IEC TR 63283-5

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TECHNICAL REPORT

colour inside

Industrial-process measurement, control and automation – Smart manufacturing – Part 5: Market and innovation trends analysis

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INDUSTRIAL-PROCESS MEASUREMENT, CONTROL AND AUTOMATION – SMART MANUFACTURING –

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The text of this Technical Report is based on the following documents:

Draft	Report on voting
65/1008/DTR	65/1028/RVDTR

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 63283 series, published under the general title *Industrial-process measurement, control and automation – Smart manufacturing*, can be found on the IEC website

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

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INTRODUCTION

The IEC TR 63283 series describes the framework for smart manufacturing concepts and in particular, terms and definitions, use cases, cyber security, market and innovation trends and new technologies.

This document describes the market and innovation trends and analyses their impediments and impacts to smart manufacturing.

The market trends are based on the tendency that the smart manufacturing markets move into a particular direction potentially using technologies described in other parts of the series. These market trends have the time prospective of 3 years to 5 years to become common smart manufacturing concepts.

The innovation trends describe those technology innovations that are considered to have an impact on or to influence the smart manufacturing concepts. These innovation trends have the time prospective of 5 years to 10 years.

This document also describes how the market and technology trends are influencing the current business models. Some examples of the forthcoming business models are described.

This document has no intention to describe an exhaustive list of market, innovation or the business model trends. It also forecasts how standards will be influenced by these market, innovation and business model trends.

INDUSTRIAL-PROCESS MEASUREMENT, CONTROL AND AUTOMATION – SMART MANUFACTURING –

Part 5: Market and innovation trends analysis

1 Scope

This part of IEC 63283 describes the market and innovation trends analysis affecting smart manufacturing (SM). The market and innovation trends will influence the evolution of smart manufacturing and it will be important to have good insights on these trends. Specific aspects of the market trends are the evolution of the business cases that is assumed to highlight new supplier chain models, new revenue streams, new customer services, and/or new customer segments.

The document will address the following topics:

- Market watch: Identify the important, likely, and/or disruptive market trends (e.g. mass customization) from an end-to-end perspective, which impact smart manufacturing topics/aspects. This includes the end-user, producers, supply chain, regulators, etc.
- Business model watch: Identify the new business model trends from an end-to-end perspective, which impact smart manufacturing.
- Technological watch: Identify the important, likely, and/or disruptive innovations (AI chipsets, 6G, quantum computing, etc.) describing the impacted smart manufacturing topics/aspects; this topic will focus on those technologies that are still under development but is assumed to influence (or is assumed to be influenced by) smart manufacturing.

There are many more new trends which are used in SM. In this document, only some frequently discussed trends are presented. Some technologies are considered to have priority according to their maturity.

This work will focus on how they can be used in SM.

2 Normative references

There are no normative references in this document.

3 Terms, definitions, abbreviated terms and acronyms

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

NOTE Numbers in square brackets refer to the Bibliography.

3.1 Terms and definitions

3.1.1
market trend
perceived tendency of a particular sector to move in a particular direction over time

Note 1 to entry: These trends are classified as secular for long time frames, primary for medium time frames, and secondary for short time frames.

Note 2 to entry: This report attempts to identify market trends using technical analysis, a framework which characterizes market trends as predictable tendencies within the market when the trend reaches support and resistance levels, varying over time.

Note 3 to entry: A trend can only be confirmed in hindsight, since at any time the future is not known.

Note 4 to entry: In this document, market trend also includes tendency of technology innovations and behaviour of the stakeholders around such innovations.

3.1.2
innovation
new idea, creative thoughts, new imaginations in form of device or method

Note 1 to entry: Innovation is often also viewed as the application of better solutions that meet new requirements, unarticulated needs, or existing market needs. Such innovation takes place through the provision of more-effective products, processes, services, technologies, or business models that are made available to markets, governments and society.

Note 2 to entry: An innovation is something original and more effective and, as a consequence, new, that "breaks into" the market or society. Innovation is related to, but not the same as, invention, as innovation is more apt to involve the practical implementation of an invention (i.e. new/improved ability) to make a meaningful impact in the market or society and not all innovations require an invention. Innovation often manifests itself via the engineering process, when the problem being solved is of a technical or scientific nature.

Note 3 to entry: While a novel device is often described as an innovation, in economics, management science, and other fields of practice and analysis, innovation is generally considered to be the result of a process that brings together various novel ideas in such a way that they affect society. In industrial economics, innovations are created and found empirically from services to meet growing consumer demand.

[SOURCE: Wikipedia article on Innovation, https://en.wikipedia.org/wiki/Innovation. This work is licensed under the Creative Commons Attribution-ShareAlike 4.0 International License. To view a copy of this license, visit http://creativecommons.org/licenses/by-sa/4.0/]

3.1.3
innovation trend
assumed innovation in the future that will have a long-term and lasting effect on and change something

EXAMPLE Current developments are moving in a different direction or intensifying even more.

3.1.4
zero-defect manufacturing
ZDM
holistic approach for ensuring both process and product quality by reducing defects

Note 1 to entry: Defect reduction is achieved through corrective, preventive and predictive techniques using mainly data-driven technologies and guaranteeing that no defective products leave the production site and reach the customer aiming at higher manufacturing sustainability.

Note 2 to entry: ZDM improves process efficiency and product quality.

3.1.5
asset
entity owned by or under the custodial duties of an organization, which has either a perceived or actual value to the organization

[SOURCE: IEC TR 63283-1:2022 [1], 3.1.26]

3.1.6
production system
system intended for production of goods

Note 1 to entry: The concept of production system includes spare parts.

Note 2 to entry: The concept of production system does not encompass the whole manufacturing facility. It excludes in particular the supporting infrastructure (such as building, power distribution, lighting, ventilation). It also excludes financial assets, human resources, raw process materials, energy, work pieces in process, end products.

Note 3 to entry: Production systems can support different types of production processes (continuous, batch, or discrete).

[SOURCE: IEC TR 63283-1:2022 [1], 3.1.350]

3.2 Abbreviated terms and acronyms

4G	4^{th} generation cellular system
5G	5^{th} generation cellular system
5G-PPP	5^{th} Generation – Public Private Partnership
6G	6^{th} generation cellular system
6G-PPP	6^{th} Generation – Public Private Partnership
AAS	asset administration shell
ADSL	asymmetric digital subscriber line
AI	artificial intelligence
AIOTI	Alliance for the Internet of Things Innovation
API	application programming interface
App	application
B2B	business to business
B2C	business to consumer
BIS	building information system
CAD	computer aided design
CAM	computer aided manufacturing
CCPA	California Consumer Privacy Act
CDD	common data dictionary
CPU	central processing unit
CSA	coordination and support action
CWA	CEN Workshop Agreement
DevOps	SW development and IT operations
DF	digital factory
DMP	digital manufacturing platform
DSP	digital signal processor
E/W	East/West
ECN	edge control node
EPON	Ethernet Passive Optical Network
ERP	enterprise resource planning

EU-OSHA	European Agency for Safety & Health at Work
F6G	6th generation fixed network
FCC	Federal Communications Commission
GDPR	General Data Protection Regulation
GHz	giga hertz
GPON	gigabit passive optical network
GPU	graphics processor unit
HAP	high-altitude platform
HPC	high performance computing
I4.0	Industry 4.0
IACS	industrial automation and control systems
ICT	information communication technology
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IIoT	industrial Internet of things
IoT	Internet of things
ISDN	Integrated Services Digital Network
ISP	image signal processor
IT	information technology
ITU-T	International Telecommunication Union – Telecommunication Standardization Sector
LCA	life cycle assessment
LGPD	Lei Geral de Proteção de Dados or General Data Protection Law
LTE	long term evolution
M2M	machine to machine
MES	manufacturing execution system
MIIT	China Ministry of Industry and Information Technology
MIMO	multiple input multiple output
ML	machine learning
mmWave	millimeter wave
MQTT	Message Queuing Telemetry Transport
N/S	North/South
NB-IoT	narrowband – Internet of things
NISQ	noisy intermediate-scale quantum
O&M	operations and maintenance
OCI	open container initiative
oneM2M	Standards for M2M and the Internet of Things
OPC	Open Platform Communications
OPC-UA	OPC Unified Architecture
OPE	operational excellence
OPEX	operational expenses
OS	operating system
OTD	open technical dictionary

OWL	web ontology language
PC	personal computer
PON	passive optical network
PSTN	public switched telephone network
QKD	quantum key distribution
QoS	quality of service
Qubits	quantum bits
RDF	resource description framework
R&D	research and development
SaaS	software as a service
SG	study group
SM	smart manufacturing
SME	small medium enterprise
SW	software
TCG	Trust Computing Group
THz	tera hertz
TRL	technology readiness level
TSN	Time Sensitive Networking
VDSL	very high-speed digital subscriber line
WFA	Wi-Fi Alliance
WIA-PA	Wireless Networks for Industrial Automation/Process Automation
Wi-Fi	Wireless Fidelity
XML	eXtended Markup Language
ZDM	Zero-Defect Manufacturing

4 Smart manufacturing trend analysis

4.1 Trend analysis template

Each trend is described by the following template introducing the following aspects of the trend:

- Description

This subclause describes the trend textually, how the trend is used in reality (use case), and the stakeholders in order to clarify the referenced market, market expectations, business model or the technology trend.

- Impediments to market acceptance

This subclause describes what the market obstacles are to realise the market trends, e.g. restrictions, uncertainty, competitive technologies, regulatory restrictions.

- Impacts to smart manufacturing

This subclause analyses the trend and describes the impacts to smart manufacturing. Potential impacts, if addressed, could be specified to the smart manufacturing use cases, architecture, information models, lifecycle, interfaces, security and safety.

- Standardization needs

This subclause describes the standardization needs internally and externally of IEC TC 65. If there are standardization needs identified for IEC TC 65, then the suggested respective working group and/or subcommittee are identified where such standardization ought to take place.

4.2 Market watch

4.2.1 General

Some of the common smart manufacturing market trends are listed within the following subclauses. They are based on the technologies as described in other parts of this series, which describe new innovative technologies expected in the coming years. It is understood that these innovative technologies are already available and have been proven useful to the domain of smart manufacturing. Therefore, the required technologies are ready to realise the described market trends below and it is assumed that these market trends will be common within smart manufacturing in 3 years to 5 years.

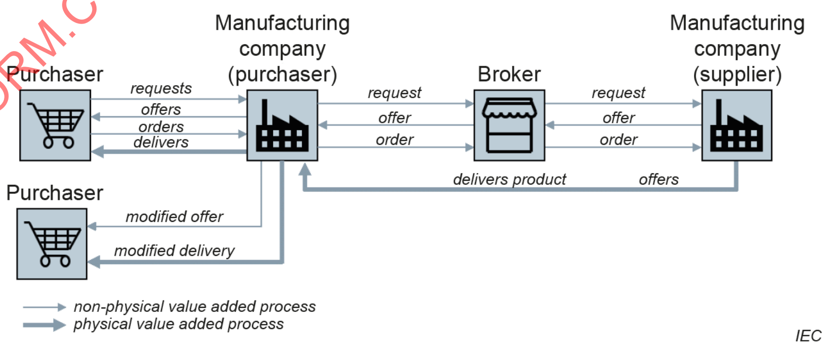
What is being described is not intended to produce an exhaustive list of market trends.

4.2.2 Mass customization

4.2.2.1 Description

The customer demands have evolved from standard mass market products towards personalised products based on the customer needs. This market trend can be realised by benefiting from the capabilities that smart manufacturing provides, like the flexible production systems.

The manufacturing market is evolving towards an individualised market that will require a manufacturing company to offer a flexible product/service portfolio. Therefore, a manufacturing company will require a strategy addressing such individualised market, while still being profitable from its operational perspective. Examples of such strategies are Manufacturing of Individualised Products, Flexible Scheduling and Resource Allocation and Outsourcing of Production, collectively named order-controlled production. Figure 1 illustrates a combined business context of the separate business contexts of Manufacturing of Individualised Products, Flexible Scheduling and Resource Allocation and Outsourcing of Production, which are further explained within IEC TR 63283-2 [2][1].



SOURCE: IEC TR 63283-2:2022, modified combining use cases 6.1.1, 6.1.2 and 6.1.3 (Figures 6, 8, and 10).

Figure 1 – Business context of "Mass customization"

[1] Numbers in square brackets refer to the Bibliography.

Such a market trend is achieved with the usage of an adaptable production system. This system will require standardized interfaces to ensure interoperability within and between production systems. One aspect of such adaptability will be related to the production outsourcing, i.e. cooperation between own and/or external factories to improve the efficiency of the manufacturing process. This market trend will allow the manufacturing company to supplement its own production capability by integrating a highly individual production capability offered by a specialised 3rd party manufacturer. The inclusion of the 3rd party manufacturing company can be established by purchaser, supplier or by an independent broker. In case of the independent broker, the business relationship between the purchaser and supplier will be managed by the broker.

Finally, the market is providing additional product configuration tools to allow customers to configure and order its products. The configuration tools will offer mandatory boundary conditions when combining the different configuration options. The configuration tool will provide the order information which will be analysed regarding the correctness of the order and additional information, such as specific customer information, order history and related service information.

4.2.2.2 Impediments to market acceptance

The market trend mass customization will be dependent on the degree of automation within the product design and production process. Currently most of these processes are carried manually, and this makes the mass customization to be a negative impact on the effectiveness and efficiency of the manufacturing process.

Another aspect is the degree of the agility of the production process. The production process is expected to be highly automated to support the high number of individualised products. Therefore, once the production processes are digitalised, additional new technologies, such as AI, edge computing, digital twin, etc., need to be introduced. Most of this digitalization will be realised in the context of digital factory and/or smart manufacturing.

The changed engagement between the purchaser and the manufacturing company will require the establishment of a new legal contract between the purchaser and the manufacturing company, in which terms and conditions are described about what the manufacturing company will offer and deliver towards the purchaser.

The current role of the broker is limited to outsourcing specific production capabilities by identifying suitable manufacturing companies and providing supportive services to establish the contractual relationship between the purchaser and the supplier. This brokering is highly manual, and mass customization will require a more dynamic, generic brokering, and platform based brokering mechanism.

Product configuration will be highly dependent on the boundary conditions that are mandatory to be followed when combining different sub-systems to form an overall system.

4.2.2.3 Impacts to smart manufacturing

The mass customization market trend will accelerate the evolution towards smart manufacturing introducing new features, like artificial intelligence, edge computing, digital twin, and asset administration shell. The market trend will also provide a much higher digitalization degree of the product and production design and allow for a full automation of the manufacturing processes.

The digitalization and automation handling of the product orders will enable applying algorithms to optimize the manufacturing operational processes. This automation will increase the efficiency and effectiveness of the factory performance. It will also broaden the order offering of the manufacturing company to their purchasers and/or brokers. The digitalization and automation will also decrease the time to market of their offerings and therefore increase the production capacity of the manufacturing company.

The digitalization and the digital twin of the product and production processes will allow the manufacturing company to give more updated information about the current status of the product and/or status of the production of the targeted product.

The automated negotiations, offered by the broker, will allow a broader market for the supplier manufacturing companies while it will be easier to integrate the supplier manufacturing company within the purchaser supply chain. Additional brokering services can be offered in the sense of logistics services, supplier offering optimization services and quality assurance services.

The information retrieved from the product configuration will provide a prediction of the customer order and will allow any manufacturing company to provide product configuration recommendations to the purchaser.

4.2.2.4 Standardization needs

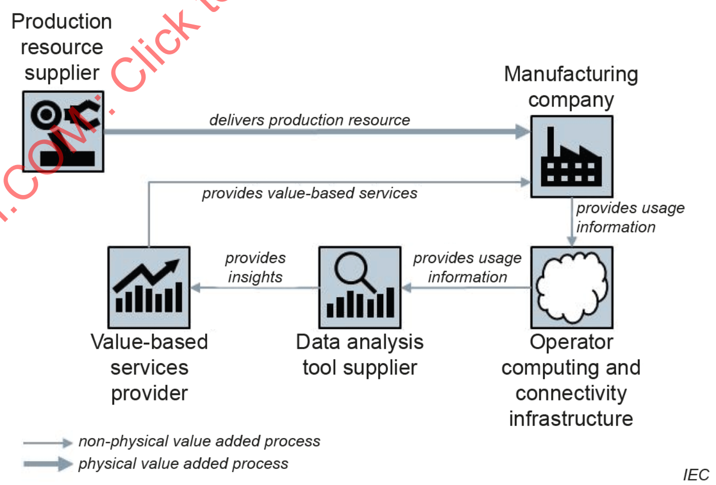
Standardization needs can be derived from the smart manufacturing order controlled production use case cluster within the smart manufacturing use cases report (IEC TR 63283-2), as specifically mentioned in the use case:

- manufacturing of individualised products;
- outsourcing of production;
- decision support for product configuration.

4.2.3 Value based service along the life of an asset

4.2.3.1 Description

The trend of the provisioning of value-added services complementing the delivered production resources is increasing the efficiency of using these resources. The value-added services will allow the manufacturing companies to increase the efficiency of the production processes and will optimize the usage of the production resources.



SOURCE: IEC TR 63283-2 :2022, use case 6.7.1 (Figure 70).

Figure 2 – Business context of value-based services for production resources

An additional business role of the value-based services provider is illustrated in Figure 2 to provide value-based services complementary to the delivered production resources. The value-based service provider will receive production insights via analysis of the production data from the manufacturer. For example, analysing production usage information can improve efficiency and predictability of the production process by providing optimizations to the product combinations and/or device programming to minimize waste and failure, reduce assembly costs and time, and simplify sourcing and ordering.

