial revolution, Nokia, 2023.
8 www.forbes.com/sites/forbestechcouncil/2022/02/22/unplanned-downtime-costs-more-than-you-think/?sh=28a71da736f7

Enhanced user experience
Smart, connected products will support intelligent, software-driven services that enable hyper-personalised experiences. The battleground for differentiation will likely not come from the physical product itself but from the experiences it delivers. It is these experiences that could garner customer loyalty and drive higher margins than physical products. The data and insights collected from connected products support a virtuous circle of features, new product iterations and continually better experiences.

New business models
I4.0 can protect existing business models from disruption by making them more data-driven and responsive to customer needs and by optimising existing processes to make them better, more efficient, faster and safer. The greater impact on businesses is likely to come from unlocking new business models and services via connected products that drive new and recurring revenue sources. The propensity among business leaders is often to protect rather than to innovate, but the latter is what likely ensures long-term success. Research has shown that business leaders that focus on innovation can see as much as a 22% increase in revenue[9].

Improved safety
There are numerous examples of how I4.0 can transform safety, among them:

- Machines could be designed with built-in safeguards by constantly collecting near-real-time data on their operation and use, while those that are out of spec could trigger alerts and proactively shut themselves down.
- Computer vision could be used to monitor workflows and identify unsafe practices.
- Connected workers, through smart PPE (personal protective equipment) and proximity sensors, could avoid dangerous conditions.

9 www2.deloitte.com/us/en/insights/focus/industry-4-0/industry-4-0-business-models.html/#endnote-5

Design Principles

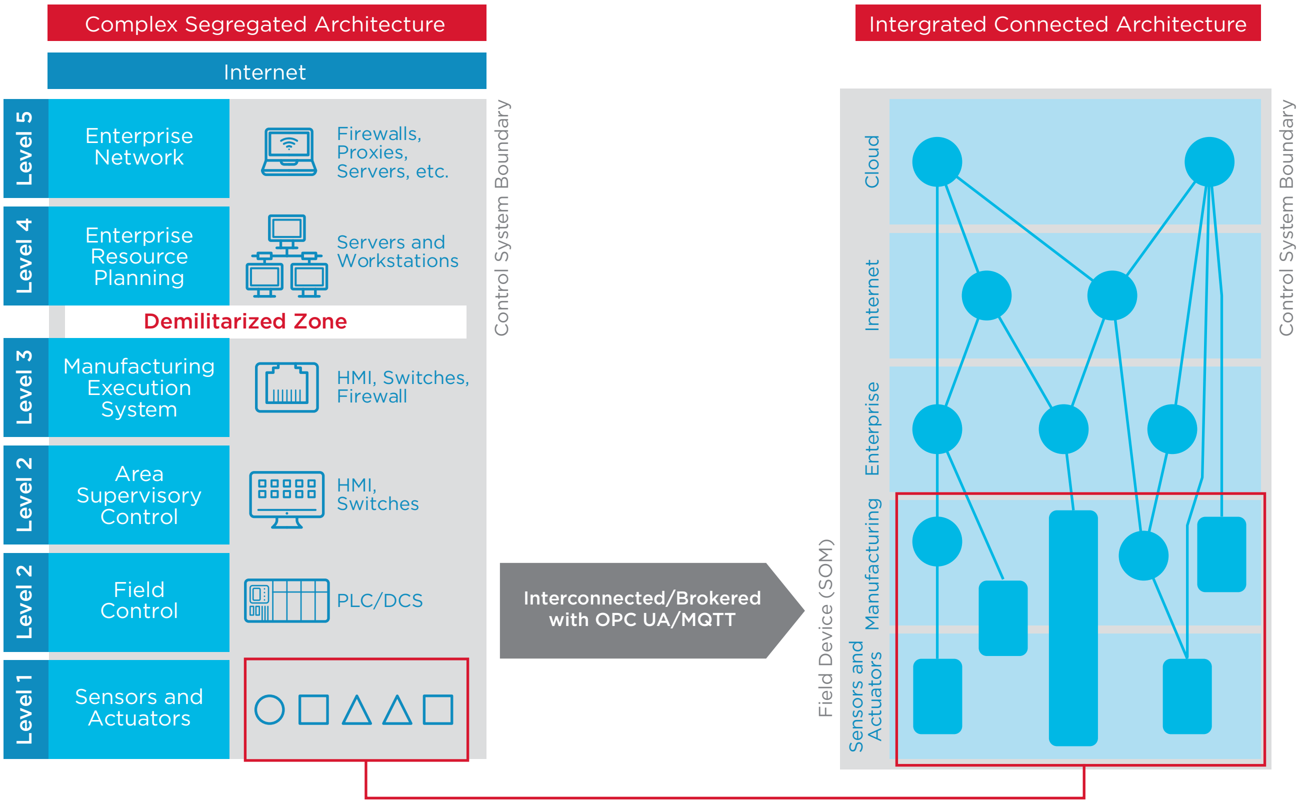
I4.0 represents the fusion of technologies to achieve these goals. There is an agreed-upon common set of design principles imbued in these technologies. While these design principles deliver value in isolation, that value is magnified when they work in concert. They include:

Interoperability
I3.0 had interoperability barriers that stood in the way of unlocking the full potential of data. Proprietary protocols that required custom code to create interfaces among systems were used. I4.0 breaks down those barriers by allowing processes and systems to interact to exchange data and insights and to coordinate actions. Without interoperability, data stays confined and disconnected within isolated systems and devices. With interoperability, data and insights can be shared and aggregated to achieve collaboration and coordination among machines and humans and across businesses, suppliers and customers. The path to interoperability is through standards, brokers like OPC UA and MQTT, and APIs. A reliable network fabric that supports peer-to-peer data interaction is critical. The following is an illustration of the expected industrial automation model transformation from a segregated architecture to interconnected architecture, with an emphasis on robust ubiquitous visibility and interconnectivity[10].

Computers will now connect to production systems (machines) creating cyber-physical systems. In addition, there will be an expansive network of industrial devices and sensors connecting with each other and with computing resources, called the Industrial Internet of Things (IIoT). Above all of these machines, devices and sensors is an interconnection of systems that monitor and control business processes, referred to as the Internet of Systems (IoS). The IoS network supports the exchange of data and insights and the coordination of activities that allows these systems to work together seamlessly and efficiently.

10 www.iebmedia.com/technology/cybersecurity/the-role-of-hardware-in-industry-4-0-cyber-security/

Figure 8 | Transition to Industry 4.0



Source: Industrial Ethernet Book. Site referenced on p10

Virtualisation

There are several different aspects of virtualisation within an I4.0 context. One aspect that has long been state-of-the-art in IT is to sever the dependency of logical functions (software) from the physical hardware on which it resides. This move to commodity-server hardware reduces costs, improves scalability and increases flexibility. Over the past decade, we have seen what started in IT move to OT (e.g. virtual PLC), IIoT (e.g. MEC-based AMR orchestration) and networks (e.g. network function virtualisation and disaggregated network OS).

Another critically important aspect of virtualisation is the modelling of the physical world in the virtual world through digital twins (i.e. 3D simulations) to quickly test scenarios and predict and diagnose issues before they arise. You can gain visibility into things not previously possible by leveraging sensor data to simulate, monitor and control physical processes or systems. The evolution from I3.0 visualisation tools to digital twins requires a network that can reliably update, in real-time, the simulations of hundreds or thousands of processes and systems.

Decentralisation

I3.0 centralised systems offered limited scalability, flexibility and agility by depending on centralised intelligence to control the various subsystems across operations and production. A single failure in these centralised systems could be catastrophic and create a domino effect that brings down the entire system.

I4.0 distributes the intelligence to local nodes closer to the point of need, where it can drive the most value. With decentralisation, the connections between machines and with humans become critical and form an intelligent fabric, a peer-to-peer network, that transforms operations and production by binding together the resources of each node. The sum becomes greater than its parts. This does not obviate the need for centralised systems to accumulate and process data and holistically orchestrate aspects of operations and production. Decentralisation lessens the dependencies on these centralised systems, providing a more agile, resilient and scalable approach for transformation. It ushers in a shift from command-and-control, where everything gets wired back to centralised controllers, to a peer-to-peer approach.

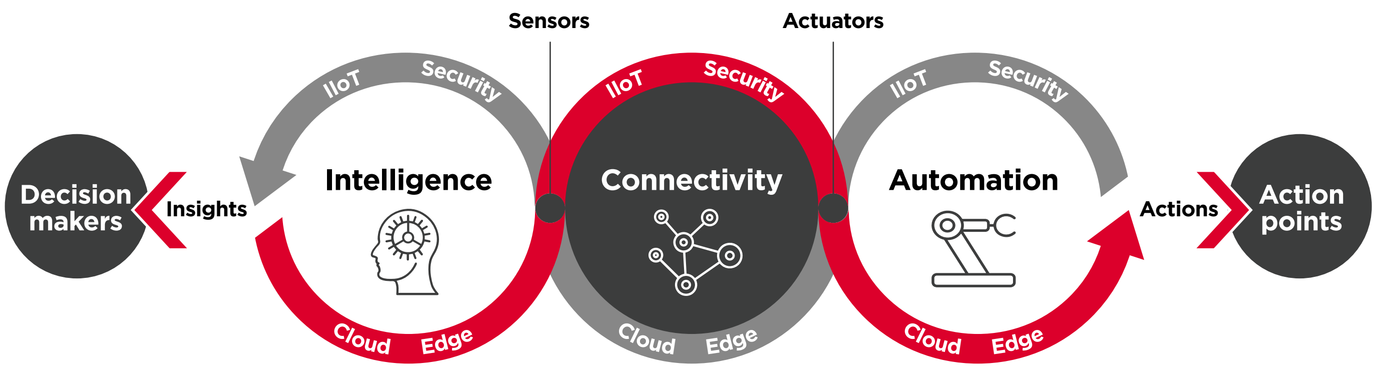
Real-time capability
I4.0 requires the ability to collect data in near real-time to drive nearly immediate, data-driven decisions and actions. Mass sensorisation will generate large amounts of real-time data. The continual analysis of this data allows for an immediate response to issues and the continuous optimisation of operations, production, supply chain etc.

Service orientation
Service orientation represents the I4.0 embrace of the as-a-service economy, where the focus is on delivering value-added services instead of just products. With this model, the customer – together with their changing and evolving needs – moves to the forefront, requiring a shift from a mass production model to one that delivers personalised, tailored services. This customer centricity requires building connected products to collect data to derive insights into customers, to adapt existing services and to develop new services. This model will not be applicable to some large-scale manufacturers of mass-produced goods.