4.2.3.2 Impediments to market acceptance

This market trend will require a substantial digitalization of the production process so that appropriate production data can be derived from the production process. An efficient infrastructure would be required to extract the production data from the different production resources. Furthermore, it is assumed that dedicated AI solutions are needed to analyse the production usage information to provide the relevant production insights, which would be the input to further optimize the collected production usage information.

One aspect that will influence the realization of this market trend is related to the privacy aspects. The availability of anonymization of the exchanged data needs to be addressed.

Therefore, smooth computing and connective infrastructures and also advanced data analytics solutions are needed within the manufacturing operations. This introduction is ongoing at this moment within the manufacturing industries, but it is far from complete.

4.2.3.3 Impacts to smart manufacturing

The current manufacturing infrastructure is very much a closed infrastructure and the production data is not always available outside the factory. Therefore, the impact related to the introduction of 3rd party computing and connective infrastructure will require a substantial change within the manufacturing culture.

A second impact is to make the production resource usage data available to 3rd party stakeholders to analyse the data to provide relevant production insights. These production insights will be the basis to develop the added value services by an independent value-based service provider.

The benefit of the required openness will be the improved efficiency of production processes across different production resources.

4.2.3.4 Standardization needs

Standardization needs can be derived from the smart manufacturing product and production services use case cluster within the smart manufacturing use cases report (IEC TR 63283-2), as specifically mentioned in the use cases:

- value-based services for production resources;
- update and functional scalability of production resources;
- condition monitoring of production resource;
- self-optimization of production resources;
- benchmarking of production resources;
- production resource as-a-service.

4.2.4 Artificial intelligence in whatever form of usage

4.2.4.1 Description

The current market trend is to optimize the value-added process of manufacturing companies via analysing data from various sources, for example production resource data, using artificial intelligence (AI) technologies to deliver the targeted improvements to the operational excellence. This will require pattern recognition within the various usage information to deliver the optimization opportunities. This pattern recognition is automated via AI technologies, for example machine learning.

The introduction of AI technologies to optimize the value-added processes can be provided by 3rd party technology and service providers. This will enable manufacturing companies to focus on their domain knowledge and the application of AI technologies.

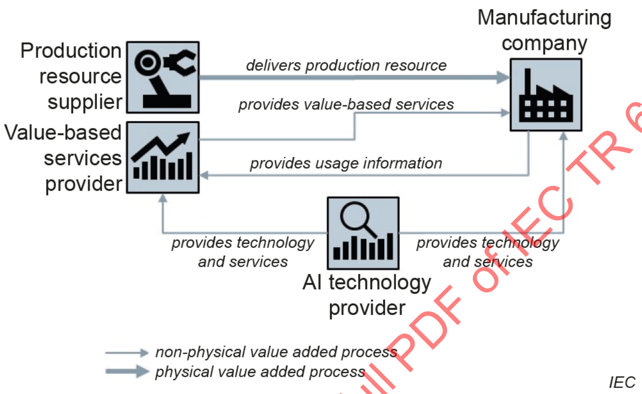


Figure 3 – Business context of "Artificial Intelligence"

As displayed in Figure 3, there are mainly three different business stakeholders in the context of AI in manufacturing industries:

- provider of AI technologies (including provision of services related to the application of the offered AI technologies);
- manufacturing companies, which internally apply AI technologies in order to optimize their value-added processes. In this case, the necessary data to be analysed using AI technologies is typically owned by the manufacturing company;
- value based service providers, which apply AI technologies in order to extend their portfolio from offering production resources to additionally offer value-based services to their customers; see also market trend "value-based services". In this case, the necessary data to be analysed using AI technologies typically needs to be provided by the customer based on some individual contractual agreement between the customer and the provider of value-based services. In the market, there are very few examples of value-based services based on AI technology being offered by companies without them also offering a physical product.

For example, in the context of production related value-added processes, automated AI based production improvements will enhance the production quality and efficiency, and will reduce the number of production faults.

4.2.4.2 Impediments to market acceptance

This market trend will require similar digitalization aspects as defined for the value based services market trend. In addition, manufacturing specific AI models are needed to target the required optimizations. Therefore, it needs to be ensured that such models can be created economically. Standardization, for example, can contribute to this to allow for interoperability between different AI based services. In addition, further research on the AI models is assumed to be needed.

The quality of AI will substantially depend on the availability of suitable and correct AI training data. The availability of the right set of AI training data is still under further research as well, especially in the context of manufacturing industries, where information models are typically very complex and application specific.

In addition, there is also a chicken-egg problem to be solved with value-based services based on AI: On the one hand, the value-based services provider asks the customer to provide suitable data so that high-quality value-based services can be offered. On the other hand, customers will only make their data accessible if the provider of the value-based services contractually promises a sufficiently high level of benefits.

4.2.4.3 Impacts to smart manufacturing

The current manufacturing infrastructure is often a closed technical infrastructure and often production data is not available outside the factory, even not to the design and engineering departments of the manufacturing company. Therefore, the impact is related to the introduction of a technical computing and connectivity infrastructure, which can also be operated by some 3rd party company. This will require not negligible investments and a substantial change especially within the manufacturing culture.

In the context of production processes, AI related improvements are:

- qualitative analysis of the produced products;
- safety improvements to the production staff;
- safe working in a collaborative environment between humans and machines;
- predictive maintenance resulting in higher availability systems;
- high level of automation of complex production processes.

There will not be a single one-size-fits-all AI solution, but there will be several specialised AI solutions within a manufacturing company. Therefore, a highly automated AI based production process is assumed to leverage the complexity of the individual products.

The benefit of the required openness will be the improved efficiency of production processes across different production resources. In addition, the production capability is assumed to include products with a much higher complexity.

4.2.4.4 Standardization needs

Standardization needs can be derived from the new technologies in other parts of the series.

Standardization needs can also to be derived from the following use cases within the smart manufacturing use cases report (IEC TR 63283-2):

- self-optimization of production resources (focus on value added process services);
- optimization of operation through machine learning (focus on value added process production execution);
- optimization in design and engineering through machine learning (focus on value added processes product design, production planning and production engineering);
- support for tactical and strategic decision making;
- decision support for product configuration.

From a value-added perspective, these use cases seem to be representative for manufacturing industries. The relationship between functional safety and AI (e.g. AI with a safety verification) is proposed in the IEC White Paper: Safety in the Future:2020 [3] and is under development within ISO/IEC JTC 1 with liaisons participating from IEC.

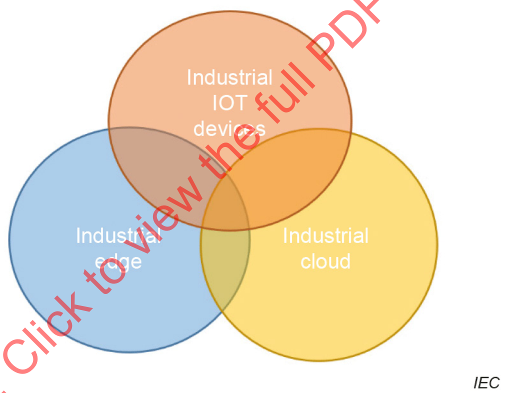
4.2.5 Distribution of analysed information (edge versus cloud)

4.2.5.1 Description

4.2.5.1.1 General

The availability of the industrial Internet of things (IIoT) has stimulated the further evolution of a distributed computing architecture evolving it from the cloud towards the distributed edge nodes. Edge-cloud computing models operate both on premise and in public and private clouds, including via devices, base stations, edge servers, micro data centres and networks. Expansion of the Internet of things (IoT) and digital transformation will generate entirely new businesses and markets, with both vendors and customers creating new demands on computing and networking infrastructures across all industries (automotive, aerospace, life safety, medical, entertainment and manufacturing, to name just a few) (IEC White Paper Edge Intelligence:2017) [4].

Digital platforms for industrial purposes can take digital factory initiatives to the next level by providing agile SW development and IT operations (DevOps) capabilities across all industrial applications in the factory. These platforms go beyond industrial IoT (not limited to device and sensor data), orchestrating applications and data in a holistic way across connected devices (embedded systems, programmable logic controllers), industrial edge computing (e.g. industrial PCs, gateways, servers), and the cloud. See Figure 4. To underline the described evolutionary shift, the move is to go away from the terminology of industrial IoT platforms, going instead towards "digital platforms for the industrial world". These platforms have the ambition to manage the factory with all its applications as an increasingly integrated and agile digital system (Vogt, 2020) [5].



SOURCE: Based on PAC RADAR, Open Digital Platforms for the Industrial World in Europe 2020, Arnold Vogt. Reproduced from [5] with the permission of Arnold Vogt, Head of Digital CX & IoT, PAK, a technology group company.

Figure 4 – Digital platforms for the industrial world orchestrate applications across IoT devices, edge, and cloud

The final aspect to be considered in this context of emerging digital platforms for the industrial world is "openness". As already mentioned, the shop floor is a highly heterogeneous place, and it will remain so in many respects. It remains a heterogeneous environment across applications, IoT devices, edge, and cloud infrastructures. While digital platforms can help to handle the infrastructure-related heterogeneity through an efficient abstraction layer (containerized applications that provide infrastructure flexibility), and integrated IoT capabilities help to connect all kinds of IoT devices, there is still the need to make newly emerging applications (potentially for innovative use cases) quickly and efficiently available to users of the digital platform. To facilitate this, an open application (app) store model integrated with the digital platform would be appropriate. This would give users not only access to new, internally developed applications, but also to external applications from the platform provider or other 3rd-party developers. Only a large ecosystem and openness to all 3rd-party application developers can provide the maximum agility required in the market today. In a high-speed world, no individual application creates a lasting competitive advantage – it is the ability to move faster on a large scale that makes the difference. Today, open digital platforms are the best approach to achieve this for the digital factory in an efficient way.

The emergence of edge computing is currently making companies reconsider the best basic architecture for their digital factory and other operational environments. Edge computing can be helpful in this respect. It is not really a new technology in itself, but it opens up new perspectives in terms of different architectural concepts. Edge computing can be seen as a competing concept to the cloud world. However, in reality, both elements are often closely connected. Technology strongly believes in two things: First, the future of the digital factory is hybrid (edge and cloud together), not pure cloud or edge. Second, even in a hybrid future, there will be different, competing concepts in the market. A basic differentiation of these different hybrid architecture models is edge-centric vs. cloud centric. However, technology distinguishes three different concepts in the market today that are increasingly competing with each other, and vendors are starting to position themselves around these different concepts.

The following subclauses provide an introduction to the different concepts and highlight their general strengths and weaknesses:

- industrial cloud;
- industrial edge;
- industrial edge cloud.

4.2.5.1.2 Industrial cloud

The "industrial cloud" concept is not a "cloud-only", but rather a "cloud-centric" concept. The idea is to bring data from industrial devices at the edge to the applications in the cloud for central data processing. This means that the cloud acts as the central hub for all data (including data management, access, and storage). In addition, the cloud acts as the central hub for all applications (including the app store). However, this does not mean that all applications are only running in the cloud. The extension of the cloud-centric concept to enable some data processing can be observed at the edge, albeit tightly integrated and controlled by the cloud.

The vendor landscape for this concept comes mainly from two corners of the market. The first group are hyperscalers, which are increasingly moving the cloud platforms into the industrial space. The second group are providers of industrial IoT platforms and industrial software, which are increasingly offering their application portfolio via the cloud.

4.2.5.1.3 Industrial edge

Similar to the industrial cloud concept, the industrial edge concept is not an "edge-only", but rather an "edge-centric" concept. The idea is to bring applications to the data at the edge for local data processing. This means that the edge acts as the central hub for all data (including data management, access, and storage). It does not mean that data storage only takes place at the edge. The cloud is assumed also to act as an extended data storage, but in an edge-controlled setup. While applications run at the edge in this concept, the related app store can operate in a private back end (edge, data center, private cloud) or in the public cloud. These central app stores enable users to download relevant applications to the edge. In this setup, IoT devices do not directly communicate with the cloud, only via the edge. This enables an edge-controlled system with local data management and data processing plus extended data storage in the cloud. It allows to run app stores for edge applications in different back-end systems (at the edge or in the cloud).

4.2.5.1.4 Industrial edge cloud

The two concepts described above – industrial cloud and industrial edge – have a clear focus on today's requirements of the digital factory. It is pretty obvious, in our high-speed world, that tomorrow's innovation will come even faster. Thanks to the latest innovations in the cloud world, it is easy to predict what the next wave of "cloud-native" innovations will bring to the industrial edge (and the edge data centre). Container based systems such as Kubernetes will be the next big thing at the edge, as it already is in the cloud. As mentioned above, Container based software systems provide a highly automated approach to managing and scaling a large amount of containerized applications across clusters of distributed infrastructures (called nodes/pods). The basic aspects of the industrial edge cloud concept are therefore quite similar to the industrial edge concept, with one addition – Orchestration software manages the edge applications (Vogt, 2020).

4.2.5.2 Impediments to market acceptance

4.2.5.2.1 General

The following impediments to market acceptance are identified (Vogt, 2020) for:

- industrial cloud;
- industrial edge;
- industrial edge cloud.

4.2.5.2.2 Industrial cloud

The key impediments of the cloud are latency, data sovereignty (not necessarily security), and vendor lock-in. The latency issue is already being addressed by many vendors; they are trying to overcome low latency by integrating more edge capabilities into the overall concept. Building a high level of trust alleviates concerns about data sovereignty. However, trust is a very volatile element, especially in uncertain times like these. As protectionism is spreading in more and more areas across the world, it is expected to see a growing tendency among users to prefer highly trusted and/or local vendors as their strategic suppliers. Another aspect is dependence on a provider in general. Manufacturing companies have the clear intention to limit their dependence on individual suppliers within their supply chains – flexibility is key. Supply chains in the automotive industry are a good example in this context. The same attitude towards IT-related suppliers can be observed. Some companies in the manufacturing industry are unlikely to be willing to place all their applications and data in the hands of one critical provider. The hyperscalers are trying to alleviate these concerns through a large ecosystem of local partners. This gives user companies more flexibility to work with different partners, even though the "cloud core" is potentially the same.

4.2.5.2.3 Industrial edge

Speed of innovation in developing, scaling, and managing applications is one of the disadvantages of industrial edge computers. Providers of industrial edge solutions are trying to overcome this disadvantage by transferring cloud innovations to the edge as fast as possible. "Cloud-native" basically refers to the adaption of cloud-centric innovations to areas outside the cloud (edge, data center). Two of these innovations are the above-mentioned cloud-driven innovations in container technology and microservices-based application architectures. Both are core elements of the industrial edge concept. To further increase the speed of innovation in industrial automation and in the digital factory, the increased adoption of Linux and more modern programming languages such as Python®[2] (especially relevant for analytics-related applications) within this concept is taking place. In addition, a strong ecosystem of application

[2] Python® is an example of a suitable programming language available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of this programming language.

development partners is also important to maximize the speed of application innovation for the edge.

Another impediment of the industrial edge concept is the fact that application management is the user company's responsibility, which, besides independence, also brings with it the need for internal IT resources and capabilities. Providers of industrial edge management solutions are trying to address this by building very easy-to-use solutions that do not require deep IT skills to manage applications. The ambition is for non-IT staff (factory workers) to be able to use the systems largely on their own.

4.2.5.2.4 Industrial edge cloud

Two challenges are currently linked to the adoption of container-based systems at the edge – complexity and "expected need". Container based systems bring clear advantages in application management and scalability at the edge, but they are currently still more complex to handle. Complexity is a very typical issue during the introductory phase of a new technology. Providers of container based solutions for the edge will of course further reduce this complexity over time, but right now, user companies have to take into account that they need a certain level of internal IT skills to cope with the current level of complexity. The second aspect, "expected need", is linked to the expectation that there will be a growing number of use cases for the digital factory.

This would lead to a growing number of applications, plus increasing complexity in managing these applications efficiently. The big question is how fast this will happen in the digital factory and how significant the "need" will be in the future. Does it make sense to invest in this concept now, or at a later stage? It is expected to see different answers to this question, mainly for two reasons. First, it depends on each company's specific stage of digitalization. Second, it depends on the specific sub-vertical in which a manufacturing company is active. Large companies with a high level of factory automation and the clear need to further optimize their operations certainly have a stronger need to evaluate this concept today than other companies.

4.2.5.3 Impacts to smart manufacturing

4.2.5.3.1 General

The following impacts to smart manufacturing are identified (Vogt, 2020) for:

- industrial cloud;
- industrial edge;
- industrial edge cloud.

4.2.5.3.2 Industrial cloud

The big impact of the industrial cloud concept is certainly the speed of innovation in the cloud. Today, the cloud world is certainly the pacemaker for the entire IT industry. The "cloud first" slogan stands for this paradigm. "Cloud first" illustrates well that IT vendors are increasingly introducing innovations first for the cloud space. This is true for various aspects of digital platforms. One aspect is application development – in the cloud, new features and functions (including security updates) can immediately be deployed to all users of the application. In addition, container technology and micro services-based application architectures are two "cloud innovations" which improve the scalability and management of applications. Another interesting innovation for the cloud in this context is the container-based systems. In summary, the cloud brings real strengths to the table in application innovations (application development), application scalability, and application management. In addition, the fully managed approach of SaaS makes cloud applications especially attractive for many user companies with rather limited internal IT resources and capabilities. This reduces the burden for them of managing applications by themselves.

4.2.5.3.3 Industrial edge

When data management and processing take place at the edge, low latency, data sovereignty, trust, and vendor independence are certainly the advantages of this industrial edge. These advantages are especially interesting for companies and industries that process real-time and/or sensitive data.

4.2.5.3.4 Industrial edge cloud

Container based systems take scalability at the edge to a new level and help to overcome the above-mentioned challenge of edge scalability (see 4.2.5.2.4). Another big impact of container-based systems is multi-cloud. This means that container-based systems can go beyond the efficient management of edge infrastructures and also integrate cloud infrastructures from different providers. Container-based multi-cloud is therefore an efficient way to manage cloud vendor dependencies and edge scalability.

4.2.5.4 Standardization needs

4.2.5.4.1 General

The following standardization needs are identified (IEC White Paper Edge Intelligence:2017):

- self-organization, self-configuration and self-discovery;
- trust/decentralised trust;
- credible information;
- east-west communication;
- containerization standard for embedded systems;
- open standard for implementation of algorithm for machine learning;
- role of open source.

4.2.5.4.2 Self-organization, self-configuration and self-discovery

There is no doubt that with the growth in the number of the edge nodes, the management of the network, the edge nodes and the application will become a huge challenge. To facilitate the deployment of edge nodes, often the complexity of the technology is masked from operators and users, and plug and play of devices is realised. The introduction of autonomic networking has been instrumental for this task. Currently, the autonomous functions already exist. However, the discovery, node identification, negotiation, transport, messaging and security mechanisms, as well as non-autonomic management interfaces, are being realised separately. This isolation of functions is leading to high operational expenses (OPEX).

4.2.5.4.3 Trust/decentralised trust

Trust means that the services provided by the computer system can be proved to be trustworthy. In other words, the services provided are trustworthy from the user's point of view and this trustworthiness is provable. Trust computing as defined by the trust computing group (TCG) has the following meaning:

- user authentication: the trust of the user;
- platform hardware and software configuration correctness: the user's trust in the platform environment;
- integrity and legitimacy of the application: the trust in the application running;
- verifiability between platforms: the mutual trust between the platforms in the network.

The decentralization trend is driven by the distributed system, for instance by an edge computing system, in which no central hub acts, so a new approach to security and trust are needed based on the distributed architecture. There exists a general view that the distributed ledger technology architecture offers a valid framework for tackling distributed system security and trust challenges. The blockchain is a distributed database that maintains a continuously growing list of records, called blocks, secured from tampering and revision. Each block contains a timestamp and a link to a previous block. By design, distributed ledgers are inherently resistant to modification of the data – once recorded, the data in a block cannot be altered retroactively.

ISO is now dedicated to standardization of blockchains and distributed ledger technologies to support secure and trust interoperability and data interchange among users, applications and systems.

4.2.5.4.4 Credible information

Credible information is crucial for an edge computing system. Credibility of information depends on trust in the system which generates the information. Trust is defined to be "confidence that an operation, data transaction source, network or software process can be relied upon to behave as expected" in system security requirements and security levels standard (IEC 62443-3-3:2013) [6]. IEC 62443-3-3 currently does not explicitly list trust as a requirement. Even though security implies a guarantee of trust, it can be useful to review whether some additional system requirements, e.g. requirements on system integration and operation, are necessary to realise trust in IACS. It can also be beneficial to investigate what additional requirements are necessary when dealing with trust in horizontal edge computing systems.

NOTE There are future challenges with IIoT and software defined architectures for separating safety-related assets as required by the IEC 62443 series East-West communication.

There are several layers of East-West (E/W) communication in question:

- Physical layer: a number of standards exist for mesh networking via physical layer relay and any of these can/could be used. Considerations are made on how that mesh could be implemented efficiently in wired networks, and also whether the physical radio standards could be merged with the narrowband IoT protocols for long-range operation.
- Link layer protocols: here again numerous protocols exist in wireless, such as Shortest Path Bridging (IEEE 802.1aq) [7], ZigBee (IEEE 802.15.4) [8], Z-Wave (ITU-T G.9959) [9] or WIA-PA (IEC 62601:2015) [10]. Again, a merge with narrowband IoT protocols could be considered to allow mesh operation in narrowband IoT for long range operation.
- In the autonomous control domain, time sensitive data needs to be transmitted within strict bounds of latency and reliability. In the case that E/W-bound communication is required between edge control nodes (ECNs) in industrial automation, automotive or robotic environments, time sensitive networking (TSN) is assumed to be needed to prioritize time-sensitive traffic in crowded networks. TSN is currently under development within IEEE 802.1 and the deterministic networking working group of IETF.
- Data layer: a flexible data ontology, allowing common definition of data types and meanings across the network. This is an area where both standards bodies and open source is assumed to play a role, such as oneM2M and OPC-UA.

The majority of open-source work could be concentrated in the area of high-level data processing in the mesh by elaborating on existing, proven and recommended standards (such as message queuing telemetry transport (MQTT)) within an open reference architecture. For example, an overarching reference architecture could employ a lightweight MQTT implementation to accept not only north/south (N/S) but also E/W transactions between modules. This could be implemented as a single queue (all transactions E/W, N/S) or as two queues, one operating for E/W and another for N/S. It can be noted that in the items above, a mesh can be implemented at each layer, but it is only with the inclusion of the third dot of the list that an application-level E/W communication can be achieved.

Finally, a successful implementation of E/W communication depends on implementation of decentralised trust.

4.2.5.4.5 Containerization standard for embedded systems

Linux containers, Docker for example, offer for the first time a practical path to using virtualization on embedded devices, as the latter do not require a very complex hypervisor architecture to operate. Containerization of IoT applications, particularly at the ECN level, would be greatly facilitated by the creation of a common standard for virtualisation support on IoT nodes. This would be an expansion of the ground covered by the open container initiative (OCI), which has initiated a general effort. There are a number of challenges facing an implementation:

- extreme heterogeneity of the device type;
- severely restricted resource envelopes in terms of storage, central processing unit (CPU), and networking;
- devices that are difficult to reach or re-provision upon failure, where power is unstable and is assumed to be turned off at any time, or which have custom hardware attached, requiring deep version interoperability. i.e. when the device returns online after weeks or months, an upgrade to the container can be made spanning several versions.

Given the level of activity in open source in this area, it seems that it would be useful to develop such an implementation, or group of implementations, into a standard defining:

- core kernel services in the host operating system (OS);
- core device implementations, and what basic devices would be supported;
- which initial builds for which mixes of processors/peripherals;
- the close linkage between kernel, devices and the containerization framework;
- choice of containerization framework to be the support.

4.2.5.4.6 Open standard for implementation of algorithm for machine learning

The complexity of convolutional neural networks, hidden Markov models, natural language processing and other disciplines used in the creation of Machine Learning (ML) algorithms and deep neural network requires storage and computing resources usually only accessible on a data centre scale consume considerable power and are relatively expensive. Clearly the backend processing in embedded devices is currently an open-source initiative, and since it has started in this manner, it is likely to remain so, with Caffe and a few others becoming de facto standards. To implement ML upon lower powered, cheaper, embedded devices, it would seem to be a reasonable approach to implement a specific hardware-based method of accepting the introduced ML models and then acting upon them, i.e. comparing the models with incoming live data.

Some efforts have already been made in this area, but these efforts are proprietary and no standards have been defined to cover the loading and comparison of features. If standards were defined in the loading of models and comparison of data, it would provide the greatest degree of interoperability between different offerings from different processor manufacturers.

4.2.5.4.7 Role of open source

Cloud computing has immensely benefitted from open sources such as Linux, Docker containers, Kubernetes orchestration, Kafka messaging, Spark streaming and multi-tier storage. The result has been a highly scalable and standardized infrastructure that meets computational and lifecycle management demands and provides a common environment for developers, driving down the cost of software solutions.

The need for standardization and open source for the edge is even greater. The edge is where vendor-specific solutions need to interoperate. Without this interoperation, IoT cannot fulfil its promises.

Microservices or pods need to be deployed on the edge (devices, IoT gateways, micro data centre, etc.) as well as in the cloud, so that applications can be configured in an optimal way, e.g. to address huge data volumes, real-time requirements and variances in connectivity.

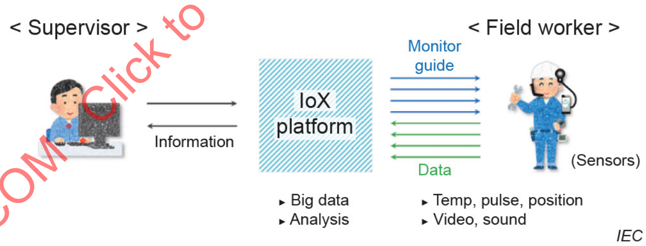
As history has shown, open-source projects fulfil these needs better than standardization of interfaces and architectures. Companies providing solutions in edge computing will have plenty of room for differentiation and revenue generation by providing differentiating functionalities, domain specific solutions, better services, higher QoS, etc.

4.2.6 Collaborative safety (Safety 2.0)

4.2.6.1 Description

Technologies such as Internet of Things (IoT), big data, artificial intelligence (AI), advanced robotics and cloud/edge systems facilitate the collection of enormous amounts of data and provide massive computing capabilities. The system allows powerful analytics to extract relevant information from raw data, interprets that information, detects unknown relationships between specified factors, takes autonomous decisions, and predicts future trends. Some of these applications mimic (or even exceed) human intelligence, as they can realise more accurate predictions and process greater amounts of data than humans are able to do.

The latest ICT developments involving sensors, cameras, etc. are enabling organizations to gather real-time information on certain safety risks, particularly those directly or indirectly associated with human and machine movements. Based on such information and once again on ICT, it is becoming possible to develop dynamic control of such risks. An existing example of this is how a steel engineering company implements safety monitoring solutions for field engineers and workers. As shown in Figure 5, a platform registers the conditions and status of each field worker. In addition to worker information such as body temperature, heart rate and posture, the surrounding situation is converted into data via a wearable camera and is analysed by AI engines in the data platform. In this way the supervisor can be informed in advance to take necessary actions to prevent accidents.



SOURCE: IEC White Paper Safety in the Future:2020, Figure 2-1.

Figure 5 – Real time risk assessment and control

The advent of new technologies impacts work in several ways. The European Agency for Safety and Health at Work (EU-OSHA) conducted a thorough investigation in 2019 focussing on changing work relationships in a digital environment under the direct impact of such technologies. Their findings identified a number of characteristics, as described in the Report Foresight on new and emerging occupational safety and health risks associated with digitalization by 2025 (2020) [11]:

- novel forms of human-machine cooperation;
- emergence of the platform (or gig) economy;
- increasing individualization of work;
- expansion of teleworking;
- rising screen time and increased sedentary work and behaviour.

Recent trends are also affecting data and privacy. Ever since the EU's General Data Protection Regulation (GDPR) took effect in May 2018, the world of data privacy has shifted its focus from guidance to stepped-up enforcement. On the legislation side, the California Consumer Privacy Act (CCPA) went into effect on January 1, 2020. In Brazil, the General Data Protection Law (LGPD in Portuguese) is slated to start in August of 2020. These two significant pieces of legislation are amplifying the momentum created by GDPR (i.e. through a shift to regulation), see report from Eliezerov, R on 3 consumer privacy & data protection trends for 2020 (2020) [12].

These legislative acts translate the growing conviction that data gathering and processing need to ensure privacy, the quality and integrity of data, and data protection. Transparency concerning access to data, decision rules, and ways to ensure the prevention of unfair bias and discrimination is judged as more important than ever. The trustworthiness of new technologies that are regarded by governments and industry as forming part of their 'vital infrastructure' will increasingly be essential for their acceptance and adoption. Such infrastructures need to be secure and resilient to physical and cyber-attacks, extreme weather conditions and natural disasters.

Initial experiences with real-time risk assessment and control have led to elaboration of the concept of collaborative safety. This approach leverages digital technologies and human-machine interaction to support industries and economies that are themselves built around digital applications. The concept has been developed in the area of machine safety and human-machine interactions but is valuable and applicable in many other situations.

Underlying the collaborative safety concept is a model of how machine safety efforts have developed over time. Key to this schema is identification of the specific element invested with the role of ensuring safety in situations of machine/human coexistence at each stage of the evolution.

The development of IoT, AI, image processing, big data and other ICT technologies has introduced previously impossible safety functions, with machines now being invested with the intelligence to deploy flexible operations, such as slow-speed motion in the presence of inexperienced workers, or suspension of operation in cases of danger. The latter situations can be identified on the basis of data transmitted to the machines via wearable devices such as radio frequency identification (RFID) tags worn by workers, which provide the machines with relevant data concerning any workers present, e.g. physical condition, experience/career history, qualifications and capabilities. Such systems are being developed in many parts of the world, giving birth to a new era of collaborative safety, termed Safety 2.0.

Collaborative safety is achieved when humans, machines and the operational environment share digital information with one another, communicate and collaborate. In this context, the environment includes physical settings, organizations, systems, databases, standards, regulations and rules. Collaborative safety, unlike earlier approaches, places the same level of importance on human capability as on technology and organization. Skills, capabilities, satisfaction, self-esteem, health, and a sense of wellbeing are equally valued.

The basic concept of collaborative safety consists of the following elements.

- maximum use of ICT to monitor information on a real-time basis concerning machine motions, human behaviour and the working environment;
- safe control of machine motions and/or human behaviours through detection and transmission of potential risk information during normal operation or maintenance service periods;
- ensuring that the adoption of safety technology using ICT does not sacrifice the operation rate of the machines or the humans' working efficiency;
- ensuring that the adoption of safety technology contributes to the trustworthiness of workers/operators in pursuing the application of safety measures in a sustainable manner.

The essential aim of collaborative safety is to establish a mutually supportive partnership between machines, humans and the environment they operate in, by way of multi-traffic information flows between them. The human is warned to restrict his or her behaviour by the machine, and the machine is warned to slow down or stop by human intervention. Thanks to maximum use of the latest ICT technology in collaborative safety strategies, the responsibility of workers/operators for ensuring safety in the use phase is largely taken over by the machine and the information technology. As a result, the operators require less specific training and expertise and experience reduced working pressures.

4.2.6.2 Impediments to market acceptance

As collaborative safety is a matter of safety, the topic of market obstacles from the safety viewpoint is covered in this subclause.

The following is an inexhaustive list of examples in the IEC White paper "Safety in the Future" describing the market obstacles from the safety viewpoint:

- Subclause 2.5 Risk management, risk governance and standardization challenges: "Sensors, cameras and ICT systems are collating enormous amounts of data, yet the things which are the easiest to measure are not necessarily the most relevant factors for controlling risk and achieving safety. Factors such as human behaviour, cultural values, organizational culture, leadership commitment and interpersonal communication are not so easily captured in data systems. Research is beginning to be conducted in this area, but it is picking up slowly, and the danger exists that such factors are neglected in a world of big data."
- Subclause 3.5.3 Assurance algorithms: "AI offers the promise of solutions to complex problems that extend beyond the reach of mere human intelligence. However, this development comes with an inherent problem: the explanation of a solution does not necessarily mean that the solution discovered is safe. The AI engine can generate hazardous events due to inappropriate data in the learning phase and generalization errors in the reasoning phase."
- Subclause 3.7 Technological necessity: cyber security: "With the increased use of information technology, cyber security forms a cornerstone of efforts to manage the growing complexity of safety control systems, particularly as this pertains to smart manufacturing and collaborative safety mechanisms. But the complexity of such systems is increasing their vulnerability to threats which can lead precisely to the loss of the safety functions."

The standardization community ought to reconsider its role in ensuring safety. Safety standards that focus on technical components alone have the same sort of limitations as prescriptive legislation: they hinder innovations and need updating at increasing frequencies, which poses a challenge for international standardization processes. As the principle of collaborative safety is commonly applicable to a variety of industrial sectors (e.g. manufacturing, civil engineering, construction, agriculture, healthcare and transportation), standards development needs to adopt different approaches involving a wider range of stakeholders. One option could be to develop more "performance-based" (as distinct from "specification-based") standards for collaborative safety, describing the intended objectives and performance targets of such a collaborative approach, and specifying the minimum requirements for the process to achieve the objectives adopted.

With governments relaxing their grip on safety via less stringent legislation, and corporations compensating for this regulatory alleviation by assuming social responsibility for safety through private initiatives, an opportunity is opening for the development of new types of industry-supported standards for safety. In this way, standards for the industrial sectors would become less restrictive, and maintenance of the standards developed would be less burdensome and more responsive to technological evolutions.

4.2.6.3 Impacts to smart manufacturing

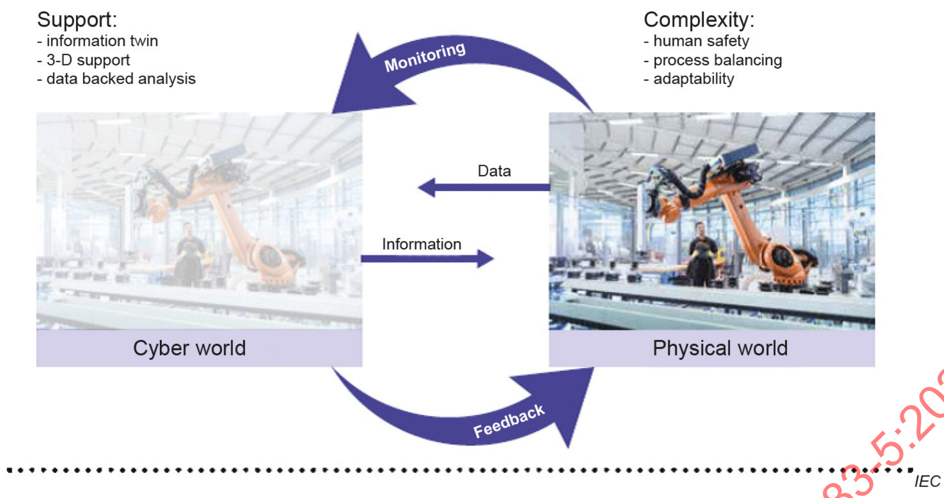
The safety standard series on functional safety of electrical/electronic/programmable electronic safety-related systems (IEC 61508 [13]) covers specific types of machines or products, includes holistic safety aspects (relevant safety technology but also communication technology, reaction time, operational management, core personnel competences, etc.).