Modularity
The I3.0 monolithic systems obstructed the flexibility and agility needed to respond to the unprecedented changes that the industrial sector now faces. Modularity creates reusable building blocks, constructed from standardised components or subsystems that can be easily assembled, disassembled and recombined to perform a variety of functions. Modularity accelerates time-to-market through ready-made, proven designs. On the factory floor, this supports the rearrangement of modules with little time and effort. It also supports the ability to invest in what is needed today, while offering future flexibility through add-on modules. A wireless network is critical to realising the benefits of modularity.

Building Blocks

Figure 9 | Industry 4.0: Keys to Evolution



Source: Original Verizon graphic

Connectivity
Reliable connectivity is an essential building block or critical driver for I4.0, with potentially hundreds or thousands of devices that need to be connected. The ability to exchange data and insights and to trigger actions requires a connectivity seamlessness across the factory floor, the rest of the enterprise, the supply chain, partners, connected assets and products in the field. This connectivity underlay enables the realisation of the I4.0 vision, which includes a tight integration across the entire ecosystem. It is by leveraging this fabric that platforms and applications deliver their value. This fabric needs to be elastic enough to support the movement and repositioning of assets and material, not only within the four walls of the business but outside of those walls (i.e. field assets and connected products).

I4.0 networks are not static. Wireless connectivity is the only choice and 5G is the wireless technology that can meet the reliability, performance (e.g. latency, jitter), coverage and density requirements. With factory automation and critical monitoring, these requirements are of paramount importance.

Intelligence
AI is a critical building block for I4.0. It is required to absorb and identify patterns and trends in all of the data generated on the factory floor, in the rest of the enterprise, within the supply chain, among partners and in the field. The insights it generates improve visibility and efficiencies on the factory floor and across business processes. It allows operations and production to continually adapt and optimise. As the number of connections grows, the discovery of 'connections' within the system becomes evident and the system becomes smarter.

Automation
Automation is a critical driver for I4.0. The degree of automation will vary per sector, with manufacturing being at the highest end of the continuum. As automation advances, it will drive operations, production, supply chain, etc. beyond human limits, leading to more efficient, productive, profitable and safer businesses.

Security
Security is a common thread with I4.0. The hyper-connected paradigm that I4.0 ushers in will significantly increase the cyber-attack surface. The huge amounts of data that will be sent over these connections and processed on edge computing – when coupled to the bridging of OT and IT – will require increased security vigilance. Traditional security approaches will have to be updated.

Computing
Cloud and edge computing (MEC) are also a common thread for I4.0. The value of I4.0 rests on applying advanced analytics that depend on cloud and edge computing. The industrial edge will need to meet stringent application requirements (e.g. QoS, redundancy) to satisfy the demands of I4.0.

IIoT
Another common thread for I4.0 is IIoT. With IIoT, a plethora of devices and sensors will have embedded wireless connectivity and data-generation capabilities. This massive sensorisation will grow the volume of data exponentially, changing the paradigm from centralised command-and-control to a much more powerful, decentralised approach; an approach where IIoT platforms are key to managing connections, devices and data. These IIoT platforms, along with horizontal-enabling services, will enable a broad set of IIoT applications.

Wireless is Critical

As I4.0 follows its maturation curve, the massive increase in sensors and actuators will quickly push wireline to its technical and economic limits. There is no alternative but to embrace an untethered, wireless approach for I4.0. Only wireless can deliver the flexible, ubiquitous network fabric needed to connect sensors and actuators to critical points in production, operations, supply chain etc. Wireless LAN (i.e. WiFi), Bluetooth and mesh networks (e.g. 802.15.4) have compelling cost structures due to their widespread use, but lack sufficient mechanisms to ensure the necessary reliability, security and performance that I4.0 often demands. There is a role to play for these technologies, but 5G is best positioned to serve as the wireless network backbone for I4.0. It is the wireless technology that can provide continuity across the broadest performance and reliability ranges, while ensuring the utmost security. It is the only logical choice for an industrial fabric to which one would entrust the movement of data needed to drive critical insights and actions, including automation; a fabric that can dependably deliver insights and actions nearly anywhere they are needed in milliseconds at scale.

Network slicing is a critical element of that fabric in that it can deliver on the performance, functional and operational requirements that I4.0 demands. Slicing creates logical software partitions in the form of end-to-end logical networks that run on shared physical infrastructure. When applied to 5G networks, in combination with network slicing, this allows connectivity and data processing to be tailored to specific requirements. The customisable network service capabilities include latency, reliability, security, coverage, quality, throughput and other services. For I4.0, a public network slice provides seamless, deterministic private network services among sites and to assets in the field. For example, a URLLC slice from a network operator can support industrial automation by allowing robots in the production line to be controlled and monitored remotely. It is also applicable to on-site private networks in that it supports the partitioning of applications and devices into isolated slices tuned to ensure that specific requirements are met. For example, a network slice could support safety in a factory by ensuring communications with AGVs to keep nearby factory workers safe, even during a surge in communications traffic.

Network Planning

There are three approaches to I4.0 brownfield network planning, with all driving varying degrees of impact:

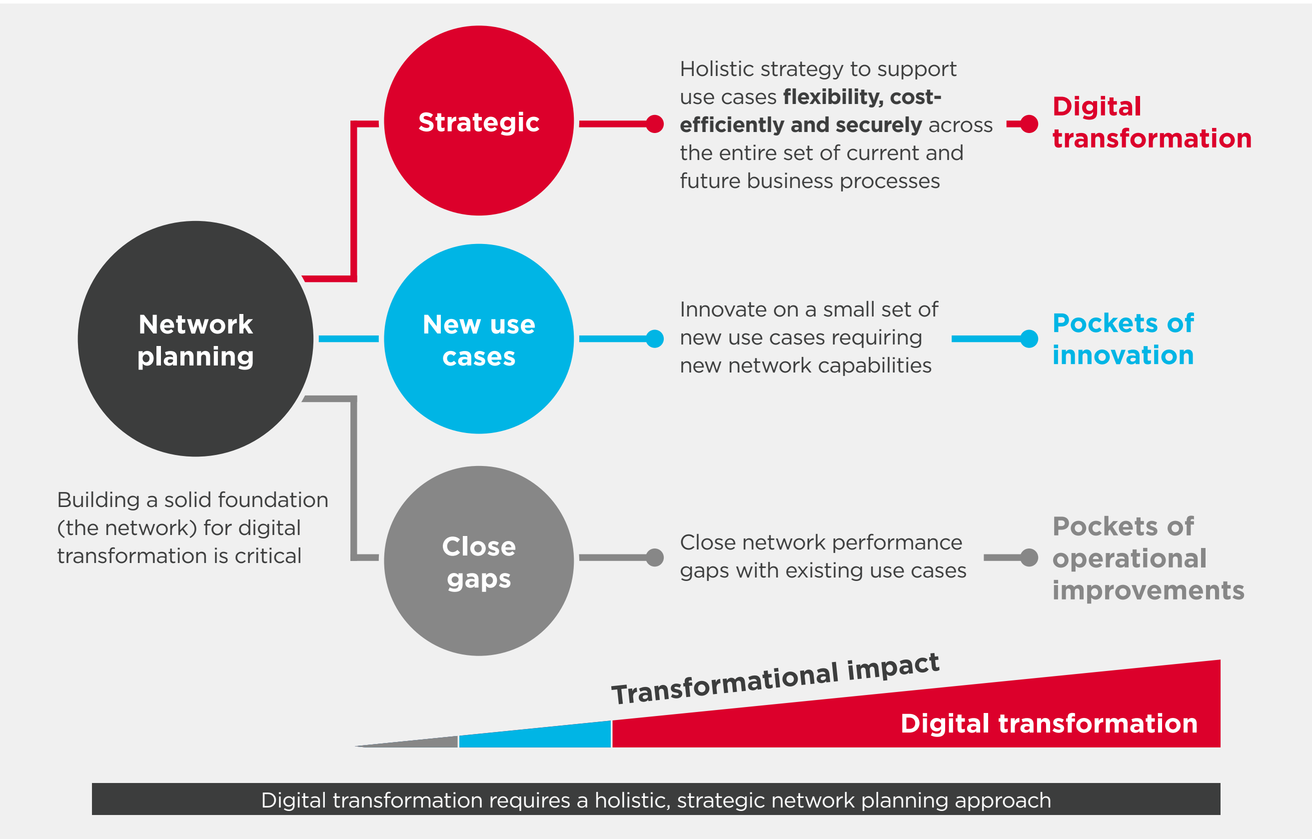
1. Close gaps. The most tactical and least impactful approach is centred on closing network performance gaps for existing use cases. Achieving a satisfactory return on the network investment (ROI) with this approach can be challenging, but it will yield pockets of operational improvement.

2. New use cases. This approach is also tactical and centred on a limited set of use cases requiring new network capabilities (e.g. ultra-low latency and mobility). A satisfactory network ROI can also be challenging to achieve, but it will yield pockets of innovation. Planning an I4.0 network leveraging these tactical approaches alone can be short-sighted and result in stranded investments.

3. Strategic. The strategic approach to planning an I4.0 network is the most impactful in that it serves as the foundation on which an enterprise can engage in digital transformation. It is a holistic approach that plans for a network that can support both current and future use cases with requirements, cost and security in mind. It plans for a solid network foundation that can ultimately deliver digital transformation. While it can be difficult to scale networks across sites and the entire ecosystem, the planning for this should be done up-front with initial investments helping to progress toward the end goal.

For brownfield deployments, evolutionary progress toward the revolutionary impact that digital transformation unlocks requires a practical approach. The ROI and improved competitive position of those that have made significant digital transformation progress is solid, with increased production efficiencies and capacity, improved quality and safety, lower carbon footprints, better customer experiences and so forth. Putting the right network and platforms in place at the start is critical.