The current market trends for collaborative safety increase the need for trustworthiness in the context of safety. The usage of the available ICT technologies will evolve the current safety systems and drives the acceptance of the "Vision Zero" regarding humans, which is "the ambition and commitment to create and ensure safe and healthy work conditions and to prevent all accidents, harm, and work-related diseases in order to achieve excellence in safety, health and wellbeing."

Among the range of possible responses in its operational arsenal, the IoT industry disposes of a ready-made solution based on established available technologies, which can simulate the workspace in a digital environment: the so-called digital twin construct. In the simplest of terms, a digital twin involves the bridging of cyber and physical worlds. In a broader sense, a digital twin is the emulation, or mapping, of the physical world into a cyberspace, by which changes effected within either sphere are reflected, predicted, or looked for in the other. In a safety context, a digital twin constitutes a holistic digital model used to support a safety case.

Examples of such mappings include building information systems (BIS) in the construction industry, through which ambitious building projects are entirely modelled on computer systems, see the BIM Handbook, Eastman, Teicholz, & Sacks, (2018) [14], and in manufacturing, where computer-aided design and manufacturing (CAD/CAM) systems aid in the design of components, parts and machines, as described in the book from Machover, the CAD/CAM Handbook, 2nd edition (1996) [15]. In terms of safety, this technology enables enhanced worker safety and contributes to a better understanding of impending or unforeseen safety issues. Digital twins offer an optimal framework for testing specific safety practices, simulating fires and explosions virtually, and deploying tested proven materials such as water sprinkler/extinguisher systems in a simulated context.

But the potential of digital twins does not end there. When a digital twin mimics a real working environment, it brings a dynamic approach to workspace practices, an approach that in the past was strictly static and limited solely to the physical world. The example in Figure 6 illustrates the case of a digital twin in a manufacturing environment. In this example, the digital twin is composed of a three-dimensional model of a room in which two novel collaborative robots are tested working with a person who performs their part of the operation from a separate desk. The digital model contains the key elements in the room: the individual, the collaborative robot, the transfer robot, furniture and doors. Through visual monitoring, the computer can update the activities and locations of both the robots and the individual in real time to assess whether dangerous situations are taking place. When the term "digital twins" is applied within the context of worker safety, a more suitable designation could be "digital twins for collaborative safety", or "digital twins for human-machine workspaces."



SOURCE: IEC White Paper Safety in the Future:2020, Figure 3-7.

Figure 6 – Digital twin operating in parallel with the physical world

4.2.6.4 Standardization needs

Standards bodies need to expand and deepen their holistic approach to safety. This will require incorporating not only traditional technical expertise but also insights gathered in the fields of safety psychology, sociology, and human behaviour. In other words, it is recommended that in the development of future safety standards, clear attention be paid to non-technical factors.

At the same time, it is the duty of standards bodies to focus on the elaboration of technical standards for machine developers, suppliers, and system integrators to ensure that they underpin security efforts in the future. A prerequisite for this effort is understanding that safety by design constitutes the most sensible approach if humans are considered paramount in a cooperative system. The standard ought to consider all stages of the life cycle of the product or system.

Standards bodies have an important role to play in promoting social responsibility in standards and conformity assessment processes. Standards bodies are already engaged with social stakeholders in contributing to the realization of social objectives such as safety and security and are uniquely positioned to bridge the gap between industry promoters and receptors.

4.2.7 Digital factory

4.2.7.1 Description

A digital factory (DF) is a digital representation of an existing or planned production system (PS). The representation of a production system can include representation of production system assets and representation of roles.

The PS asset is an asset that is constituent of a production system, The PS asset can be a part, a device, a machine, software, a control system or any collection of PS assets. It can have physical characteristics, for example mechanical, electrical, and electronic. It can also be assigned to one or more role(s).

NOTE The digital factory can represent the production system in all stages of its production life cycle.

The DF is based on well-defined semantics, data classification schemes and production ontologies, e.g. IEC 61360 Common Data Dictionary (CDD) [16] and ISO 22745 Open Technical Dictionary (OTD) [17]. In addition, the digital factory framework provides modelling elements and rules for describing the assets of a production system together with relationships between them.

4.2.7.2 Impediments to market acceptance

The DF concept is a disruptive change to the current operational technology deployed within a traditional factory. The DF will require the deployment of new technologies, new operational manufacturing processes and a new shop floor culture.

The introduction of the DF will require the introduction of new competences and new experiences of the factory staff and these skills will require new education. Therefore, re-education programs will be required starting in the regular engineering schools.

Therefore, the DF will require a substantial support from the authorities to introduce a new curriculum in the engineering schools as well as complementary re-schooling of the current factory staff.

4.2.7.3 Impacts to smart manufacturing (SM)

An example of how to derive information is to look at the narration of a robot that grips things out of a container and then mounts them into a production line. The storytelling is about a thing that passes-by e.g. the three contexts of the container, of the robot grip-arm, and of the production system, where the latter is the major the asset. In that case the DF would reorganize the specification of the production system assets based on the three contexts of the container, e.g. size of the robot hand, e.g. pressure of the gripper, and of the production system, e.g. material and surface.

Thus, it is important to notice that data always represents physical assets and that is what is being discussed. The cyber data representations of the physical entities are exposed to various transformations that lead to various consequences of handling. On a common semantics base, it would be possible to derive, from all representations, comparable information and knowledge and to transform this knowledge gained from observation into an operational model. The operational model will provide data that can be used to perform (big) data analytics to optimize the factory operational processes.

The approach of meta-data derivation shows that the hierarchical data definition is not useful since ‘knowledge’ cannot be derived from unstructured low-level coded data.

4.2.7.4 Standardization needs

The current immediate standardization needs are addressed by the IEC Digital Factory standards, IEC 62832 series [18].

4.2.8 Zero-defect manufacturing

4.2.8.1 Description

Due to the increasingly competitive global market and its dynamic development, companies need to implement agile demand-driven and sustainable solutions. This allows to react not only to market changes and constantly changing requirements, but also offer concrete resource-saving solutions for companies in view of the world's scarce material and energy resources. The zero-defect manufacturing (ZDM) idea is not new. It was originally developed from the Six Sigma methodology as described in the report Six Sigma: concepts, tools, and applications, by M. S. Raisinghani and others (2005) [19]. This Six Sigma methodology is a management method that was introduced in 1987 as a new procedure for standardized quality control with the goal of zero-defect production. Six Sigma provides a methodical approach to mapping and analyzing the actual process in order to identify the error possibilities that are important for the process. The original goals of the methodology are customer satisfaction and continuous productivity increases in all areas of the company.

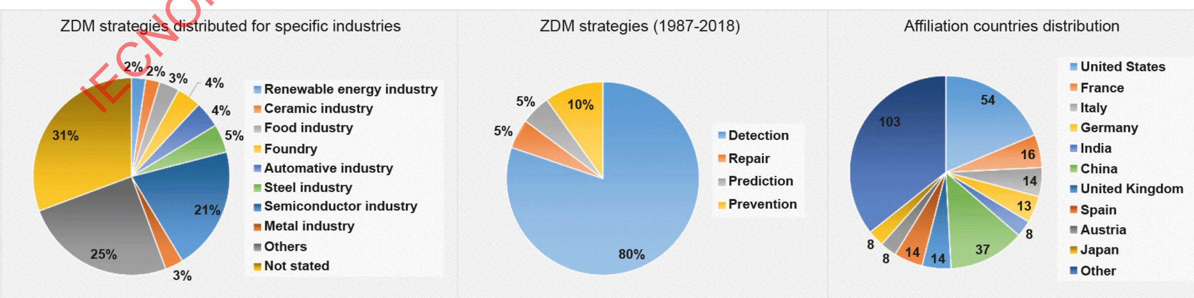
Zero-defect manufacturing is defined by newly published CEN Workshop Agreement (CWA 17918:2022) [20] as a holistic approach for ensuring both process (ISO 9000:2015 [21], 3.4.1) and product (ISO 9000:2015, 3.7.6) quality by reducing defects (ISO 9000:2015, 3.6.10). It commonly uses mainly data-driven technologies, e.g. originating from big data and machine learning domains/areas/fields for predictive or prescriptive analytics referred to as zero-defect manufacturing tools and requires that no defective products leave the production site and reach the customer (ISO 9000:2015, 3.2.4) by performing 100 % inspection (ISO 3534-2:2006 [22], 4.1.5). The general aim of this approach is to reach the higher manufacturing sustainability.

Zero defects is a trend approach to eliminating defects caused by manufacturing defects. Poor quality is usually associated with high costs and non-compliance with customer requirements. In other words, the trend aims not only to improve quality, but also to significantly reduce the cost of manufacturing one or other product. More details about zero defects manufacturing can be read within the report by Fulvio Bernardini and others, on new visions towards zero defect manufacturing (2020) [23]. The prevention of defects is usually achieved by identifying and eliminating the causes of their occurrence. For example, checking the production process for steps where defects are assumed to occur, and checking them without errors, contributes to error-free production. ZDM is no substitute for quality control. Quality management, especially regular preventive quality controls such as quality related planning, inspection to ensure that a defective product does not reach the customer, audits, only guarantee positive zero-defect production results.

4.2.8.2 Impediments to market acceptance

Market acceptance of ZDM is based on how its services meet the customer requirements, such as quality, safety, data analysis and processing, etc. A significant increase is observed with respect to the number of publications where the majority of the articles have been published in the last six years. Thus, the recent ZDM-specific research is described in the report from F. Psarommatis and others on zero defect manufacturing: state-of-the-art review, shortcomings and future directions in research (2020) [24] and illustrates the outcomes of publications for the last 32 years focusing the distribution for ZDM strategies (i.e. detect, predict, prevent, repair) and ZDM purpose (i.e. generic, manufacturing process specific, method specific). From the strategic point of view there is an increasing trend for the 'detection' along with the 'prevention', though 'prediction' and 'repair' have been sparsely addressed in the research development so far (Figure 7). Additionally, the outcomes regarding the ZDM purpose are showing clear dominance for the development of manufacturing process specific applications in the latter.

In particular, the affiliation of countries distribution (Figure 7) reveals a slight tendency and importance of the ZDM topic in the United States, in a large number of European countries such as Spain, Italy, France and Germany, as well as other international market players such as China and Japan.



SOURCE: F. Psarommatis, G. May, P.-A. Dreyfus, and D. Kiritsis, "Zero defect manufacturing: state-of-the-art review, shortcomings and future directions in research", International Journal of Production Research, vol. 58, no. 1, pp. 1–17, 2020, doi: 10.1080/00207543.2019.1605228. Reproduced from [24] with the permission of Foivos Psarommatis.

Figure 7 – ZDM trend development based on research outcomes 1987-2018

With the exception of the manufacturing industry, which currently holds a leading position in the application of ZDM technologies, the following industrial sectors play a dominant role as well: semiconductor industry with 20,33 %, followed by steel industry with only 4,67 % and then automotive (4,33 %), foundry (4,00 %), food (3,33 %), metal (3,00 %), ceramic (2,33 %) and renewable energy industries (2,33 %) as depicted in Figure 7.

The following conditions and their factors can ultimately be used to describe the acceptance of a technology on the market:

- High product quality is one of the most important conditions for market acceptance. The quality of a product depends on both the (plant) equipment and the manufacturing processes, since any failure or malfunction can lead to a critical failure. Quality (quality management) is one of the most important measures when it comes to meeting resource-related requirements. In order to address quality-related problems, the requirements for a product and the organization need to be reviewed in advance, and customer needs and expectations need to be measured against appropriate standards. Only in this way is it possible to determine whether the product meets these requirements. To avoid above-described obstacles and to achieve zero-defect quality of the products, a ZDM system needs to integrate innovative standards for manufacturing systems with special emphasis on safety, security, reliability and other important standard requirements.
- Another challenge for ZDM in this area is the analysis of massive raw data sets. This kind of analysis requires an autonomous and self-organized system for decision-making. AI, machine learning and data mining, which focus on the non-trivial extraction of implicit, previously unknown and potentially useful information from data, are effective methods to discover interesting knowledge within a huge data set.
- Other obstacles to the introduction of ZDM are quality management and the lack of standardized corporate strategies in this area. The zero-error strategy is a method of the continuous improvement process to reduce errors as much as possible. The lack of standardized and robust solutions for identifying sources of error and their types, as well as for identifying the most problematic phases within the life cycle assessment (LCA) approach, hampers development and technological breakthrough. The accumulation of errors (and subsequent solutions) is one of the further obstacles in this area. Clustering operations usually take place on the basis of the most common cases in an industrial manufacturing activity, which need to be thoroughly described and standardized. These results influence the development and implementation of appropriate ZDM tools as solutions addressing the upstream production and the downstream spread of production errors.
- Other brief comments on the acceptance of the ZDM, worth to be brought into the discussion, are for example:
  – preference diversities for certain industrial sectors and a comparative cost-benefit analysis are not obvious;
  – lack of clear description of new business models for zero-defect production (including an investigation of the advantages and disadvantages);
  – lack of clear definition of the ZDM life cycle and its role in smart manufacturing;
  – lack of a uniform and clear definition of ZDM terms;
  – the role of human and its activities/influence on the ZDM cycle as described in the report from F. Psarommatis and others on zero defect manufacturing: state-of-the-art review, shortcomings and future directions in research (2020).

4.2.8.3 Impacts to smart manufacturing

ZDM goes beyond traditional approaches that are typically characterized by small batch production, customized or even one-off products, inline or online product testing and other typical proprietary features. This means that ZDM imposes new rules for the manufacturing of products revising old strategies and introducing new SM technologies in the trend applications. Within smart manufacturing, the increasing complexity of both products and production systems makes it much more difficult to apply systematic methods for monitoring and preventing errors in the manufacturing workshop floors. The increasing complexity of both products and production systems is usually due to increasing customer requirements.

Furthermore, mass customization and lean production – as side results of smart manufacturing – demand critical and rapid changes in production processes. This requires significantly shorter optimization times by production process lines for smaller batches of customer-specific products. As a result, the rate of defective products will increase. In order to take these factors into account and to avoid defects, newer and more sophisticated strategies and tools are urgently required. This also includes better quality management techniques that can meet current needs.

Application in the field of artificial intelligence and autonomous quality production are important key factors in ZDM development, providing the necessary advanced technological qualifications to support the integrated quality processes. ZDM as a trend, especially in combination with innovative smart manufacturing technologies, promises advanced solutions with a variety of positive effects on production, including higher productivity and competitiveness through lower production costs, shorter production times and waste/scrap reduction.

Digital manufacturing platforms for ZDM play an increasing role in dealing with competitive pressures and incorporating new technologies, applications and services. The challenge is to make full use of new technologies that enable manufacturing businesses, particularly mid-caps and small and medium-sized enterprises (SMEs) to meet the requirements of evolving supply and value chains.

Besides innovation and research activities, there are also coordination and support activities in order to cross-fertilise the industrial platform communities, facilitating the adoption of digital technologies from ongoing and past research projects to real-world use cases and encouraging the transfer of skills and know-how between industry and academia. An example is the digital manufacturing platform (DMP) cluster, which is an H2020 project cluster established with the aim of promoting cooperation between the projects of "DT-ICT-07-2018-2019: Digital Manufacturing Platforms for Connected Smart Factories". The DMP cluster is described in the research results: Digital Reality in Zero Defect Manufacturing, CORDIS (2020) [25]. The DMP cluster is based on the joint initiative of the following EU projects and is coordinated and supported by the coordination and support action (CSA) Connected Factories 2, CORDIS (2020) [26]. The activities described above led to joint work by the DMP cluster projects on ZDM terminology and produced the first tangible results concerning an agreed terminology in a CEN workshop agreement (CWA 17918:2022).

Within smart manufacturing, the ZDM can be implemented in two different approaches as identified, i.e. the process-oriented ZDM and the product-oriented ZDM. These approaches are identified within the report on zero defect manufacturing: state-of-the-art review, shortcomings and future directions in research, F. Psarommatis (2020) and these approaches are submitted for standardization as described in the research results: Digital Reality in Zero Defect Manufacturing, CORDIS (2020).

- ZDM approaches at process level:
  - machine health inspection to identify specific sources of error and to avoid error propagation in downstream flows, e.g.: integration of intelligent, autonomous, and self-adaptive sensors and actuators for process monitoring, control and quality management; process adaptation by self-learning, quality and process database-based modelling of process behaviour;
  - machine health correlation with product quality acquisition at all process stages (i.e. before, during and after the process) such as re-measurement and testing as well as development and integration of testing techniques; use of modern sensor technologies that automate end-of-line testing without significant process-related cost increases or time losses;
  - machine health data analysis and data mining characterized by advanced sensing throughout the manufacturing chain and data processing techniques, such as combining and harmonizing heterogeneous data collected throughout the product life cycle (from design to manufacturing) and transforming this data into information and knowledge; plug-and-test data acquisition systems based on the auto-configuration of data exchange protocols and smart manufacturing system solutions, and statistical evaluation of variation in manufacturing quality.

- ZDM approaches at product level:
  - product quality correlation with machine health;
  - product quality data analysis;
  - product quality inspection.

Common high-level requirements for ZDM can be described as follows:

- realise vertical integration and interoperability of the IT infrastructure with other manufacturing and operating systems (ERP, MES, proprietary, etc.);
- unify quality management and compliance systems;
- increase transparency and track ability at the machine level across multiple metrics, in particular measurement of conformity authorization and traceability to the machine level (e.g. introduce a data acquisition system distributed on various points on the production line to capture: in-process sensor data, data from production monitoring system and operator data);
- analyse early indicators and trends from process signals of individual system components in real-time to predict quality of the manufacturing product;
- introduce continuous improvement opportunities through integrated advanced analytical frameworks and increased efficiency, revenue, accuracy, quality and yield of production (e.g. apply machine-learning algorithms to find structures and patterns related to the required key quality indicators such as critical defects per track, distortion, maintaining dimensions, etc.);
- achieve greater transparency of supplier quality levels and greater accuracy in forecasting supplier performance over time;
- give proactive recommendations for preventive maintenance through monitoring processes, i.e. learn from unknown data interactions to predict quality;
- reduce investment cost for quality tests;
- support safe, secure and trustworthy data processing and storage;
- reduce product line disruptions through the avoidance of optional inspections;
- apply a common and holistic semantic model able to represent concepts at different stages of product lifecycle;
- have correction capability over the future course of overall production (e.g. recommend process adjustments to the operator or directly change the parameters in real time);
- effectively increase operational excellence (OPE) by helping the factory operator to take correct process adjustment decisions.

4.2.8.4 Standardization needs

ZDM includes a vast variety of involved physical systems and virtual services in its cycle. There is no specific standardization working group covering ZDM scope as it is. Clearly, there is a need to analyse this challenge and make relative recommendations. To utilise standards in ZDM applications, one must:

- clearly identify and describe life cycle areas affected by ZDM;
- specify the overall architecture framework and list requirements, KPIs;
- list systems and processes involved;
- list co-standards involved;
- investigate standards contribution to the existing requirements;
- review the CEN Workshop Agreement (CWA 17918:2022) with regard to IEC TC 65 standardization needs.

4.3 Business model watch

4.3.1 General

Smart manufacturing (SM) will influence the creation of new value propositions and the creation of new revenue streams for the manufacturing industry based on SM concepts and changed business models. Some of the business models are highly linked to the different manufacturing market trends.

The subclauses below describe only a few examples of how the business models are impacted. It is not the intention of 4.3 to give an exhaustive list of business models triggered by SM concepts but rather an illustration of how the SM concepts influence the traditional manufacturing business models.

4.3.2 Platform business models

4.3.2.1 Description

Currently, there are seven platform companies among the ten companies with the largest market capitalization worldwide. The business of these companies is based on the operation of a digital platform via which an ecosystem is orchestrated in order to enable strong growth of the ecosystem and thus also the business of the platform operator. The result is a "the winner takes it all" phenomenon.

The business perspective adopted in this subclause focuses on value-added relationships between business roles in relation to digital platforms. This perspective focuses on the exchange of value propositions between defined business roles. The underlying concepts have been examined and discussed in many ways, for example in the book "Platform Revolution" by G. Parker, M. Van Alstyne and S. Choudary (Choudary, Van Alstyne, & Parker, 2017) [27]. The core of these concepts is that – as shown in Figure 8 – a platform enables interactions between producers and consumers, with access to the platform being made possible via providers, see also M.W. Van Alstyne, G.G. Parker, S.P. Choudary "Pipelines, Platforms, and the new Rules of Strategy", (Van Alstyne , Parker, & Choudary, 2016) [28].

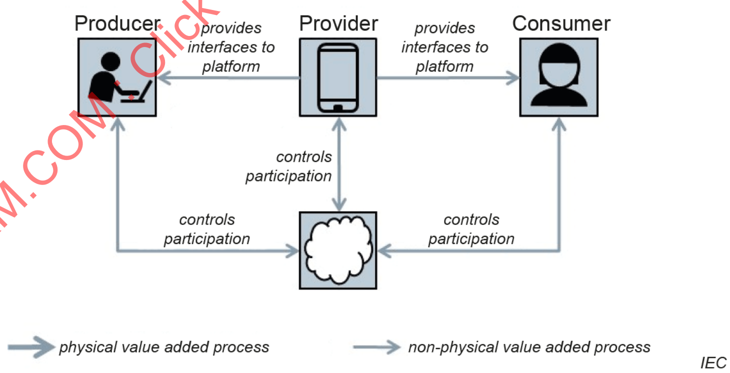


Figure 8 – Value added processes in platform ecosystems

The large platform companies mentioned have so far addressed business-to-consumer (B2C) markets, but the ideas and concepts have already been used in many ways in business-to-business (B2B) markets, even if the "winner takes it all" phenomenon has not yet been observed there.

4.3.2.2 Impediments to market acceptance

In contrast to the B2C markets, which are addressed by the successful platform companies, in B2B and especially in the manufacturing industry, for example, the following boundary conditions need to be considered:

- Both the value-added processes in the overall value network and the objects that are exchanged between producer and consumer are much more complex in the manufacturing industry. For example, arranging an overnight accommodation via a platform is significantly less complex than arranging a required production capacity.
- In the manufacturing industry, the integration of the services offered by a platform into the existing business processes usually requires considerable engineering efforts, while in B2C the onboarding processes on platforms are very simple.
- The possibility of financing a platform through advertising, as is often the case in B2C, does not seem to be an option for the manufacturing industry.

In summary, in the manufacturing industry, self-reinforcing positive network effects are more difficult to achieve with platforms – or take more time to be achieved with impact on both pace and cost of growth.

4.3.2.3 Impact to smart manufacturing

4.3.2.3.1 General

Nevertheless, efforts by new platform companies can also be observed in the manufacturing industry. There are currently many different examples and forms of digital platforms in the manufacturing industry, but they differ in purpose and in the underlying value networks. Four approaches are briefly explained here:

- brokerage platform;
- IIoT platform;
- edge management provider; and
- cloud based platform provider.

4.3.2.3.2 Brokerage platform

In the case of a brokerage platform, the operator of a brokerage platform offers the value proposition of making a corresponding offer in response to the demand for a product or service. The brokerage platform records the demand or requirements and uses algorithms to determine the ideal product or service provider. The result and pricing are not fixed at the beginning of the request. It is therefore necessary to carry out a request, an offer and a final order in several coordination steps between the business roles and to exchange them via the brokerage platform. There are various forms of brokerage platforms, for example the offer can be guaranteed to the requester by the platform operator or the provider. Figure 9 illustrates a possible setup of the value network of a brokerage platform.

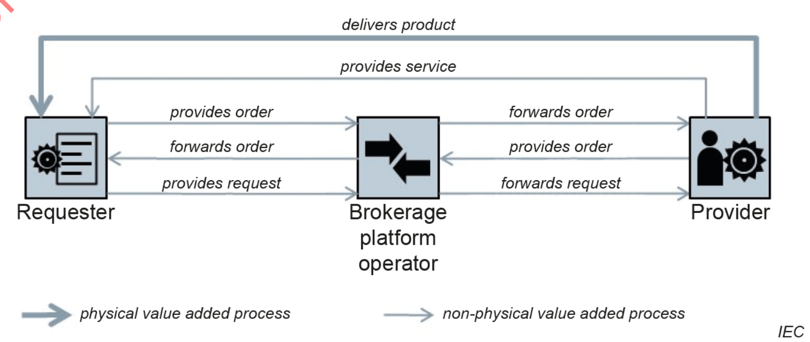


Figure 9 – Value added processes in the context of a brokerage platform

The requester has the benefit that, with the help of the brokerage platform, the effort involved in searching for and coordinating with a provider is reduced or, if necessary, even eliminated. The brokerage platform gives the latter access to a larger number of potential providers and can thus, for example, receive a product or service cheaper, faster or to a different extent.

The provider benefits from the brokerage platform by receiving additional orders without having to operate their own infrastructure for customer acquisition. However, the provider can be compared to its competitors via the brokerage platform.

The use case "outsourcing of production" (IEC TR 63283-2:2022) details the business interests described here from a technical perspective.

4.3.2.3.3 IIoT platform

An IIoT platform offers the value proposition, to enable, for example, machines that are physically used in different locations for data transmission to the IIoT platform. As a result, data from the machines from operation and their utilisation can be collected, processed and analysed on the IIoT platform and the operation can be evaluated. For this purpose, the IIoT platform offers the possibility of creating apps and making them available via an app store. A user can choose between several apps from the app store and run them on the IIoT platform. These apps can then access the operating information made available by the machine user. By using the IIoT platform, it is possible to offer services based on the available operating and usage data. These services include the value proposition to improve the operation or use of the machine. Depending on the form of the IIoT platform, the business roles can be taken over by different companies. It needs to be contractually regulated to whom which data is made available and who can use which applications. Figure 10 illustrates the value network of an IIoT platform.

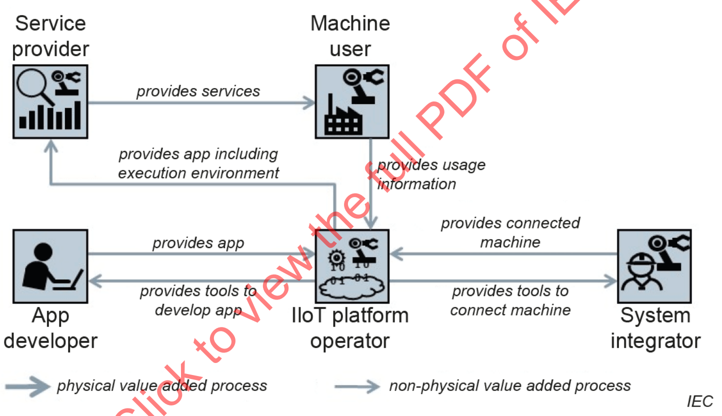


Figure 10 – Value added processes in the context of an IIoT platform

Thus, the IIoT platform operator offers a technical infrastructure that enables users to receive data on the use of machines to generate added value out of it. The IIoT platform is the information technology basis so that new digital services can be offered, and users can concentrate on their core competencies.

The IIoT platform gives the service provider the opportunity to access applications and machine data to be able to offer the machine operator data-based services. If the machine supplier acts in the role of the service provider, they benefit from the IIoT platform that they can offer and monetize further services in addition to the sale of their machine along the life cycle of the machine.

The app developer is interested in the IIoT platform, as it offers a development environment and assures the functionality and executability of the apps on the IIoT platform. At the same time, the IIoT platform's app store serves as a sales opportunity for the apps developer.

The machine operator has an indirect interest in the IIoT platform because it offers others the opportunity to offer their data-based services based on which they can improve the use of their machine.

As a service provider, the system integrator benefits from the IIoT platform through the possibility of simply being able to connect machines to the IIoT platform regarding data transmission.

The use case "value-based services for production resources" (IEC TR 63283-2:2022) details the business interests described here from a technical perspective.

4.3.2.3.4 Edge management provider

Figure 11 shows the core of the classic value chain in manufacturing industries, where machine suppliers integrate components into a machine and the machine is integrated into the production system via a system integrator according to the requirements of the machine user. Both the component supplier and the machine supplier have an interest in not just selling their physical product once, but in generating additional revenue streams via data-based or remote services along the life cycle of their product. The system integrator is also interested in not only executing services according to the specifications of the machine user, but also in offering its own optimization services.

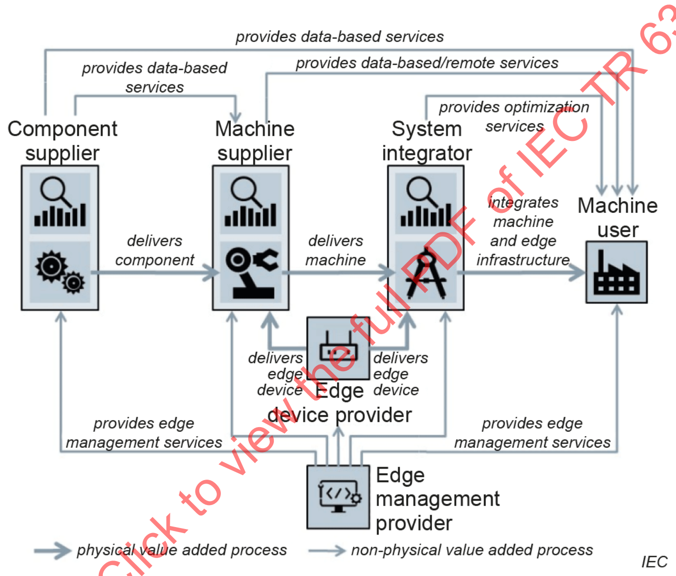


Figure 11 – Value added processes in the context of an edge management system

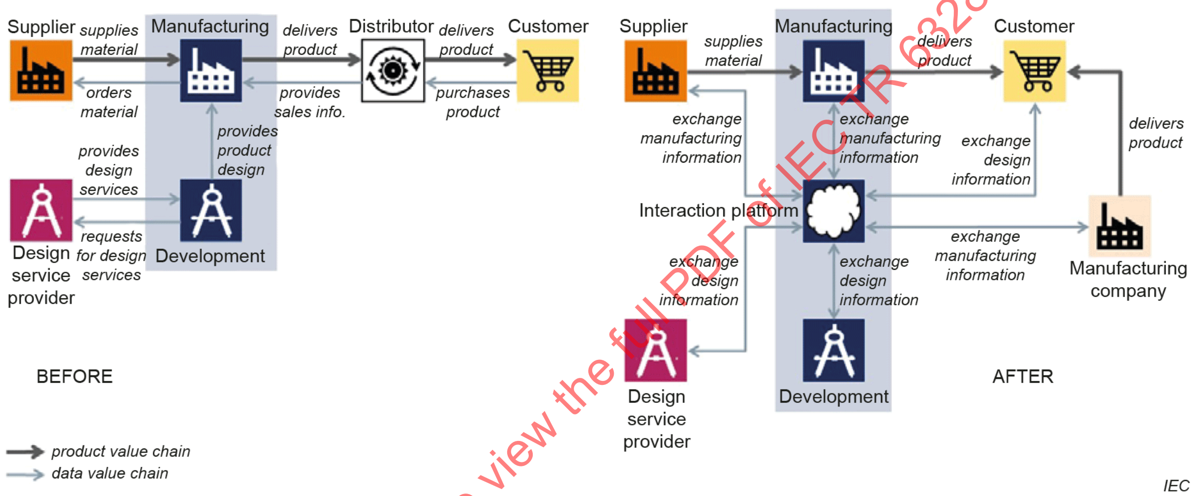
All these services are based on software applications, for which the providers do not necessarily want to provide their own computing resources. They assume that in the future edge devices will be available where they can deploy such software applications. In order to be able to design the deployment independently of the specific edge devices used, they all have an interest in a standardized management of the edge devices. This is an opportunity for a new business stakeholder who provides such an edge management system.

The edge management provider enables the interaction between producer and consumer according to Figure 11, while the edge device provider acts as a provider according to Figure 11. Further details can be found in the document "Business View Edge Configuration" (Löwen & Others, Testbed Edge Configuration – Business View, 2020) [29]. The use case "Device configuration (IEC TR 63283-2:2022) details the business interests described here from a technical perspective.

4.3.2.3.5 Co-design platform provider

The smart manufacturer provides the capability to manufacture co-designed products via its cloud-based platform. The smart manufacturer owns the co-design platform to interact with the platform key stakeholders, i.e. customer, design service provider, supplier and other manufacturing companies. The smart manufacturer will engage the stakeholders to improve their production, such as the supply chain reduces the delivery time which will reduce the inventory costs, based on the shared information via the platform. The smart manufacturer will be able to provide a bigger portfolio of products which will increase the customer loyalty, additionally the smart manufacturer will be able to have direct feedback from the customers on their product plans, which is referenced as mass customization. The co-design opportunity will provide the smart manufacturer the benefit to optimize its designs and engineering value creation process.

The supplier will be able to evaluate the raw material supply and optimize the supply towards the smart manufacturer to optimize its inventory and take advantage of faster delivery towards the manufacturer. The design service provider will benefit from the early understanding of the customer requirements. The other manufacturing companies will benefit from a new channel of interactions with more customers by the usage of the platform. Finally, the customer will benefit from the realization of its individual demand based on a deep integration into the overall value networked platform. The business scenario "Haier: Platform COSMOPLAT for Mass Customization" (Löwen, Business Scenarios, Version 0.6, 2020) [30] details the business interests, see Figure 12.



SOURCE: Examples for business scenarios in manufacturing industry, global project quality infrastructure, GIZ, October 2020. © Ulrich Löwen/GIZ – GPQI. Reproduced from [30] with the permission of Sarah Wagner, GIZ – GPQI (rights of use were given by author Ulrich Loewen to GIZ/GPQI).

Figure 12 – Value added processes in the context of a cloud platform

The use case "co-creation in design" (IEC TR 63823-2:2022) details the business interests described here from a technical perspective.

4.3.2.4 Standardization needs

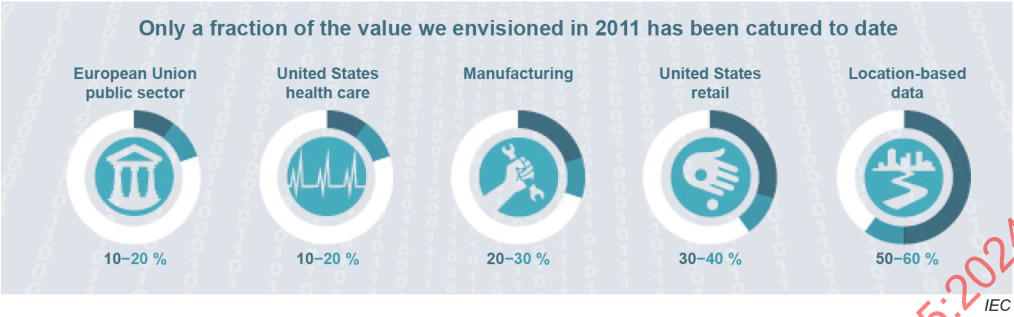
The cloud-based platform needs some basic standardization activities to ensure the basic set of functionalities within the platform. The access towards the platform needs to be standardized to allow the availability of standardized interfaces and/or application programming interfaces (APIs) towards the platform. Furthermore, data privacy needs to be secured.