Figure 10 | Industry 4.0 Network Planning



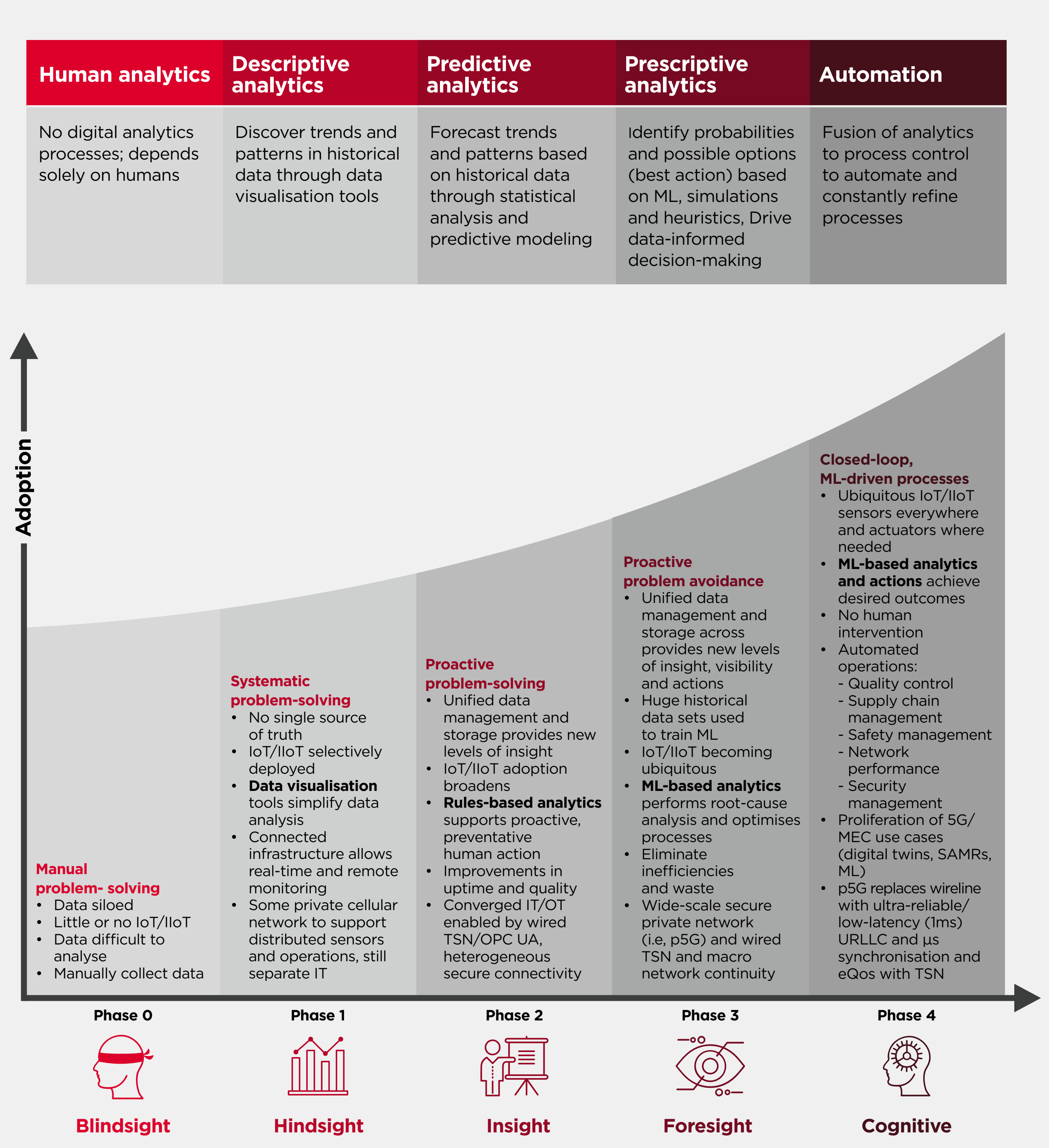
Source: Verizon Original

Framework Components and Dimensions

Data is the animating force for I4.0. It is the ability to derive insights from that data that provides differentiation and a competitive advantage. The value extracted from the data correlates to the sophistication of the analytics applied. It is also dependent upon the ability to drive actions (i.e. automation) from the intelligence derived from the analytics.

The first dimension of this framework is a continuum organised into phases that reflect increasingly sophisticated analytics. The progression starts with what we refer to as blindsight (Phase 0), where data remains largely siloed and human analytics is used to interpret the data and take actions in response. It progresses through three phases (Phase 1 to 3), where increasingly sophisticated analytics are used to augment human capabilities. It culminates in the final phase (Phase 4), where insights can be turned into actions in milliseconds through automation.

Figure 11 | Brownfield Evolution Framework



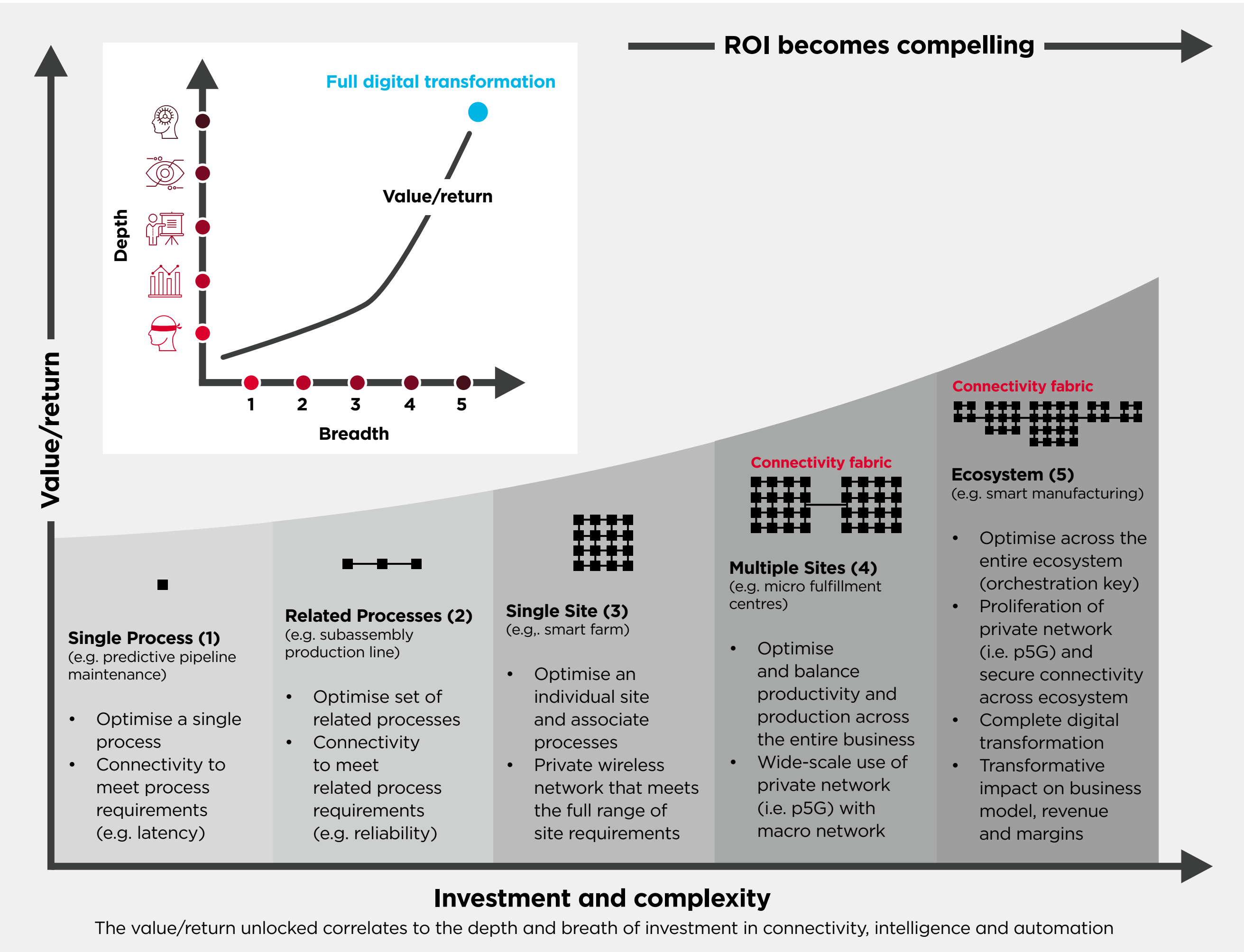
Source: Original Verizon graphic

Another component of the framework is the extent to which IIoT is deployed. We are at a tipping point in technology adoption where IIoT platforms and associated applications are becoming an essential part of workflows. The framework continuum begins with little to no IIoT (Phase 0) and legacy systems (i.e. SCADA, MES) still in place. These legacy systems solve a particular set of production problems, but they are complex and monolithic systems with high costs along with slow deployment and development cycles. IIoT platforms and associated applications break the monolithic approach of legacy systems, providing modular building blocks that are extensible well beyond what was possible with legacy systems. It affords greater levels of control, visibility, flexibility, agility, extensibility and so forth. In subsequent phases, IIoT will supplement or supplant legacy systems. The continuum progresses beyond Phase 0 by broadening IIoT deployment and culminates in ubiquitous IIoT through mass sensorisation along with actuators that drive autonomous action. This progression includes a broadening set of IIoT applications.

A critical component of the framework is the progression of the network. It begins with wired and WiFi connections and an air gap between OT and IT. It progresses by broadening private cellular deployment and through the convergence of OT and IT through wired TSN/OPC-UA. It culminates with private 5G replacing wireline with URLLC and TSN over 5G.

It is important to recognise that the business can occupy more than one phase at a given time and that there will not be a clear delineation of phases in the real world. The second, equally important dimension of this framework is centred on the breadth of the deployment of analytics. On the simplest end of the spectrum is analytics applied to optimise a single process or a set of related processes (e.g. a production line). It advances to include optimising a complete site (e.g. factory) and its related processes. The next phase would be the optimisation and balancing across the entire business (e.g. across manufacturing sites), which would require wide scale deployment of private 5G along with macro network continuity. This progression culminates in optimisation across the entire ecosystem, tying together planning, research, operations, production, supply chain, logistics, distribution, connected products etc. This requires the proliferation of private 5G and secure connectivity across the entire ecosystem.

Figure 12 | I4.0 Evolution Breadth



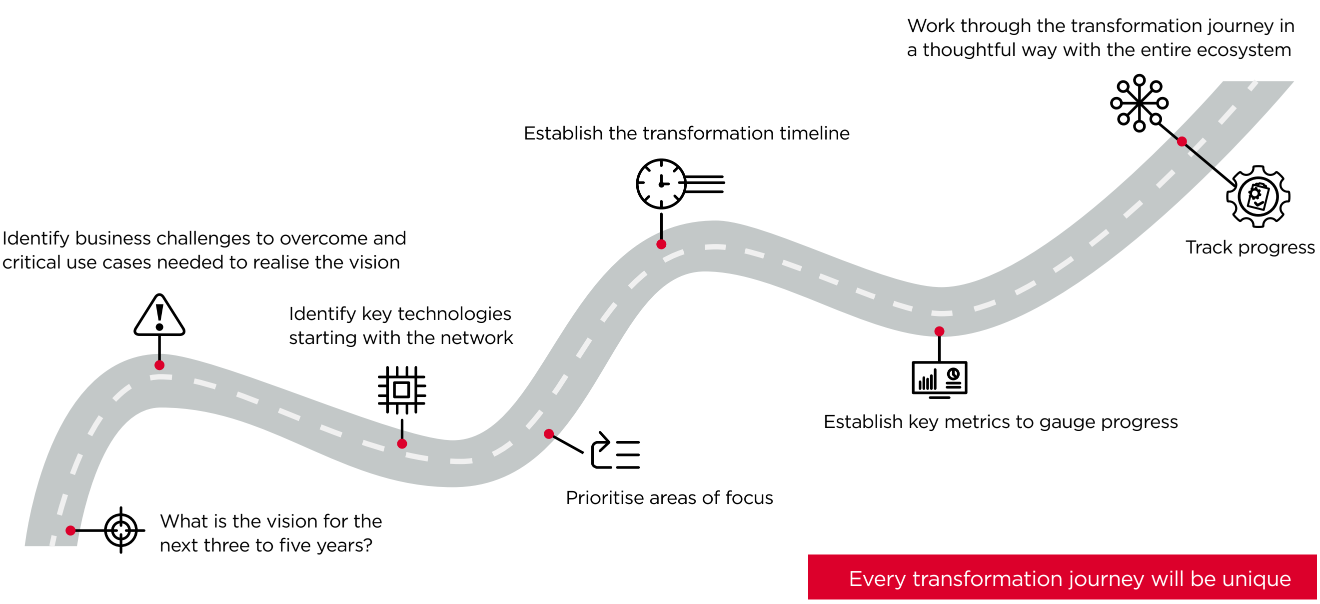
Source: Original Verizon graphic

Interpreting the Framework

The framework is intended to serve as a reference along the progressive journey toward I4.0 digital transformation. Every transformation journey will be unique, with the depth and breadth of that journey specific to an enterprise and their processes. Below is a course that an enterprise can follow, with the framework serving as a guide map of the technology maturity needed to arrive at the various waypoints (phases) on that journey.

Given the complexity of technologies and use cases involved in I4.0, it is key to set the vision and lay out a clear roadmap. It is important to understand the value that vision will deliver and to evangelise it within a company and its ecosystem. That could be followed by identifying the most pressing business challenges to overcome and the initial set of use cases that will move you the furthest along the way on your digital transformation journey. Identifying the key technologies and, in particular, the network needed to realise the vision is critical. It serves as the backbone to that vision. Prioritising the areas of focus and establishing the transformation timeline is important. Setting KPIs to gauge and track progress is important. It is also important to recognise that the strength of your ecosystem will determine the strength of your business and its vision. Collaboration and communities of innovation are key to digital transformation. Working through your transformation journey with your entire ecosystem is key. Keep in mind that this technology journey revolves around connectivity (the network fabric), data and data sharing, actionable intelligence and automation.

Figure 13 | Industry 4.0: Evolution Roadmap



Source: Original Verizon graphic

The Five Phases

For brownfield deployments, I4.0 is not a discrete event or revolution; it is an evolution occurring over time and in phases. It is not a journey that reaches the same terminus for all manufacturers. For some, the journey may end on the factory floor. For others, the journey may include waypoints such as planning, research, supply chain, distributors, connected products etc.

Phase 0: Blindsight

Phase 0 involves manual problem-solving where data is siloed and little, if any, IIoT is deployed. In this phase, data is difficult to analyse and quite a bit of fighting fires occurs.

Figure 14 | Phase 0: Siloed – manual problem-solving

Business snapshot	Operational snapshot	Infrastructure/ technology snapshot
• Rigid and slow business processes ("We've always done it this way") • Information technology is managed and funded separately from operation technology • Culture/rewards based on disjointed and/or competing goals • Limited to no visibility of end-to-end business • Manual data collection and analysis process (reports, spreadsheets, etc)	• Reactive problem resolution, only deal with problems after they happen • Antiquated, siloed mechanical and/or manual operational and production processes • Very little systems interoperability with little centralised data, visualisation or standards • Long lead times for retooling and problem resolution • Opportunities for reducing waste, improving overall quality and equipment efficiency	• Private IT LAN (mostly wired and some WiFi for ERP, BSS, CRM) • Wired, appliance-based OT systems from different vendors: PLCs/SCADA/ HMI systems • Air gapped, propietary field buses/wired industrial ethernets • Fixed, inflexible, expensive equipment requiring specialised skill set • 10-30 year equipment refresh cycles depending on industry

Source: Original Verizon graphic

Phase 1: Hindsight

Phase 1 involves systematic problem-solving that leverages data visualisation tools to convert complicated datasets into understandable visualisations (e.g. graphs, charts). Dashboards capture trends and patterns – like uptime/downtime, production levels etc – for human analysis. This phase ushers in visibility by beginning to break down silos through interoperability and sensorisation that enables data flows critical to deducing the reason behind events.

Figure 15 | Phase 1: Descriptive – systematic problem-solving

Business snapshot	Operational snapshot	Infrastructure/ technology snapshot
• No major changes in business processes or culture from Phase 0. • IT/OT are still managed as separate and disjointed domains. • Start of digital transformation journey due to increased pressure to improve quality, productivity and efficiency in order to remain competitive. • In addition, shortage of skilled workers and other external factors are driving need to be more flexible and resilient.	• Shift towards systematic problem resolution with the introduction of more sensor data, incremental automation. • Historical data used to determine trends to help solve problems. • Addition of remote control and monitoring capabilities • Introduction of limited data visualisation. • However, little systems interoperability and many data lakes complicate data normalisation and insights.	• Additional secure private network deployed to support more wireless and distributed sensors to support operators. • Device and network management functions needed to configure, run and maintain the private network. • Limited deployment of IIoT and cloud services. • Introduction of dashboards and centralised visualisation tools.

Source: Original Verizon graphic

Phase 2: Insight

In this phase of the continuum, a shift from reactive to proactive problem-solving occurs. Predictive models, data mining and AI leverage historical and near-real-time data to predict and prevent problems. It can yield significantly fewer quality issues and downtime. Near-real-time alerts deliver insights to humans that allow them to take near-real-time actions. It can also be used to forecast business demands or the need for products, raw materials etc. As part of this phase, we start to see virtualisation of process logic controllers (vPLCs) and human/machine interfaces (HMI), reducing the physical footprint of controllers on the factory floor.

Figure 16 | Phase 2: Predictive – proactive problem-solving

Business snapshot	Operational snapshot	Infrastructure/ technology snapshot
• Productivity, quality and overall equipment efficiency improvements, but more can be done. • Increased visibility into end-to-end business. • Additional investments in infrastructure fueled by success of select digital transformation efforts. • Increased visibility into end-to-end business processes. • IT/OT convergence is now valued and drives operational and business process reengineering (culture shift).	• Proactive problem resolution by implementing predictive maintenance. • Rules-based AI helps infer data-driven outcomes to improve key indicators. • Increased systems interoperability through a unified architecture help provide holistic view of entire operation. • Centralisation of data facilitates normalisation, visualisation and consumption.	• Converged IT/OT enabled by TSN/OPC UA enablement. • Private MEC greatly improve data processing, latency and reliability. • Rules-based AI + consolidated historian function hosted on MEC. • Proliferation of IIoT.

Source: Original Verizon graphic

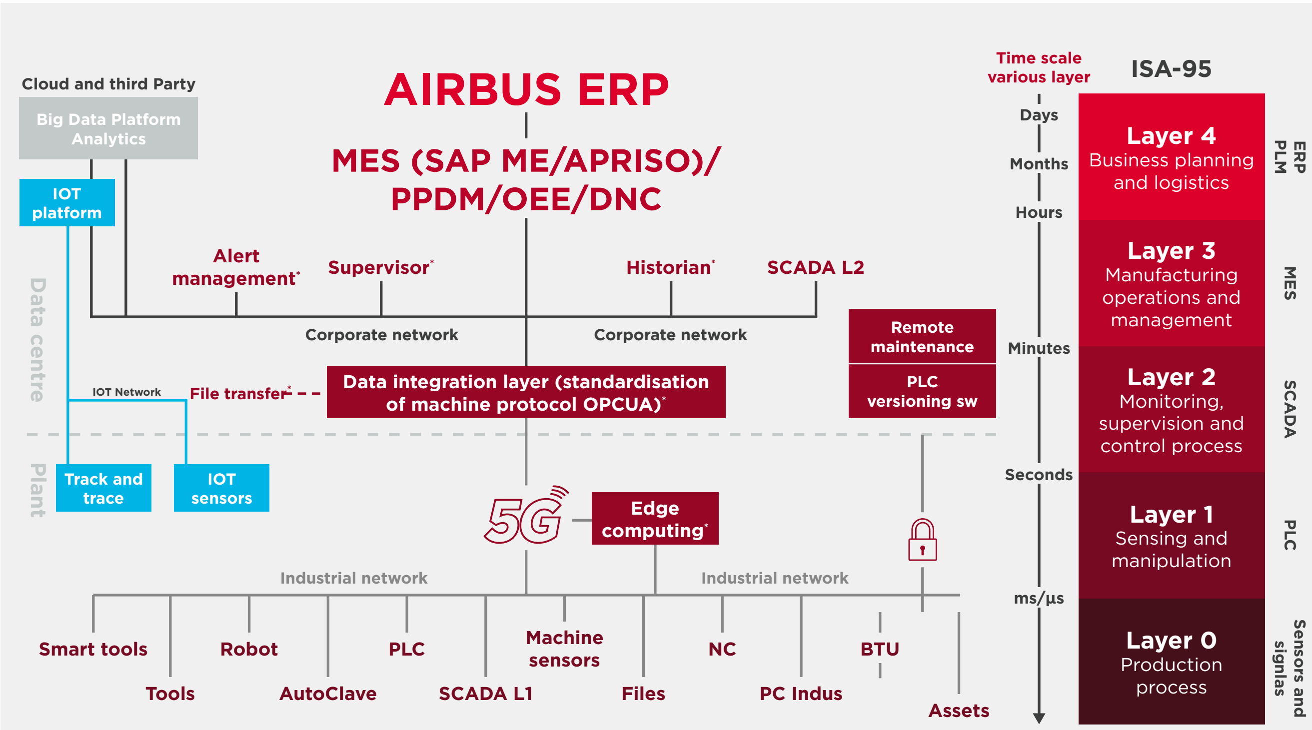
Case study of Airbus' network transformation effort

Most companies have begun their digital transformation journey to some extent and currently operate in the earlier phases of the Brownfield Framework. If we take Airbus as a case study, we are encouraged to see how their investments are already yielding both operational and business outcomes that will further evolve and give them a strong position to mature to Phase 3 of the Brownfield Framework.

Operationally, Airbus has assets in many plants around the world. This includes tens of thousands of machines, sensors and PCs, among which are 4,000 industrial assets (smart tools, drilling centres, milling, molding, AGVs, robots, automated parts shop etc). Due to historical reasons, none of the plants are the same and the solutions and machines differ from one plant to the other, making it an ideal case study for Brownfield deployments.

A few years ago, Airbus decided to create a data integration layer for all industrial assets, providing a single and unified interface for any operational and business application. They recognised that the lack of visibility and interoperability presented too many drawbacks and limitations (i.e. poor insight in shop floor operations, diminished automation and poor machine integration). By pulling together resources from both their IT and OT organisations, they successfully deployed this data integration layer (AMI) which offers ISA-based security, data normalisation and integration points across the business from industrial devices to the Enterprise Resource Platform.