In principle, standardization facilitates the described scenarios with respect to simplifying the process supported by the platforms and thus lowers the hurdles for platform business models in the manufacturing industry.

4.3.3 Data driven business models

4.3.3.1 Description

Today, the potential of data is widely recognized in the industry in the form of big data, data analytics, data warehouse, Data Lake, AI, just to name some terms that are "hot" in the market. The challenge is to structure the availability of data into a company asset that contributes towards the data driven business model. McKinsey has stated that only a fraction of the estimated business value in 2011 has been realised. Considering that the value has only been increased since 2011, it is obvious that the gap between the leaders and laggards has grown bigger (McKinsey, 2016) [31], see Figure 13.



SOURCE: McKinsey. (2016, December). The age of Analytics, Computing in a data-driven world. Retrieved from McKinsey & Company: https://www.mckinsey.com/business-functions/mckinsey-analytics/our-insights/the-age-of-analytics-competing-in-a-data-driven-world, Figure In Brief, page 9. Reproduced from [31] with the permission of Rebeca Robboy, McKinsey Media.

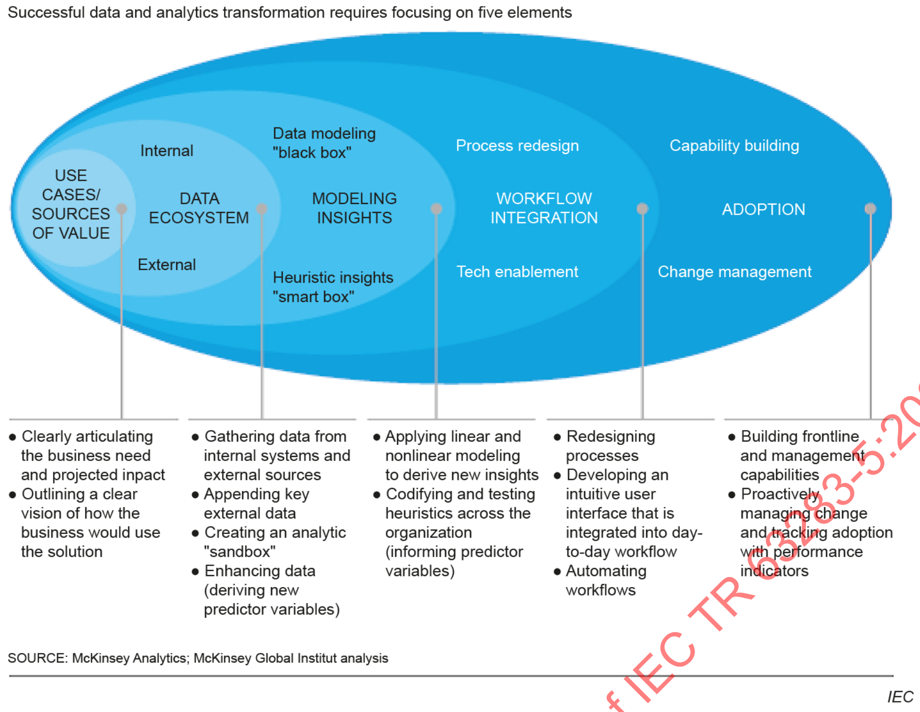
Figure 13 – Potential value from data and analytics

4.3.3.2 Impediments to market acceptance

Although the captured value from location based and retail has progressed reasonably, the captured value from manufacturing, healthcare and public sector are largely untapped. One of the obvious reasons why the market failed to capture the estimated value is the incapability of companies to incorporate the captured data insights into the business processes. From the other hand, the successful companies benefited from the improved day-to-day operations and the creation of new business revenues. Another reason is attracting and retaining the right set of employees. Not only data scientists but also business domain experts are able to map the acquired data with the industry and market indicators. It is clear that companies that have optimized the effects of the networked data platform have created a very competitive position compared with their less fortunate colleagues.

There are many different business models available but none of them is recognized as the data driven business model and it would be too premature to analyse all the available models within this document. However, to reflect some thoughts in this domain, some aspects are considered.

Many companies started to capture data, but they do not understand the full value of these data. Companies have established an organizational change to address the data and analytical transformation within their organization. See Figure 14.



SOURCE: McKinsey. (2016, December). The age of Analytics, Computing in a data-driven world. Retrieved from McKinsey & Company: https://www.mckinsey.com/business-functions/mckinsey-analytics/our-insights/the-age-of-analytics-competing-in-a-data-driven-world, Figure Exhibit E2, page 14. Reproduced from [31] with the permission of Rebeca Robboy, McKinsey Media.

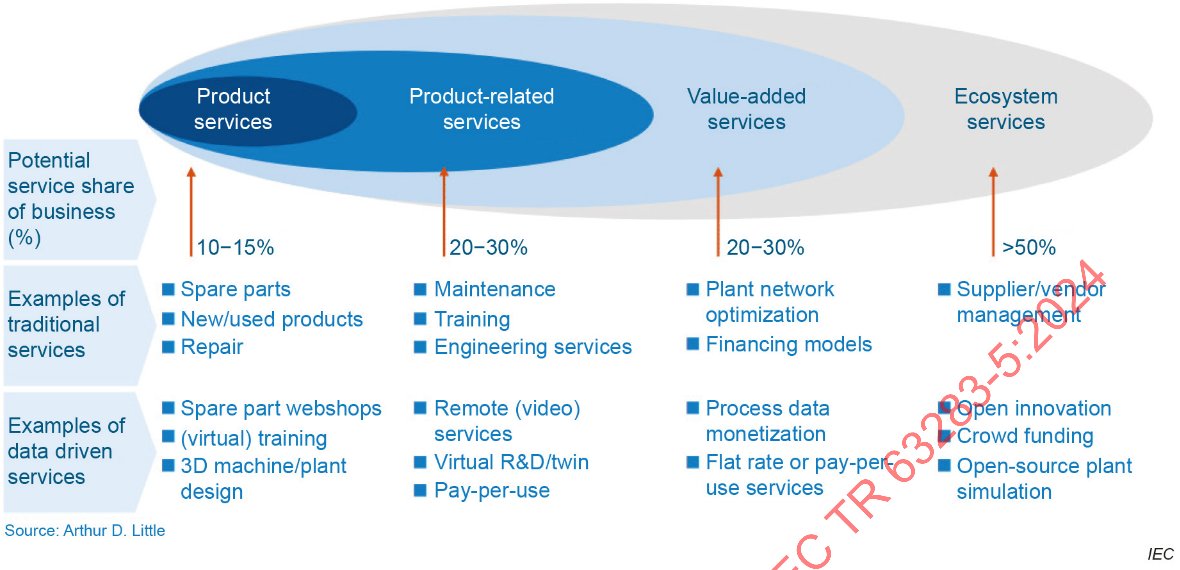
Figure 14 – Data and analytics transformation steps

The data and analytical transformation can be illustrated in 5 steps (McKinsey, 2016):

- Use cases/Sources of value. It shapes the strategic vision and responds to a number of critical questions, such as what will data and analytics be used for? How will the insights drive value? How will the value be measured?
- Building the data ecosystem. It addresses the required data architecture and the data collection/generation capabilities. This will require that digitization is introduced within the business processes, such as customer interactions, supply chains, equipment, and internal operations.
- Modelling insights. This step derives the required insights from the captured data and applies in-house capabilities or outsourced specialists to create additional insights on the collected data.
- Workflow integration. This is a critical step where most companies will fail. Workflow integration means to incorporate the modelling data insights within the business processes. Most times it will include organizational change to implement the modified business processes with the right set of employees.
- Adoption. This final step builds the capabilities of executives and mid-level managers to understand how to use data-driven insights − and to begin to rely on them as the basis for making decisions.

4.3.3.3 Impacts to smart manufacturing

4.3.3.3.1 General



SOURCE: Arthur D. Little. (2017, September 22). Data driven business models. Retrieved from Arthur D Little Global: http://www.adlittle.com/sites/default/files/events/adl_executive_event_data_driven_business_models_0.pdf, Figure – page 1. Reproduced from [32] with the permission of Dr. Michael Opitz, Partner, Head of TIME Practice Central Europe, Arthur D. Little GmbH.

Figure 15 – Data driven business model – value add (example industry goods)

The data driven business model extends the value of product services towards the ecosystem services as illustrated in Figure 15. It is interesting to note that the value of the traditional business offerings reflects only 10 % to 15 % of the data driven business value. The mentioned services have an increasing share of business – over 50 percent for ecosystem services. Examples of those data-driven services to enhance traditional services include remote services via video or a digital twin with significant value added through extensive data collection. A digital twin can be used for further optimizations or for cost reduction in R&D. New ecosystem services include open-source products, such as plant simulation software, which is also an enabler of open innovation.

The value-based service provider uses the production resource data analytics as an additional service within the manufacturing system and monetizes this production data acquisition. A specific case of value-based services is the provisioning of anonymized performance information from other production resources to compare the production efficiency and effectiveness with other manufacturing companies. The use case "Value based services for production resources" and "benchmarking of production resources" (IEC TR 63283-2:2022) details the business interests described here from a technical perspective.

More detailed description of this data driven business model can be found in McKinsey, 2016 and Arthur D. Little, 2017 [32].

Operational management within smart manufacturing optimizes the management of the shop floor through maximizing throughput, minimizing down-time, and cost reduction to maximize the profits. Industrial IoT and the data analytics will provide intelligent data gathering from machines to provide insights of the smart manufacturing shop floor processes.

There are four level of analytics that enable the smart manufacturing insights.

4.3.3.3.2 Descriptive analytics

The basic analytics provides information about "what is happening" in a particular area. For example, it provides understanding of the lifecycle of a product, where and when the product was manufactured, and by which machine. It also enables understanding of the manufacturing processes, such as the performance of a production line: yield, beat rate and running costs. The usage of visualization tools will increase the human understanding of these analytical data.

One example of descriptive analysis is the provisioning of the condition prediction information to the operational staff, such as the production resource operator, production manager and maintenance planning engineer. The use case "condition monitoring of production resources" (IEC TR 63283-2:2022) details the business interests described here from a technical perspective.

4.3.3.3.3 Diagnostic analytics

The next level of analytics is to look into the data to determine the cause of the problem, "why did it happen". For these diagnostic analytics, time series data is used to create an analytics dashboard for the entire business. If the performance of the production line decreases, then diagnostic analysis of data is performed to visualise why the drop-in performance in production occurred. The root cause for this performance loss will become evident in the diagnostic analysis.

4.3.3.3.4 Predictive analytics

Predictive analysis evaluates the past data trends and predicts the future, "what is likely to happen". Algorithms can be used on past data trends to predict the likelihood that an event will happen sometime in the future. The prediction that a machine will fail and scheduling preventive maintenance before the failure will happen is a substantial cost saving within the production process.

4.3.3.3.5 Prescriptive analytics

The highest value of analytics is provided by the prescriptive analysis, "What should I do about it". This analysis takes into account the analysis of the previous levels, what has happened, why it has happened, and several scenarios of what is like to happen to determine what actions could be done to improve the production efficiency.

Prescriptive analytics used within manufacturing is self-optimization. Self-optimization is an approach to flexible and reactive automation. Production resources learn from previous actions, for example, optimized scheduling, and use such knowledge for further evaluations. The use case "self-optimization of production resources" (IEC TR 63283-2:2022) details the business interests described here from a technical perspective.

Big data analytics will provide the following advantages to smart manufacturing (Keysight Technologies, 2018) [33]:

- Flexibility: a factory can adapt much faster to changes with minimal intervention if it has the right insights into the business and its operations. The insights will also enable flexible scheduling, increased factory uptime, and improve yield by minimizing changeovers due to scheduling or product changes.
- Speed: Real time analysis provides faster business decisions due to the available data coupled with the right tools.
- Efficiency: Operational excellence is delivered by applying analytics in process control and optimized business operations.
- Quality: Real-time data collection and analytics during the operational process will enable the factory to predict and detect quality defects. It identifies discrete human, machine, and environmental causes. It is evident that the prediction and detection of quality defects will result in the product quality improvements.

4.3.3.4 Standardization needs

Data analytics requires the standardization of the information that is exchanged between the different systems, components and devices. It is critical to continue the standardization of the smart manufacturing common data dictionary (CDD) but complement this CDD with the semantics and ontology of the CDD properties. Furthermore, tools need to be defined to manage the ontology prefix and ontology dependencies. Further, the version management could be addressed as well, which includes content discovery.

Another aspect is the management of the semantic interoperable information models. It is clear that the digital transformation is lowering the barriers between the traditionally vertical separated industry segments. More and more use cases are defined that require the semantic interoperability between different systems, such as the energy management within the smart manufacturing. Common tools between different standardization organizations are needed to manage the ontology and data dictionaries. The standardization organization needs to ensure that the information models and ontologies become discoverable and that data libraries include an API.

The ontologies and data dictionaries ought to be machine readable. The aspect to use AI to optimize the data analysis means that AI systems need to understand and interpret the data dictionaries and ontologies. This means that models need to be provided that can translate human-centric information into a machine-readable form, such as eXtended Markup Language (XML) and Web Ontology Language (OWL)/Resource Description Frameworks (RDFS). This means that the machine-readable information models can be matched with the system information models, which have to implement the requirements.

4.3.4 Service-driven and performance-based business models

4.3.4.1 Description

Manufacturing companies already offer accompanying product-related services in addition to their physical products, for example spare parts, maintenance services or (software) upgrade services. More and more data-based services are also being offered. The manufacturing company therefore receives a one-time payment for the delivery of the physical product and then recurrent payments along the life cycle of the product for post installation services.

In the case of service-driven business models, however, the manufacturing company no longer sells the services as an add-on to the physical product, but as an independent offer. The company provides the product to the customer, who can use the product without having to buy services. The payment can either be a fixed price or usage-based fee. It is also conceivable that all maintenance and repair services are included in the offered service.

In the case of performance-based business models, the manufacturing company also guarantees product performance, for example availability or processing quality for a machine. If the guaranteed performance characteristics are not achieved, the manufacturing company pays a contractually agreed penalty to the product user.

4.3.4.2 Impediments to market acceptance

From the customer's point of view, these business models are particularly interesting from a financial perspective, because for them the capital costs are reduced at the expense of the operational costs. For this reason, usage-based models are also of interest to customers.

From the provider's point of view, these business models are interesting from the point of view of customer loyalty. Due to the insights into the use of a product by the customer, the provider can often discuss concrete process improvements with the customer. Therefore, they can offer a higher value proposition than the pure capabilities of a product, for example, the provider can offer targeted upgrades to a specific product. As another aspect the provider can draw important conclusions regarding the further development of the product based on the feedback on the usage of the product.

Some products such as production resources are used in core processes. The user is then often not interested in disclosing information about the use of the production resources to others. This is why service-driven and performance-based business models are particularly popular in auxiliary processes such as compressed air, cooling or logistics. Subordinate to this business model discussion, there is often a discussion about who gets access to which information and how and for which purpose it can be used.

Some products in the manufacturing industry are very long-lasting. However, once these investments have been depreciated, a pure as-a-service model is often no longer attractive.

Contract drafting is a challenge with service-driven and performance-based business models. The rights and obligations of both contractual partners need to be clearly defined and especially how compliance with the obligations of the user of the product can be ensured.

4.3.4.3 Impact to smart manufacturing

Service-driven and performance-based business models can often only be implemented economically if the products that are offered as-a-service are connected via an IIoT platform. On the one hand, the IIoT platform can be used to ensure that the products are used in accordance with the contract and, on the other hand, measures can be taken on the basis of suitable condition monitoring to ensure the guaranteed performance of the product.

The use case "production resource as-a-service" details the business interests described here from a technical perspective, see IEC TR 63283-2:2022.

4.3.4.4 Standardization needs

See the corresponding explanations for the use case "production resource as-a-service", IEC TR 63283-2:2022.

4.4 Technology watch

4.4.1 General

The innovation trends describe innovative technologies that are expected to further evolve in mid-term (5 years to 10 years) and they are very likely to disrupt the different industrial systems. The impact on smart manufacturing is still unclear but there are certain assumptions how these will influence the smart manufacturing concepts, e.g. creating new revenue streams or making the concepts more cost efficient and effective.

NOTE 1 That these technologies are still evolving so the exact details how these will impact smart manufacturing is still to be seen.

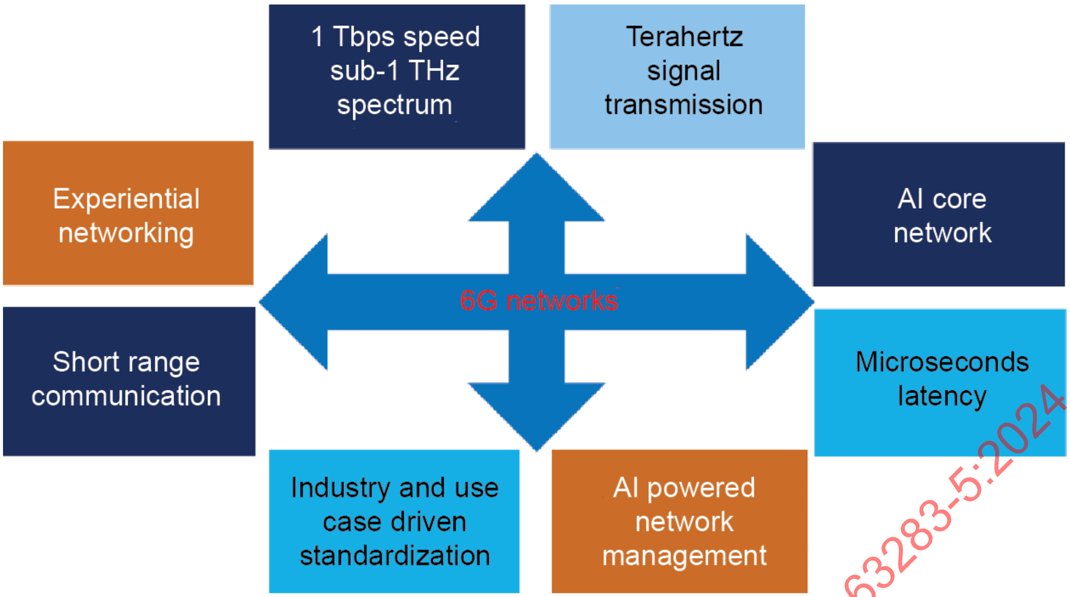
NOTE 2 It is not intended to produce an exhaustive list of technology innovations.

4.4.2 6G

4.4.2.1 Description

The 6th generation cellular system is the obvious successor of the 5th generation cellular system (5G), which is under global deployment. The 5G characteristics have attracted interest from constituencies outside the telecommunication domain. These characteristics address some of the required communication needs from the electrotechnical industries, but further evolution will require more enhanced communication characteristics from the cellular system.

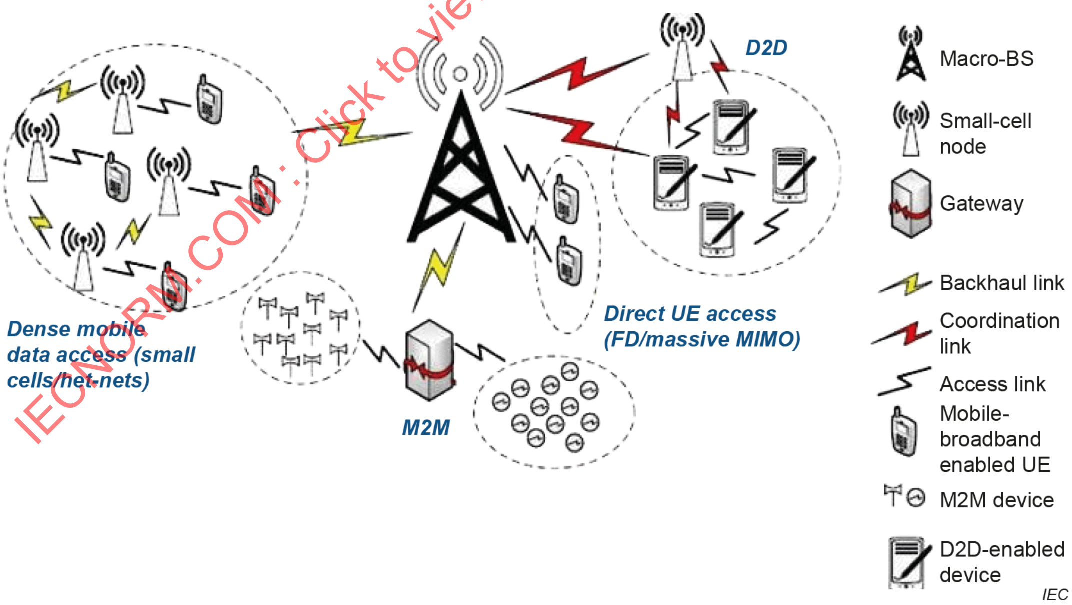
It is expected that the 6G network will use much higher frequencies than 5G, will have much higher bandwidth capacity and much lower latency allowing the 6G network to facilitate new innovative applications in wireless cognition, sensing and imaging. The current understanding is that the 6G pilots are expected in 2030 with commercial 6G launches in 2030 to 2035. The expected Terahertz spectrum will secure the higher capacity (1 terabyte per second, Tpbs) and the latency times in the order of microseconds. See Figure 16.



SOURCE: Mind Commerce; Report on 6G Wireless Technology Market 2021-2030, Figure 10. https://mindcommerce.com/reports/6g-technology-market/. Accessed on 30 June 2021. Reproduced from [36] with the permission of Dawn Stokes, Director, Customer Care, Mind Commerce.

Figure 16 – 6G Key features

Other technologies for the ultra 6G radio exploit the spatial dimension by using advanced multiple input and multiple output (MIMO) and massive MIMO, exploiting the untapped spectrum for mmWave & Terahertz communication systems and exploiting the cost efficiency of cloud and distributed computing, providing multi-technology heterogeneous networks and improved cell edge coverage (Jefferies, 2018) [34]. See also Figure 17 (Alexiou, 2014) [35].



SOURCE: A. Alexiou, WWRF, ITU-R: Study Groups: SG 5: Workshop – Ho Chi Minh City, Viet Nam, 12 February 2014 – 5G: on the count of three paradigm shifts, https://www.itu.int/oth/R0A06000060. Reproduced from [35] with the permission of Angeliki Alexiou, Wireless World Research Forum (WWRF) and University of Piraeus, Greece.

Figure 17 – Heterogeneous network

The 6G wireless sensing solutions will selectively use different frequencies to measure absorption and will adjust frequencies accordingly.

The 6G radio networks will not only cover the communications part but will also use the computing capabilities within the radio network. It will be able to process the expected data tsunami by the 6G system approach for data processing. It will provide data analytics, artificial analytics, and the next generation computing capabilities via high performance computing (HPC) and quantum computing. The 6G capabilities in the areas of wireless sensing, imaging and location determination will generate a data tsunami that needs to be processed on HPC data centres and make optimal use of edge and cloud computing.

4.4.2.2 Impacts to smart manufacturing

The 6G cellular systems provide the following advantages affecting smart manufacturing: (Mind Commerce, 2020) [36]:

- THz communication systems

  The usage of the Terahertz (THz) frequencies will allow much faster data speeds in the order of Tbps which will enable the 6G cellular system to process much more data compared with 5G. The acquired data from the asset administration shells (AAS) and other resources will require big data analytics as well as AI to identify the context and to render into usable information.

- High performance computing

  The 6G radio networks will provide increased computing capabilities using HPC and quantum computing with hyper low latency and high reliability. Therefore, the 6G networks will be able to combine the communication and the computing platform to host the innovative smart manufacturing capabilities (e.g. AAS) and applications (imaging, sensing, positioning, and others).

- Microseconds latency

  5G network introduced applications using milliseconds on latency. There will be an increased number of applications using the milliseconds latency but already now it is understood that some smart manufacturing capabilities will require less than milliseconds latency. The 6G network will be able to address the mass market demand for milliseconds latency while also providing the mechanism to support microseconds latency.

- Integrated artificial intelligence

  Smart manufacturing integrates AI within its operational functions. The 6G network will provide a single platform to address the required communication, computing, and the AI capabilities. This will allow for centralised and distributed intelligence (at the edge). Therefore, the 6G network will provide a single platform to host intelligent AAS and other AI applications within the smart manufacturing.

- Heterogeneous networks (HetNets)

  6G networks provides the capability to support multi-technology heterogeneous networks which will allow the smart manufacturing to deploy different access networks, e.g. Wi-Fi, 6G, satellite, narrow band – IoT (NB-IoT) so that the end-devices can be offered the best quality access to the network.

4.4.2.3 Standardization needs

The 6G standardization will be a basis for many new innovative applications within the smart manufacturing. Therefore, it will be critical to drive the smart manufacturing requirements within the different organization doing the 6G research as a pre-standardization activity. It should be noted that these pre-standards activities will set the scene for the first scope of the 6G standardization.

The current 6G research activities (Rouse, 2019) [37] are:

- The university of Oulu in Finland is committed to a 6G research initiative referred to as 6Genesis. The project will be conducted for the next eight years and will develop a vision for 2037.

- South Korea's Electronics and Telecommunications Research Institute is conducting research on Terahertz band for 6G and envisions making it 100 times faster than 4G long term evolution (4G LTE) networks and 5 times faster than 5G networks.
- The Ministry of Industry and Information Technology (MIIT) in China is directly investing and monitoring the research and development process.
- The United States is planning to open up 6G frequency for R&D purposes pending approval from the Federal Communications Commission (FCC) for frequencies over 95 gigahertz (GHz) to 3 THz.

In terms of vendor commitments to 6G, major cellular wireless infrastructure companies have all signalled that they have R&D in the works.

Industry and the European Commission are working on the successor of the successful 5G-PPP (Public Private Partnership), referenced informally as 6G-PPP. The creation of the 6G-PPP is currently ongoing and no public information exists at this moment.

4.4.3 Quantum computing/networking

4.4.3.1 Description

In quantum communication, two distant parties exchange secure information by using both bits and qubits. Information prepared in qubits cannot be perfectly copied, and correlations delivered by qubits cannot be reproduced by bits. One of the advantages of establishing quantum communication by distributing qubits is the possibility of achieving information-theoretic security (ITS) without any assumptions about computational capabilities. Extensive efforts have been devoted to the implementation of QKD protocols. Recently, quantum network protocols are under investigation.

In practical implementation, photons are used as a physical realization of qubits. They can be distributed through optical fibre or in free space. Either way, a natural limitation exists in the distance over which photons are distributed. Although quantum information prepared in photons cannot be amplified because it cannot be copied by conventional means, the limitation can be overcome by sharing entanglement with repeaters. In recent developments, satellite-based quantum state distribution technologies can play the role of a quantum repeater.

Technologies for autonomous QKD systems for metropolitan and urban areas are expected to achieve low-cost, high-security key rates of 10 Mbps or faster, including multiplexing (Stage 4 technology readiness level (TRL)). Systems for certification and standardization of quantum communications devices will likely be established according to the requirements of the security community, industries, European Space Agency, and government authorities (Stage 7 TRL).

Methods for realizing QKD devices can overcome the limitations of direct-wired communications, utilizing high-altitude platforms (HAPs), satellite integrated trusted nodes, and quantum repeaters (Stage 4 TRL).

The performance of multi-party network building blocks based on quantum repeaters and quantum entanglement will be improved (Stage 4 TRL) through the development of core technologies such as efficient and scalable interfacing with quantum memories, frequency modulation, teleportation, entanglement purification, error correction, single photons, and entangled light sources.

Also on the horizon are practical protocols and various types of efficient algorithms for quantum networks, such as digital signatures, location-based verification, security sharing, and anonymous data queries (Stage 6 TRL).

Demonstrations will be carried out for: long distance transmission through target tasks for supporting QKD on test bed networks, trusted nodes, HAPs, and satellites (Stage 7 TRL); realization of multi-nodal or inter-city network switches linked with components of infrastructure (Stage 7 TRL); automated, autonomous QKD systems suitable for low-cost mass production

(Stage 7 TRL); realization of QKD systems of 100 Mbps or faster that improve secure key rates on urban streets (Stage 5 TRL); and networks based on quantum repeaters and quantum entanglement beyond the ranges of direct communications (Stage 4 TRL).

Along with the prerequisite of visible and demonstrable security, hardware and software developments, including device-independent protocols for realizing quantum entangled networks, will be made (Stage 5 TRL). Quantum computing is facilitated by realizing quantum dynamics – that is, transformations of a quantum state in time – for computational purposes. Just as conventional electronic computing is done on circuits composed of logical gates, transformation of a quantum state can be manipulated by a quantum circuit.

Quantum state transformations can be achieved in computationally equivalent but physically distinct ways. For example, a large-size entangled state can be exploited to transform another quantum state in a process called measurement-based quantum computing. Or quantum dynamics can be realized in continuous-time evolution, known as adiabatic quantum computing.

Current quantum technologies employ different means of realizing quantum dynamics. As yet, however, these "noisy intermediate-scale quantum" (NISQ) technologies do not permit arbitrary control of quantum states with sufficiently high precision. The prospect of designing and building quantum computers has justifiably received a great deal of attention in recent years. Quantum computers are devices that exploit fundamental properties of quantum mechanics to resolve specific problems that even a high-performance classical computer would otherwise find impossible to solve. If such a device could demonstrate that it can perform calculations exponentially faster than a classical computer, it would achieve what is called "quantum supremacy".

The current generation of quantum computers relies on various platforms. Those of most interest to date include ion-trap systems, optical systems, cold-atom systems, silicon systems, and superconducting systems.

In general, two types have been created so far: general-purpose quantum computers and dedicated quantum computers.

A general-purpose quantum computer utilizes quantum bits to perform expandable, fault-tolerant quantum computation, placing emphasis on the number of quantum bits and the fidelity of the logic gates.

A dedicated quantum computer exploits controlled single-body quantum systems to simulate a multibody quantum system, resulting in vastly superior, if not unsurpassable, performance compared to classical computers. However, a dedicated quantum computer is limited to solving specific kinds of problems, and no more.

The complexity and range of unsolved challenges of practical, general-purpose quantum computers, may compel researchers to focus their efforts on dedicated quantum computers.

By numerous accounts, "quantum supremacy" has already been achieved by dedicated quantum computers built with superconducting and optical systems, and progress has been made in chemistry simulations. Ongoing developments in quantum computing, coupled with improvements in quantum system accuracy, fidelity, and fault tolerance, strongly suggest a roadmap of quantum computing potential.

Near-term efforts in quantum computing are anticipated to concentrate on realizing fault tolerant quantum computation by improving the fidelity of quantum logic gates and the quantitative scale of quantum bits.

Emphasis will likely be placed on implementing fault-tolerant quantum computation culminating in general-purpose, error-correctable quantum computers that consist of hundreds of quantum bits. However, it will be problematic to achieve precise parallel control of so many qubits. Other probable impediments are programmable lattice problems and medium-scale non-lattice problems. Finally, specialized operating systems and software ecosystems will be necessary for the practical use and sustained development of quantum computers.

The performance of logical qubits is expected to be improved through repetitive error corrections of physical qubits, allowing for the development of quantum computers of hundreds of qubits. These developments may then be deployed in the initial field tests of data centres, for example.

Eventually, beyond 10 years, quantum computing systems will comprise hundreds or even thousands of individual quantum computers (quantum simulators), making it possible to explore quantum learning theories, new algorithms, and applications, and to solve the challenges of error corrections of benchmark quantum computing simulators and existing devices. That will require an array of technologies and approaches.

Superconducting technologies can take advantage of advanced integrated circuit processing techniques to achieve rapid expansion in the number of qubits. However, there are shortcomings in the fidelity and coherence time of superconducting logic gates, and the difficulty of physically wiring inter-qubit connections increases significantly with greater qubit numbers.

For superconducting systems, crosstalk becomes prominent as the number of quantum bits increases. The performance of superconducting qubits is highly affected by the manufacturing process and material defects. Therefore, microfabrication techniques and top-down chip design will require further development to precisely control the parameters of greater numbers of quantum bits. In addition, with the need for superconducting quantum computers to operate at extremely low temperatures, next generation resources such as cooling systems will be needed to accommodate the thousands of quantum bits and related wiring.

Nonetheless, while it is presently very difficult to achieve global entanglement among all the physical bits, within the coming 10 years, the number of qubits will reach 1 million while the quantum volume indicators will exceed 128. The concept of quantum volume emerged a few years ago as developers and users grappled with how to evaluate the performance of the myriad quantum hardware technologies and their varying levels of operational fidelity.

Ion-trap technology route has certain advantages in terms of physical bit quality and logic gate fidelity, as well as the ability to operate at room temperatures. However, the level of integration remains the biggest challenge, with microfabrication technology considered to be the most feasible solution.

Much work on ion-trap systems shows that motional heating limits the fidelity of quantum gates due to electrical noise. To eliminate this effect, a deeper understanding of the mechanism behind noise generation is needed, and more suitable trap materials and surface cleaning techniques need to be discovered. Future experiments will focus on enhancing the fidelity of multi-qubit quantum gates, increasing gate speed, optimizing two-dimensional ion-trap arrays, and increasing the integration level of optical and electrical control systems.

Based on current progress, it can be predicted that the number of trapped-ion qubits will reach 60 in the next 10 years.

Optical quantum technology represents advantages in coherence time, room temperature operation, high-dimensional entanglement manipulation, etc., and has natural advantages in the realization of quantum information system interconnection.

However, a complete architecture of the quantum computer still needs to be developed and hard bounds on the required performance of photonic components need to be studied. High-brightness single-photon sources, entangled photon sources, and detectors need further development. To achieve error correction, it is also necessary to study how to effectively control many error correcting quantum circuits on the nanosecond time scale.

The current pace of R&D suggests that the number of optical qubits will reach 200 within 10 years, a stage at which currently unsolvable problems will be successfully tackled, and the milestone of "quantum supremacy" will have been achieved.

[Source: IEC White Paper Quantum Information Technology [38]]

4.4.3.2 Impacts to smart manufacturing

High density computing capability is assumed to influence smart manufacturing (e.g. asset administration shells) in supporting substantially increased complexity fully integrated with AI and security. However, this technology is still within the research phase and will require further evolution. It is anticipated that the first commercial prototype deployments will be 5 years to 10 years away and its applicability towards smart manufacturing still needs to be proven.