Figure 17 | Airbus shopfloor connectivity, automation and analytics - manufacturing reference architecture based on ISA-95 standard



AIRBUS MANUFACTURING INTEGRATION (AMI)* KEY FIGURES

- 600 asstes connected to AMI
- 4 core European countries
- 14 plants
- Wired Wireless

- Process contextualisation
- Secure File Transfer
- E2E Cybersecurity
- OT safety
- OT integrity

Source: Original Verizon graphic

Private 5G and edge computing proved to be key enablers for this architecture and allowed them to deploy some of the following use cases:

- Automatic quality/process control, automatic ordering of parts and tools from the tool shops, automatic data transfers between various production stations avoiding human errors.
- The monitoring and modularisation of the data coming from the machines allows for predictive maintenance, reducing the downtime of machines and allowing for higher production efficiency.
- Linked to this, the possibility to have remote maintenance through wireless private 5G connectivity (cameras, smart glasses etc) guarantees faster reactivity, worker guidance, repairs and training. This was exceptionally important during the COVID-19 pandemic.
- Private 5G allows smooth shopfloor flexibility, highly efficient wireless performance, data isolation/security, machine automation and integration.
- Connectivity and reactivity of 5G smart tools allows them to be used in conjunction with the geolocation system, making sure that the actions performed by the operator are made as defined by the process (avoiding human errors in production).

This full automation framework combined with private 5G allowed Airbus to increase availability of its assets and therefore decrease costly maintenance activities (due to potential breakdowns being detected in advance and prevented). It allowed for optimised production processes and quality control, resulting in an overall increase in ROI of about 20% (e.g. if a drilling head breaks in a simple titanium piece, it may be necessary to scrap the entire piece at a cost of €200,000).

The proliferation of private 5G in all of its plants, enabling connectivity on previously unconnectable assets, is the way forward in this data-centric approach. The technology advances of 5G 3GPP Releases 17 and 18 (URLLC and TSN) and its integration with multi-functional industry domains (5G, AI, automation) will help Airbus move closer to proactive problem solving (Phase 3) and, eventually, closed loops and ML driven processes (Phase 4).

Phase 3: Foresight

Phase 3 requires more advanced analytics that leverage machine learning to perform root-cause analysis and optimise processes and production. It taps into huge historical datasets to train the machine learning algorithms. Reaching this phase in the continuum is more complex and requires highly reliable technology, including advanced networking. It provides insights that highlight the steps needed to achieve a desired outcome. It has an eye to the future and what actions will yield the largest positive impacts and steps to take to avoid negative consequences.

Figure 18 | Phase 3: Prescriptive – proactive problem avoidance

Business snapshot	Operational snapshot	Infrastructure/ technology snapshot
• Agile and flexible business processes with some automation. • Hierarchies and data siloes are gone. • Culture based on harmonised goals (KPIs). • Increased visibility into end-to-end business processes • Maximise throughput/ productivity and quality. • Minimise inefficiencies and waste.	• Apply root cause analysis to production and business operation driving optimisation • Robust network (on site and wide area) to securely transmit significant amounts of real-time data. • Digital interfaces to remotely and optimally control and configure assets and processes. • Connected products with full lifecycle visibility. • Partners committed to capturing and sharing relevant data in real-time to be integrated into workflows.	• Wide-scale use of private network (i.e. p5G) with macro network continuity. • Partial network fabric (mesh) across sites, processes and partners/suppliers. • Public and private MEC. • Near-ubiquitous IIoT • ML-driven root cause analytics.

Source: Original Verizon graphic

Phase 4: Cognitive automation

Phase 4 on the continuum is the most advanced phase, where analytics is fused with control systems to automate and constantly refine processes. The processes become closed-loop processes and the time-to-execute on discovered insights can be reduced to milliseconds. This phase depends on large datasets that build confidence in the machine learning algorithms that drive automation. Automation is not a binary, all-or-nothing element. Every manufacturer is likely to have some automation, but its breadth will depend on how well-suited their production processes are to automation.

Automation may be applied to a repetitive single task, to an entire process or to an entire factory (i.e. lights-out manufacturing).

In brownfield factories, achieving a lights-out factory end state will be challenging. Greenfield factories can leverage critical technologies (e.g. 5G, modularity, AI/ML) from their inception. The stability of automation is dependent upon low latency and high reliability. This can be achieved through control systems wired to sensors but, for this to scale, 5G networks and edge computing are critical.

Figure 19 | Phase 4: Smart – closed-loop processes

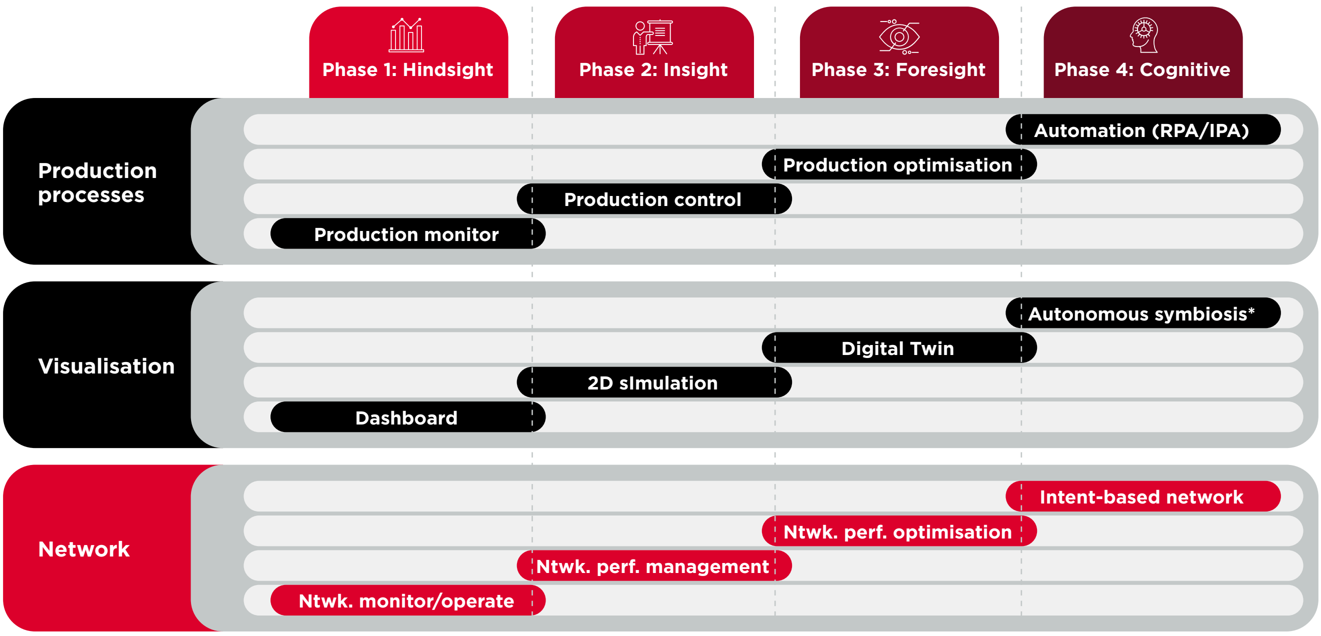
Business snapshot	Operational snapshot	Infrastructure/ technology snapshot
• Automation drived a rethinking of the business model (e.g. design, production, customer experience). • Culture based on harmonised goals and symbiotic relationship with automation/ robots/cobots. • Closed-loop, demand-driven manufacturing synchronising orders with supply chain with production. • Revolutionary leap in productivity, quality, revenue, profits, sustainability, consistency etc.	• Fully adaptive manufacturing through process automation with minimal human intervention. • Agile and flexible production to adapt to different products and changing demand. • High-performance network (on-site and wide area) that delivers ultra-low latency along with high reliability/ availability. • Operations management to orchestrate and oversee automated processes.	• Proliferation of 5G/MEC use cases (e.g. digital twin, AMR). • Over-the-air converged IT/OT enabled by the URLLC/TSN/ OPC UA. • Full network fabric (mesh) across sites, processes and partners/suppliers. • Public and private MEC. • Ubiquitous IIoT (i.e. sensors, actuators, applications).

Source: Original Verizon graphic

Use Case and Technology Journeys

I4.0 is only a greenfield endeavour for startups and new builds. For most, it will take an evolution to get to the revolution that is digital transformation. Most enterprises will need to maintain continuity and evolve over time. There are a broad set of use cases, platforms and key enablers that will each take their own evolutionary journey through the phases. The chart below highlights the journey for three representative technology areas. In reality, a diverse set of technologies need to be pointed in the same direction, with a bold vision that is grounded in concurrent but unique pathways to realisation; pathways that will yield incremental progress. Those technologies that yield the most significant business benefits or serve as the critical foundation for digital transformation should be the initial focus. Planning for and implementing the network vision is critical. It must serve as the guide that stays out in front of the other technology and use case journeys.

Figure 20 | I4.0 Evolution journeys



*Physical assets modified by twin and twin by physical assets

Source: Original Verizon graphic

An expanded view of the network layer in the chart below shows a phased approach to implementation of key wireless network features to ensure that value is derived incrementally by the enterprise. It is not meant to be exhaustive, but rather an example of how this could play out.

Figure 21 | Wireless network-centric view - generalised progression

1 Independent processes

Hindsight enablement

Independent OT networks for each process and/or device type
- Profinet: Temp Sensors
- Modbus: SCADA/PLC
- CC-Link-TSN: Servo Drives

Systematic problem-solving
- When problems occur, extract data from devices to solve specific problems (i.e. error codes, logs).
- May use vendor's HMIs to view/monitor in real-time.
- Define processes to address problems based on data (after the fact), generally human tasks.

2 Related processes

Insight enablement

Converged IT/OT wired Networks, limited wireless
- TSN, MQTT, OPC UA, TCP IP, IE
- ERP, MES, IIOT platform(s)
- End-to-end security + device management
- Wired + wireless (WiFi, cellular)
- >50ms latency, >10ms sync, >150cm precise location, 99.999% reliability (assumes Rel16)

Proactive problem-solving
- Implement backbone network to connect and extract data from all devices (industrial ethernet-wired to industrial gateways).
- Normalise and centralise data collection and visualisation (MQTT, OPCUA, Real-time dashboard).
- Scale up IIOT sensorisation, automation .
- Implement rules-based AI for proactively addressing anomalies to improve OEE.
- Deploy 5G/MEC/Cloud solutions for targeted use case(s).
- Where it makes sense, retrofit existing devices with wireless capabilities (WiFi/ LTE/5G dongles connected on ethernet port) to wireless APs (routers/gateways).
- Orchestrate processes for smart collaborative operations (e.g. sensors trigger AMR inspection).