Cybersecurity aspects of smart manufacturing will require the security of the communication network as well within smart manufacturing. It is generally believed that quantum networking will contribute to this aspect. But also, further research is needed here.

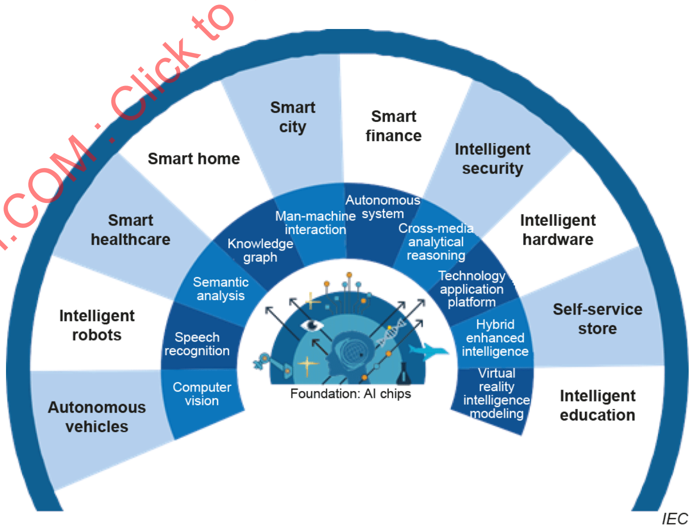
4.4.3.3 Standardization needs

The quantum computing/networking is still in the research phase and this technology still needs further development.

4.4.4 AI chipsets/Tools

4.4.4.1 Description

AI chips are the relevant technology and physical basis for the rapid development of the AI industry. Today's AI chips are based on traditional computing architectures, combined with various hardware and software acceleration schemes. (Tsinghua University; Beijing Innovation Center for Future Chips, 2018) [39]. Figure 18 shows the AI industrial structure and technology stack.

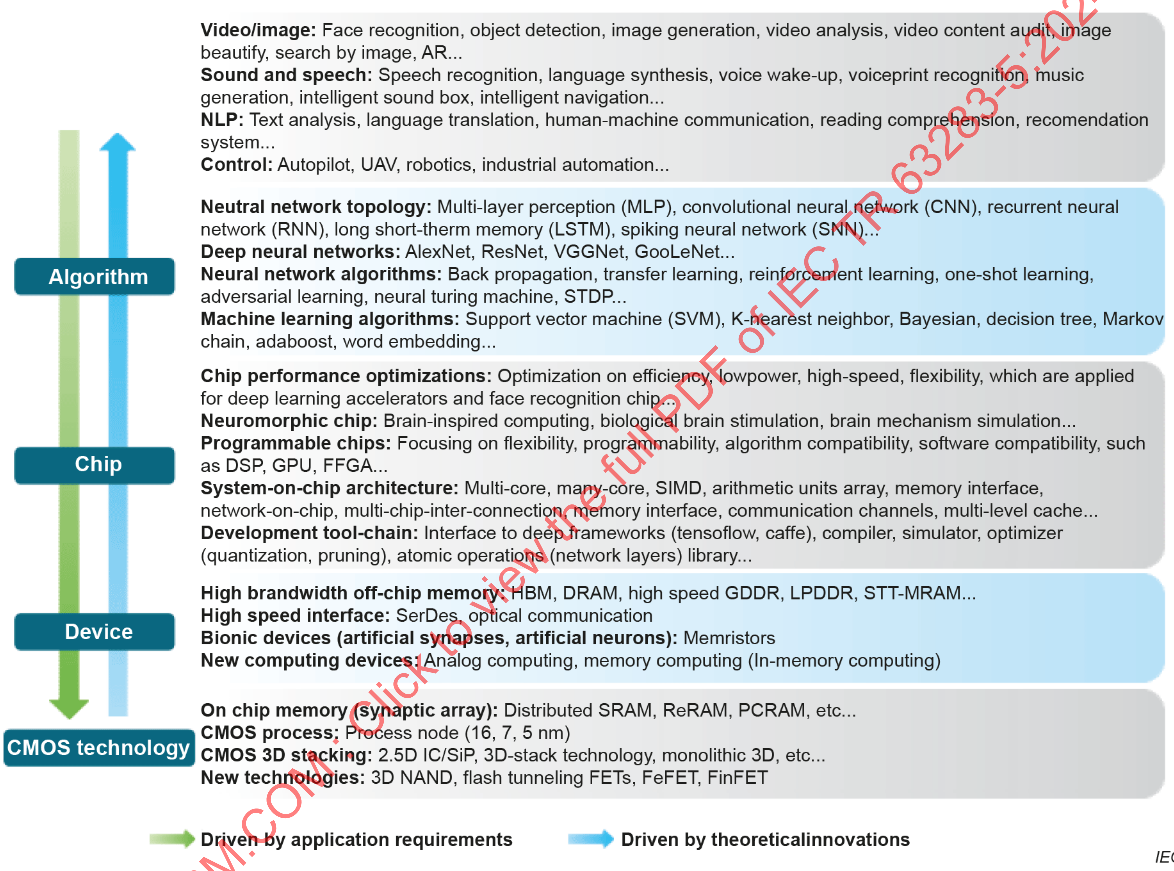


SOURCE: Tsinghua University; Beijing Innovation Center for Future Chips. (2018, 12 10). White Paper on AI Chip Technologies. Retrieved from Future Chips 2018, The Third Future Chips Forum; Reconfigurable Computing in a new Golden Age: https://finadium.com/icfc-whitepaper-on-ai-chips/ Figure 1-1. Reproduced from [[39] with the permission of Xiao ZHONG, Beijing Innovation Center for Future Chips.

Figure 18 – AI industrial structure and technology stack

However, due to the diversity of requirements, it is difficult to have any single design and method that can be well applied to all kinds of AI usages. AI chips can mainly be classified into three types: the first one is universal chips that can support AI applications efficiently through hardware and software optimization, such as graphics processor unit (GPU); the second one is chips that focus on accelerating machine learning (especially neural networks and deep learning), which is the most popular form of AI chips at present; the third one is the neuromorphic computing chips inspired by biological brain (Tsinghua University; Beijing Innovation Center for Future Chips, 2018).

AI technology is multi-layered, it runs through the application, algorithm mechanism, chip, tool chain, device, process, and material technology levels. The AI chip itself is in the middle of the whole chain, providing efficient support for applications and algorithms. See Figure 19.



SOURCE: Tsinghua University; Beijing Innovation Center for Future Chips. (2018, 12 10). White Paper on AI Chip Technologies. Retrieved from Future Chips 2018, The Third Future Chips Forum; Reconfigurable Computing in a new Golden Age: https://finadium.com/icfc-whitepaper-on-ai-chips/ Figure 2-1. Reproduced from [39] with the permission of Xiao ZHONG, Beijing Innovation Center for Future Chips.

Figure 19 – Overview of AI chip related technologies

For smart manufacturing use cases, AI processing from the cloud to the edge, cloud AI computing versus edge AI computing requires the need of specifically designed AI applications. Being able to handle big data is one of the most important considerations for AI chips and AI applications. Furthermore, the software tools to support the AI chips are gaining in importance.

There are several platforms for AI algorithm development, such as TensorFlow™[3], Caffe[4], etc. building an integrated flow, which can seamlessly combine the AI model development and training, hardware-independent and -dependent code optimizations, and automatic instruction translation to AI chips. Finally, the AI chips in edge devices are an integral part of the whole SoC systems, and ultimately the efficiency of hardware is expected to be reflected through the complete chip functions. In this case, it is important to consider the optimization of the architecture from the perspective of the whole system. Therefore, AI chips are often presented as a heterogeneous system; special AI accelerators and other components such as CPU, GPU, image signal processor (ISP), digital signal processor (DSP) work together to achieve the best efficiency.

4.4.4.2 Impacts to smart manufacturing

For smart manufacturing, the collaboration between cloud and edge AI chips and applications is one of the major challenges. The present collaborative pattern for cloud and edge devices is to train the neural network on the cloud and use edge devices for inference. With the increasing capability of edge devices, more and more computing workloads are executed on the edge devices. The collaborative training and inference among cloud and edge devices will be one of the most important questions to be answered.

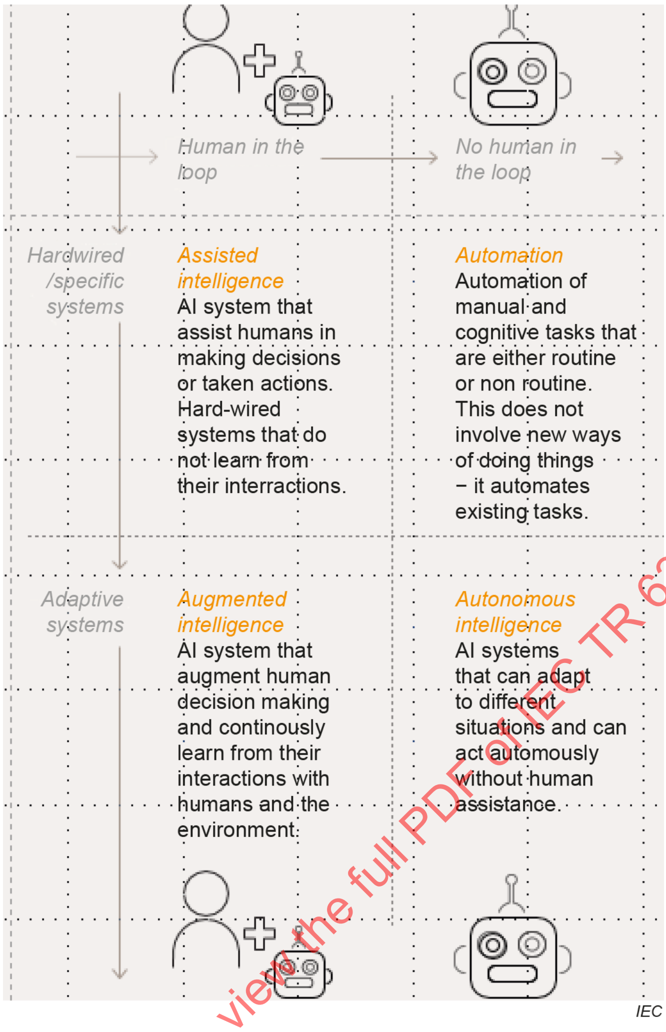
In the future, more and more edge devices will need to have a certain "learning" ability to train, optimize and update models locally based on the collected new data. This will also put forward some new requirements for edge devices and the entire AI implementation system.

AI is probably the most promising technology for a successful introduction of digital transformation in the industry besides 5G and edge/cloud-computing.

The added value from AI in industry 4.0 (I4.0) can be marked in the four major areas of real-time decision making, cost reduction, operation reliability, and security enhancement. In addition, many other use cases such as self-optimizing-production, automated inventory management, efficient production visibility, etc. can be implemented. One of the most common applications of AI for manufacturing is predictive maintenance to formulate predictions. Higher level in quality can be achieved with the use of AI algorithms developed through machine learning, and manufacturers can be alerted of initially minor issues causing quality drops, similar to the way alerts are created for predictive maintenance. As the adoption of robotics in manufacturing increases, AI will play a major part in ensuring the safety of human personnel as well as giving robots more responsibility to make decisions that can further optimize processes based on real-time data collected from the production floor. Manufacturers can also make use of AI in the design phase. AI permeates the entire I4.0 ecosystem and is not only limited to the production floor. One example of this is the use of AI algorithms to optimize the supply chain of manufacturing operations and to help them better respond to, and anticipate, changes in the market. Figure 20 (PwC [40], page 2) shows a broad definition of AI.

[3] TensorFlow™ is a free and open-source software library for machine learning and artificial intelligence. TensorFlow is trademarked by Google LLC. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of this software library.

[4] Caffe (Convolutional Architecture for Fast Feature Embedding) is a deep learning framework, originally developed at University of California, Berkeley. It is open source, under a BSD license. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of this learning framework.



SOURCE: PwC. (2017). Exploiting the AI Revolution; What's the real value of AI for your business and how can you capitalise? Retrieved from Sizing the prize: https://www.pwc.com/gx/en/issues/analytics/assets/pwc-ai-analysis-sizing-the-prize-report.pdf. Reproduced from [40] with the permission of Anand Rao, PricewaterhouseCoopers International Limited.

Figure 20 – Defining AI, PwC broad definition AI

4.4.4.3 Standardization needs

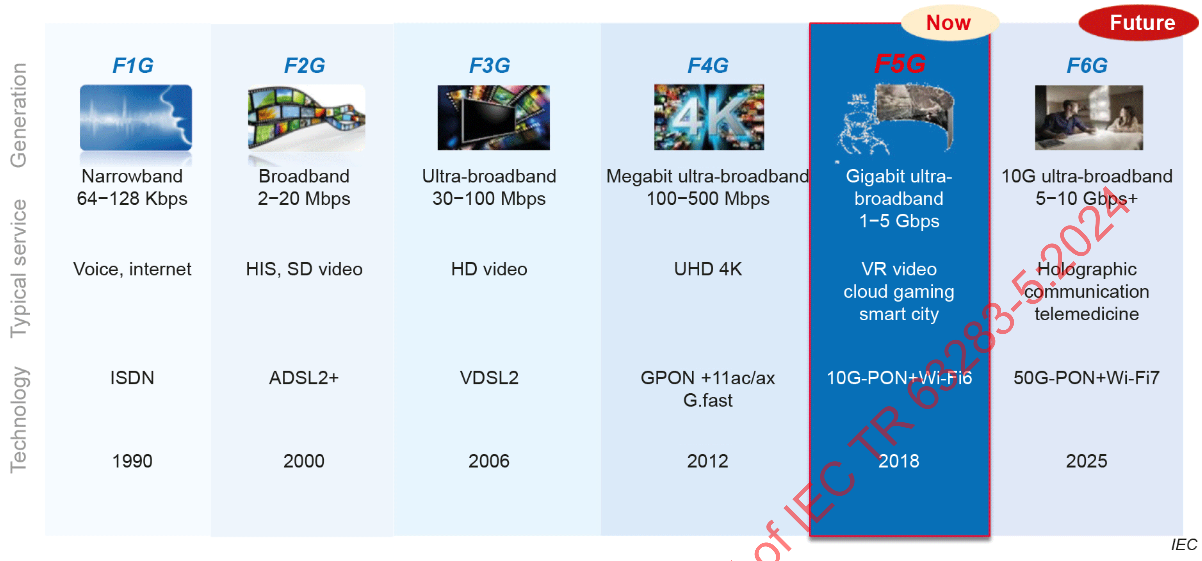
At present, there is no strict and widely accepted standard for the definition of AI chips. Standards will eventually appear within the next years, and standardization will stabilise the number and specialties of architectures and ensure interoperability among the different vendors. The standardisation of architectures, data exchange formats, semantics, vocabularies, taxonomies, ontologies and interfaces are key to creating interoperability between the different technologies involved. In addition to technology standardization, ethics guidelines for trustworthy artificial intelligence plays an important role in creating an environment of trust for the successful development, deployment and use of AI (High-Level Expert Group on Artificial Intelligence, 2019) [41].

4.4.5 5G fixed networks

4.4.5.1 Description

The development of fixed networks has been driven by business needs and supported by technological advancements. First came the narrowband era supported by public switched telephone network (PSTN)/integrated services digital network (ISDN) with data speeds of 64 Kbps. This was followed by ADSL (asymmetric digital subscriber line) -based broadband (10 Mbps), very high-speed digital subscriber line (VDSL)-based ultra-broadband

(30 Mbps to 200 Mbps), and then 100 Mbps enabled by Gigabyte/Ethernet passive optical networks (GPON/EPON), with speeds ranging from 100 Mbps to 300 Mbps. The current technology is 10G passive optical network (PON)-driven gigabit ultra-fast broadband. In the future, it is forecasted a 10G era based on 50G PON driven 6th generation fixed network (F6G). Figure 21 shows the evolution of fixed networks.



SOURCE: Courtesy of Huawei Technologies Co., Ltd. Reproduced with the permission of Yun Chao HU, Senior Director Strategies – Standardization and Industry Development, Huawei Technologies Duesseldorf GmbH.

Figure 21 – Evolution of fixed networks

The future of fixed networks is all-optical. The technology that will support the F6G gigabit era is 50G PON-based full-fiber access. Compared with previous generations of fixed access technologies, the F6G gigabit network represents a huge leap in three ways: bandwidth, number of connections, and network experience.

- Ultra-high bandwidth: Network bandwidth has symmetric uplink/downlink gigabit broadband capabilities. Wi-Fi 7 eliminates the final 10-meter bottleneck of gigabit connections, enabling a single-point connection experience for the cloud era.
- Full-fibre connection: The comprehensive coverage of fibre optic infrastructure will support ubiquitous connections, including connections to every home, machine, room, and even desktop. This in turn will support the expansion of vertical industry applications, a ten-fold plus increase in service scenarios, and a 100-fold increase in the number of connections, and thus enable the era of fibre optic connectivity.
- Ultimate experience: F6G will combine with network slicing and built-in AI on the network side, supporting zero packet loss and microsecond latency. In conjunction with cloud platform AI + big data-based intelligent operations & maintenance (O&M), this will meet users' service requirements. F6G will continue to optimize the home device experience and reduce Wi-Fi latency, improving user experience for applications like 8K video, interactive games, and holographic application in different vertical industries.

These three key features of F6G will enhance user experience on the manufacturing shop floor by introducing high resolution images, holographic manufacturing simulations, etc. Meanwhile, F6G will help optical fibre networks overcome traditional industry barriers and rapidly penetrate various sectors like enterprise, transportation, security, and campuses. It will help industries transform digitally.