3 Single or multiple sites

Foresight enablement

Mature, mostly wireless, single IT/OT converged network
- WIFI + MESH + 5G
- OTA URLLC, Ethernet PDU
- Multisite Continuity
- <30ms latency, <10ms sync, <100cm precise location, 99.999% reliability (assumes Rel16)

Proactive problem avoidance
- Employ ML models based on big data sets to anticipate problems before they happen.
- Ubiquitous IIOT sensorisation
- Scale up Private 5G/MEC to consolidate converged connectivity where it makes sense.
- Wider adoption of vPLCs and MEC-based applications (computer vision, safety).
- Extend coverage beyond the plant with continuity to WAN (multisite, mobility).
- Increased automation and robotics solutions, with greater awareness among all connected things for intelligent orchestration.

4 Ecosystem

Cognitive enablement

Single 5G Backbone Network for all connected things
- Dynamic, API-enabled network functions
- OTA URLLC/TSN
- <5ms latency, <1ms sync, <20cm precise location, 99.9999%+ reliability (assumes Rel 16+)

Closed-loop, ML-driven processes
- End-to-end automation of all processes/tasks (zero touch)
- Dynamic resource and tasks, allocation based on real-time complex AI/ML models
- Integration with all logistics, plants, suppliers, customer systems from order to delivery
- Self-healing, software-driven network deployment and maintenance with as a service model.

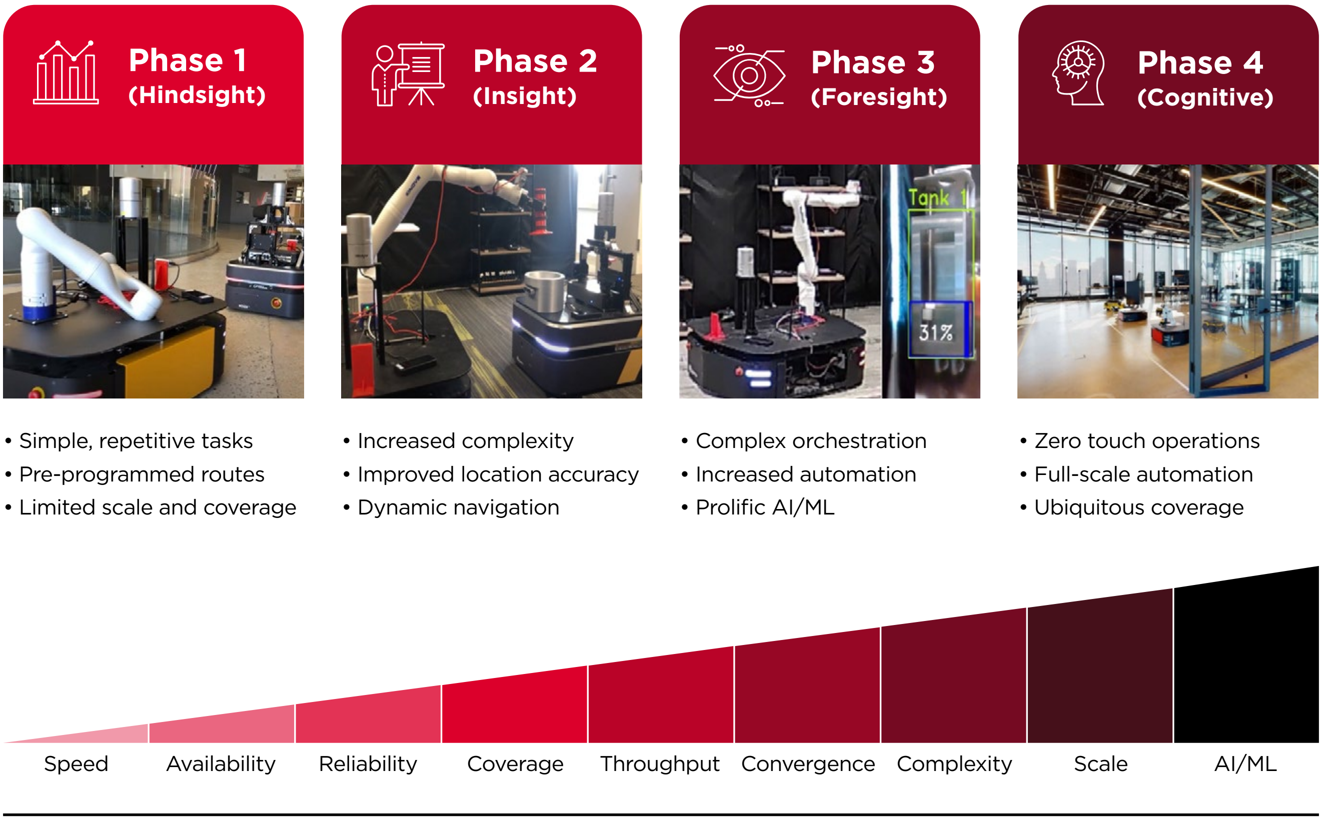
Source: Original Verizon graphic

AGV/AMR Use Case Detailed Example

This section takes a look at how the AMR/AGV use case could progress through the different phases of the Brownfield Evolution Framework, starting with a simplistic pictorial representing the progression of complexity, scope and breath, underpinned by incremental improvements of the underlying infrastructure.

If we were to dissect this example by its main components, we could highlight more specifically the different aspects of each phase from the use case itself to the device UEs, network, platform and application changes as it progresses through the framework.

Figure 22 | AGV/AMR use case evolution example



Source: Original Verizon graphic

Figure 23 | AGV Evolution Example

	Phase 1 (Hindsight)	Phase 2 (Insight)	Phase 3 (Foresight)	Phase 4 (Cognitive)
AGV/AMR Use Case	• Standalone, proprietary solution to solve a specific problem • Simple repetitive tasks • >100cm location accuracy and >80ms latency, 99.99% reliability • Limited navigation and scale • Mostly POC stage or limited production deployment • Examples: autonomous pre-programmed navigation, materials transport • Analytics not part of solution, historical reporting	• Increasingly complex tasks, but still standalone solution • More production deployments but with limited scale • >50ms latency, >10ms sync, >150cm precise location, 99.999% reliability (assumes Rel16) • Examples: semantic mapping, materials pick/place, computer vision, object recognition, limited collaboration tasks • Analytics introduced in limited scope for QA	• Complex tasks with integration to other independent processes and or actors • Mature production deployments • <30ms latency, <10ms sync, <100cm precise location, 99.999% reliability (assumes Rel16) • Examples: predictive maintenance with integration to supply chain for automatic ordering • Improved coverage and scale for large fleets	• Interoperable and extensive open solution • Large fleet scalability and ubiquitous coverage capacity • Complex tasks, including 'lights out' operations • <5ms latency, <1ms sync, <20cm precise location, 99.9999%+ reliability (assumes Rel 16+) • Self-healing, repair and maintenance services, including parts ordering and installation
Device UEs	• WiFi5 UEs and APs • External 5G Modules-limited availability • 5G gateways/routers-limited availability	• External 5G modules-limited availability • WiFi6 UEs and APs • 5G gateways/routers-limited availability	• Integrated and external 5G modules, readily available • Large-scale deployment of 5G routers/gateways and radios	• Integrated 5G modules • 5G gateways/routers
Network	**Independent, dedicated network per process** • Best effort cellular and WiFi • Limited coverage and scale • Isolation of AMR traffic • Data patterns require more throughput on the UL than DL	**Converged IT/OT wired networks, limited wireless** • Best effort cellular and/or WiFi • Limited coverage and scale • Heterogeneous network integrations (WiFi+cellular) • IT/OT convergence w/OPC UA and wired TSN	**Mature, mostly wireless, single IT/OT converged network** • Converged network for all connected devices • Ubiquitous coverage indoors and outdoors • Increased scalability, reliability, availability, location precision (URLLC)	**Single 5G backbone network for all connected things** • Primarily 5G NR advanced • NaaS • URLLC/TSN OTA
Platform	• Primarily on board compute • Little central processing	• IIOT platform (device mgt, app enablement etc) • Rules-based AI for optimisation • MEC-based centralised control	• ML dynamic adaptations for optimisation • MEC-based centralised control	• NaaP • Services-based IIOT • API microservices
Application	• On board system • Offline programming	• Increased MEC-based computation • Centralised data management	• Dynamic resource tasking based on demand	• Full centralised MEC-based control • AI/ML driven, adaptive closed loop flows

Source: Original Verizon graphic

Converged network case study

In order to illustrate this evolution in a more practical application, we will share our IT/OT convergence test bed case study where we took a set of independent commercial off-the-shelf industrial devices and processes and evolved through the different phases of the framework.

In our scenario, we have a brownfield deployment for an active factory. It has many systems online that serve specific purposes. Initially, each of these systems were deployed in their own self-contained network and had no visibility to each other. System management and control was through their own respective protocols and human/machine interfaces (HMIs). This factory had no support for remote access and could not leverage the data produced by each system. The vision was to undergo a digital transformation journey that would enable a new, converged, optimised, flexible, wireless, remote-capable and streamlined way of working where insights can drive near-real-time decision-making and actions across multiple phases of the operation.

Figure 24 | Case Study On Board Systems

System	Physical media	Protocol(s)
Radar sensor for water management system	1RS-485 Shielded Twisted Pair	Profibus-PA
A wireless SmartMesh of temperature and humidity sensors	2.4GHz, IEEE 802.15	SmartMesh-IP
A wired setup with distance sensors	2 standard sensor cabling	IO-Link
Motion control over TSN for a set of sychronised drives (@10ms intervals)	Industrial ethernet	CC-LINK TSN, IEEE802.1 AS IEEE802.1 Qbv
HD CCTV surveillance system	Ethernet	H.264, M-JPEG, TCP-IP

Source: Original Verizon graphic

Variant 1 topology: converged, no 5G, no virtualisation

In this scenario, the first step in our digital transformation journey was to connect all of the independent processes from Phase 0 (Blindside) to enable near-real-time data collection, monitoring, control and visualisation so that the operations engineer could supervise and control the systems from one central location and/or remotely. This maps to Phase 1 (Hindsight) of the framework.

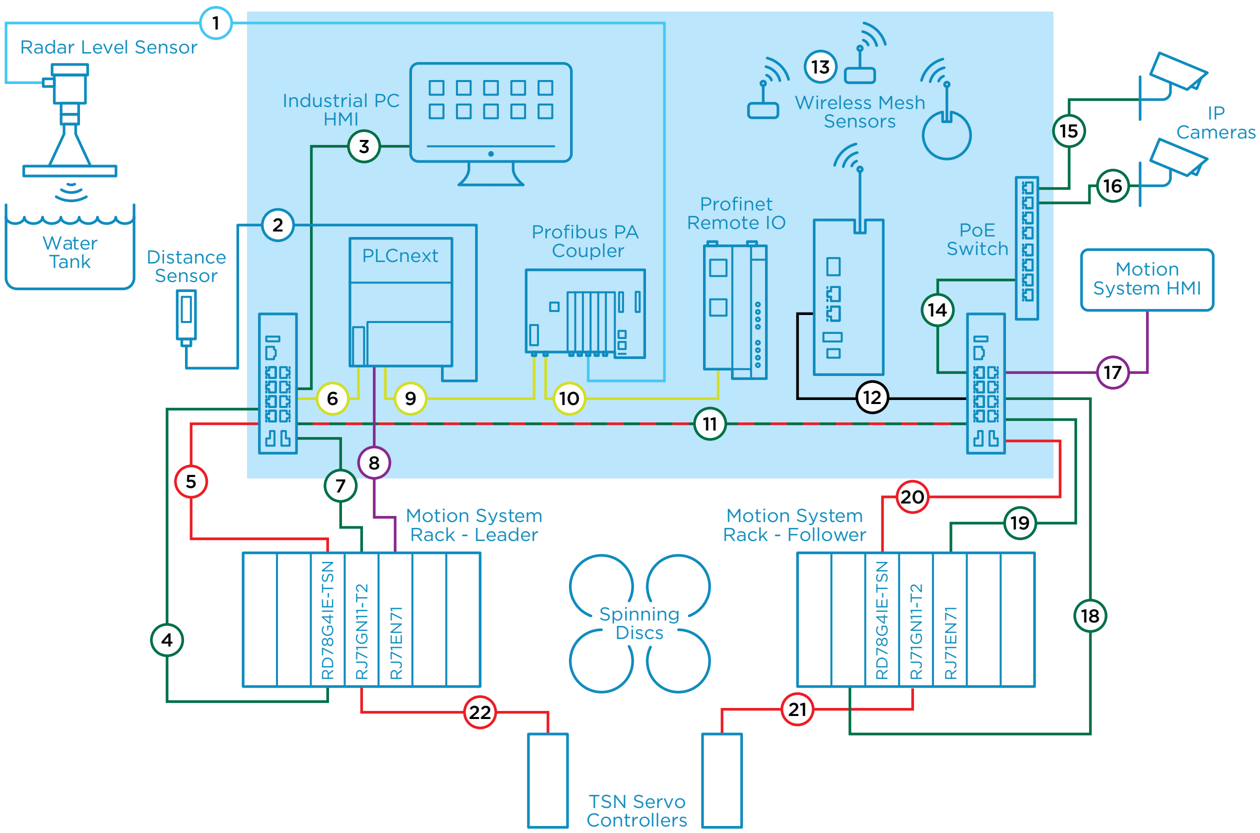
We took the following actions:

- Converged all data traffic onto a wired TSN-enabled trunk or backplane (#11 below).
- Introduced both OPC UA and MQTT brokers to facilitate telemetry data collection and control communications.
- Added central control with PLC, coupler and I/O appliances.
- Added a centralised dashboard for monitoring and control.
- Enabled remote access and control via secure virtual private network.

Operational outcomes:

- IT/OT convergence enablement.
- End-to-end visibility of all existing processes on a single pane of glass.
- Industrial network bus enablement for heterogeneous connectivity types.
- Real-time monitoring and control (local and remote).

Figure 25 | Variant 1 topology: converged, no 5G, no virtualisation



Please see p46 for the interfaces key

Source: Original Verizon graphic

Variant 2 topology: converged, release 15 5G, virtualisation

In this second step of our evolution, we wanted to transition towards virtualised control, add an AI component on the MEC and enable a mobile interface. This eliminates some of the physical appliances and gives the operations engineer flexibility to view and control operations anywhere on the factory floor. The AI component is a rules-based engine running on the MEC to optimise processes. In this scenario, the physical TSN trunk remains because the URLLC and TSN features are not yet available over the air. This maps to Phase 2 (Insight) of the framework.

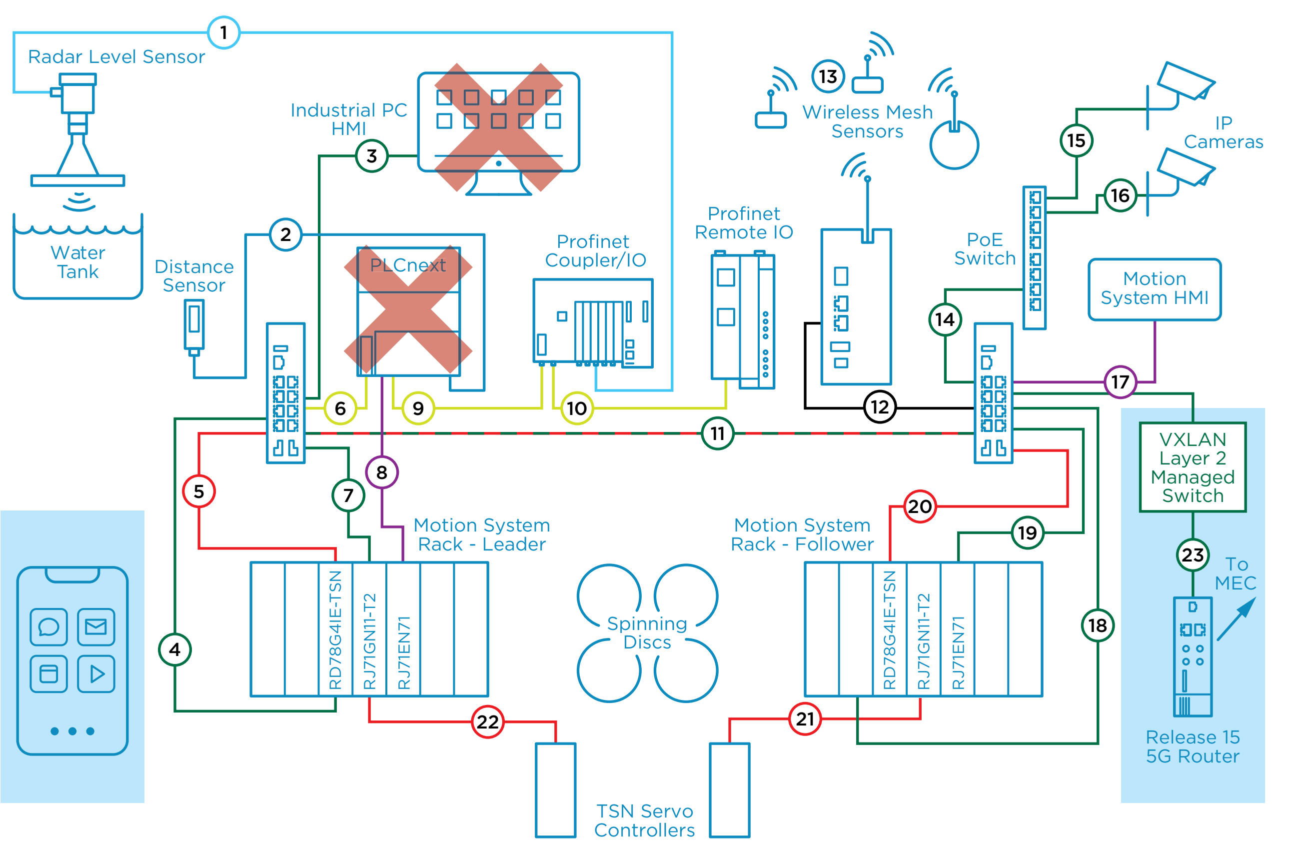
We took the following actions:

- Eliminated the physical controller and IPC HMI (represented by X).
- Virtualised the controller and HMI connected to the MEC over VXLAN (to enable layer 2 routing).
- Added a remote I/O unit to enable remote control.
- Introduced a phone/tablet connected to the system hosted on the MEC.
- Enabled MEC hosted AI rules-based system for optimisations.

Operational outcomes:

- Virtualised PLCs and HMIs to flatten topology for centralised control and distributed operations.
- Enable mobile dashboard interface.
- Predictive maintenance.
- Computer vision.
- Orchestration of predictive maintenance and computer vision above for autonomous safety inspections.

Figure 26 | Variant 2 topology: converged, release 15 5G, virtualisation



Please see p46 for the interfaces key

Source: Verizon Original

Variant 3 topology: converged, release 16+/17+ 5G, virtualisation

In this scenario, we will integrate advanced cellular capabilities such as OTA URLLC and TSN when they become available. This will allow us to virtualise all operations and run the TSN trunk wirelessly, eliminating the cable and simplifying the topology even more, while at the same time adding more flexibility towards modularisation. We maintained mobile and remote access. This maps to Phase 3 (Foresight) of the framework.

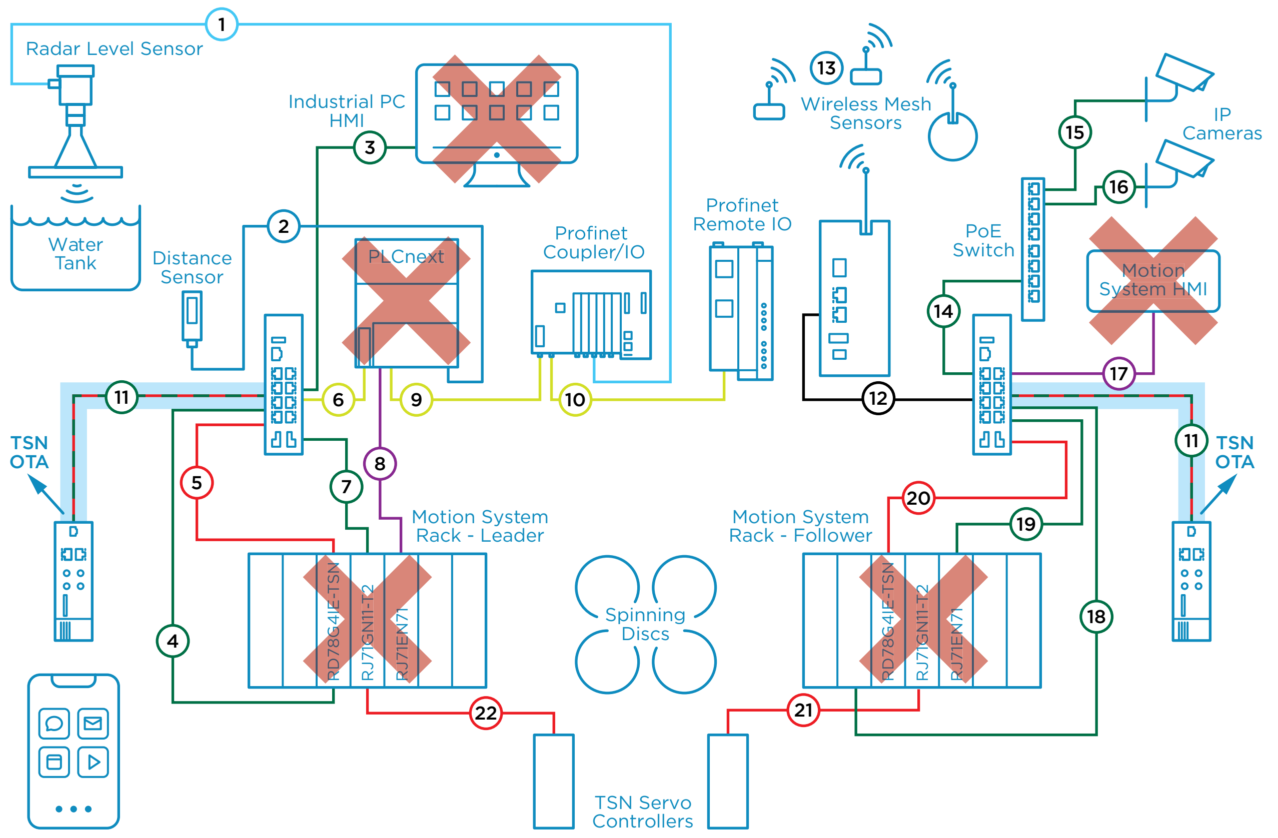
We will need to take the following actions:

- Replace the physical TSN trunk cable with a 5G OTA TSN enabled backbone.
- Eliminate the TSN system PLC and HMI.
- Move the OPC UA and MQTT servers to the MEC.
- Add ML component.

Operational outcomes:

- Replace the TSN industrial trunk with OTA 5G TSN, eliminating the physical wire.
- Further flatten the network topology by virtualising more components, including TSN control.
- Enablement of more advanced and modular components.
- Dynamic operational improvements using ML real-time modelling.

Figure 27 | Variant 3 topology: converged, release 16+/17+ 5G, virtualisation



Please see p46 for the interfaces key

Source: Verizon Original

Variant 4 topology: converged, release 17+ 5G, virtualisation (ultimate vision)

In this final scenario, the devices and 5G network capabilities will be further advanced to the full complement of URLLC and TSN capabilities. Existing devices are either upgraded to 5G or replaced with new generation devices that have 5G UEs integrated. The endgame is eliminating all wires, culminating in a 100% wireless deployment for all use cases. Mobile and remote capabilities are maintained and a full digital transformation goal is achieved.

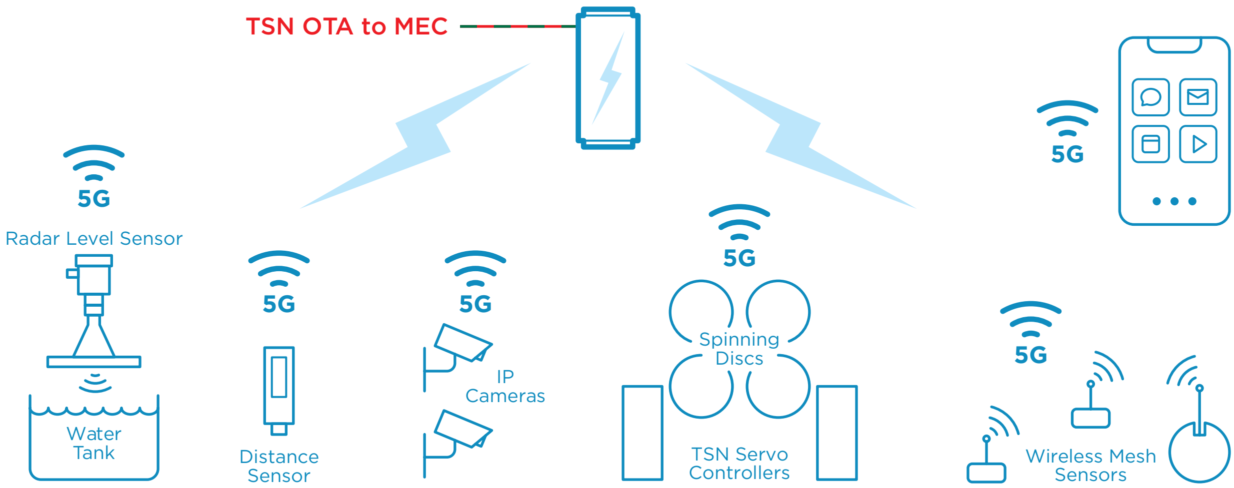
We will need to take the following actions, which map to Phase 4 (Smart) of the framework:

- Eliminate all wires.
- Replace with new devices or upgrade existing ones with cellular modules.
- Optimise virtual control and AI/ML models adapt in real time.

Operational outcomes:

- 5G connected devices, eliminating need for all industrial wires.
- Flexible and agile production model.
- Full transformation of brownfield deployment to modernised infrastructure.

Figure 28 | Variant 4 topology: converged, release 17+ 5G, virtualisation



Please see p46 for the interfaces key

Source: Verizon Original

Key

Protocols per cable - Networking information			
Cable	**Physical media**	**Protocols carried on the table**	**Symbol**
1	RS-485 Shielded Twisted Pair	Profibus-PA	
2	Standard Sensor Cabling	IO-Link	
3	Ethernet	TCP-IP, OPC-UA, MQTT	
4	Ethernet	TCP-IP	
5	Ethernet	CC Link IE - TSN	
6	Ethernet	Profinet	
7	Ethernet	Socket, TCP-IP	
8	Ethernet	Modbus TCP	
9	Ethernet	Profinet	
10	Ethernet	Profinet	
11	Ethernet	TRUNK LINE - CC Link IE TSN, OPC-UA, MQTT, TCP-IP, Socket, Modbus TCP	
12	Ethernet	MQTT	
13	2.4GHz per IEE 802.15 wireless	SmartMesh-IP	
14	Ethernet	TCP-IP, OPC-UA, MQTT	
15	Ethernet	H.264, M-JPEG, TCP-IP	
16	Ethernet	H.264, M-JPEG, TCP-IP	
17	Ethernet	Modbus TCP	
18	Ethernet	TCP-IP	
19	Ethernet	Socket, TCP-IP	
20	Ethernet	CC Link IE-TSN	
21	Ethernet	CC Link IE-TSN	
22	Ethernet	CC Link IE-TSN	

Next steps

1. Apply this framework to a specific I4.0 vertical (e.g. warehouse and logistics) and develop a detailed implementation plan for such verticals. Also, highlight the specific use cases that can be enabled, the required level of investment, and quantify the business outcomes enabled.
2. Promote engagement with operation technology leaders, device vendors, system integrators, communication service providers and standards bodies to experiment with the framework and provide feedback in order to continue to improve the model.
3. Solidify the ROI and new business models for strategic investments in infrastructure that will enable the convergence and eventual enablement of the desired I4.0 use cases.
4. Continue to define the governance and cultural models that will facilitate the adoption of I4.0.
5. Ground the customers on the tangible goals and benefits of what is possible today, but drive the evolutions towards the north star in order to fully benefit from the I4.0 vision.

Conclusion

The goal of this white paper is to introduce a reference framework for transitioning brownfield deployments/operations towards I4.0 enablement. It provides the context for and the north star towards each individual digital transformation journey, which will take time and involve a mix of organisational, tactical and strategic decisions. This framework also provides the flexibility of depth and breadth from select processes to complete operational uplifts. The overlay of example use cases and transformation examples help to ground these concepts in familiar devices, protocols and deployment scenarios and hopefully drive discussion and stimulate efforts in the ecosystem towards mass adoption. If the ultimate goal is to transform operations to be flexible, agile, resilient, optimised and data-driven (smart), all through ubiquitous industrial-grade connectivity, the network cannot be an afterthought because it must enable all of these capabilities. The good news is that customers can start now with thoughtful planning and tools like this framework to incrementally add value towards that I4.0 ultimate vision.

Key Assumptions, Dependencies and Constraints

1. This framework is not intended to be prescriptive for any operation category or specific deployment because each will have its own technology and deployment challenges. It should be used as a reference to help guide decision-making when assessing processes, infrastructure and/or entire operations for digital transformation. It should be balanced with tactical and strategic decisions that are right for the business.

2. The framework is formulated based on a representative sampling of requirements, use cases and applications and does not imply exclusions of any use case, technology or process not explicitly mentioned.

3. The framework does not dictate that any one process or operation graduate through every single phase. Rather, it depicts a spectrum across phases where overlap and intentionally stopping at any phase is based on need and ambition.

Acronyms/Terms

API	Application Programming Interface
AI	Artificial Intelligence
AR	Augmented Reality
AMR	Autonomous Mobile Robot
AGV	Automated Guided Vehicles
CV	Computer Vision
CORE	Core Network
DT	Device Technology
eMBB	Enhanced Mobile Broadband
eMTC	Enhanced Machine Type Communication
ERP	Enterprise Resource Planning
HMI	Human Machine Interface
I3.0	Industry 3.0
I4.0	Industry 4.0
IOS	Internet of Systems
IIOT	Industrial Internet of Things
IT	Information Technology
mMTC	Massive Machine Type Communications
ML	Machine Learning
MQTT	Message Queuing Telemetry Transport
MEC	Multi-Access Edge Computing
NSA	Non-StandAlone Network
OEM	Original Equipment Manufacturer
OPC UA	Open Platform Communications Unified Architecture
OEE	Overall Equipment Effectiveness
OT	Operational Technology
OTA	Over-the-air
QA	Quality Assurance
QoS	Quality of Service
PPE	Personal Protective Equipment
PN	Private Network
PLC	Programmable Logic Controller
POC	Proof of Concept
POV	Point of View
RAN	Radio Access Network
ROI	Return On Investment
SA	StandAlone Network
SCADA	Supervisory Control and Data Acquisition
SCM	Supply Chain Management
TSN	Time-Sensitive Networking
URLLC	Ultra Reliable Low Latency Communication
UE	User Equipment
UX	User Experience
vPLC	Virtualised Programmable Logic Controller
VR	Virtual Reality
VXLAN	Virtual eXtensible Local Area Network
XR	Extended Reality

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Tunde leads Strategy Development for Global Network and Technology at Verizon. He is responsible for developing technology and product innovation strategies to ensure Verizon maintains its technology leadership. He has led strategy and innovation management across industry verticals. Tunde has held responsibilities for deal negotiation, growth strategy, strategic planning, corporate venturing and M&A evaluation within Verizon over the past decade.

Prior to Verizon, Tunde worked with IXL Center, where he helped Fortune 100 corporations develop strategies and commercialise innovative business concepts. Tunde previously held a regional leadership role in a multinational telecommunication provider in Nigeria, successfully designing sales expansion strategies and leading significant business turnaround initiatives.

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