Whitepaper on Smart Manufacturing

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SMCC

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Smart Manufacturing

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White Paper on Smart Manufacturing

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Foreword

This white paper is aimed at people who are curious about smart manufacturing, searching for generic information about the concept, and/or trying to get an understanding of what is being done in the arena of international standardization and the implications it might have to industry.

The white paper presents the enablers and the enhancers of smart manufacturing and their predicted effects.

The white paper also presents the roadmap (proposal) that the ISO Smart Manufacturing Coordinating Committee (SMCC) uses in their work to advance the concept of smart manufacturing. The aim is to make it easier for companies to adapt to and benefit from the concept.

Executive Summary

For the last two and a half centuries manufacturing has been an important component of our global society. Manufacturing has evolved though paradigm changes, commonly known as "industrial revolutions". These four revolutions (the first three are considered to be steam and water power, electricity, and automation) have had a great impact on economic growth and living standards. Economic historians agree that the start of the first industrial revolution was the most important event in the history of humanity since the domestication of animals and plants.

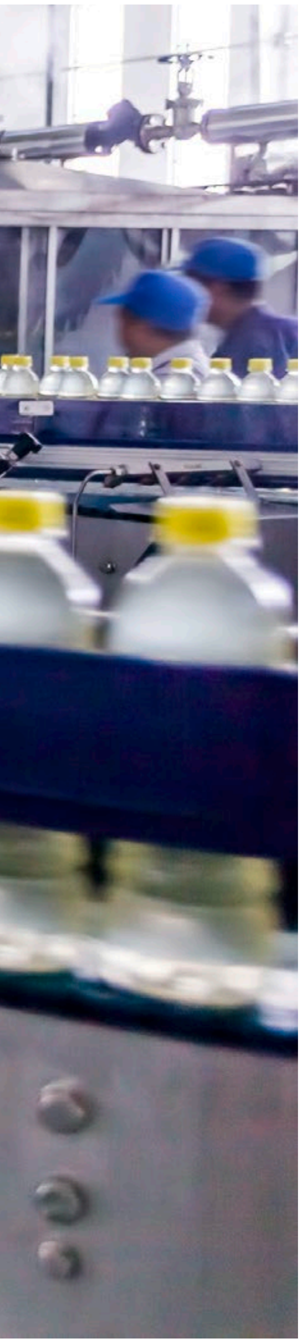
The fourth industrial revolution, otherwise referred to as smart manufacturing, can be explained in many ways. The approach taken in this white paper is to explain it by utilizing models from innovation. New disruptive technologies are regularly becoming available, paving the way for a new wave of innovations. When the effect of these new innovations is large enough, they will revolutionize the current norm of how things are seen and done.

In this white paper we will present new disruptive technologies that are mature enough to be leveraged by industry; we will call them the "enablers" of smart manufacturing.

We will also present a set of design principles, referred to as the "enhancers" for smart manufacturing, that are currently under development and of high relevance for achieving a successful implementation of smart manufacturing. We will also present the "effects" that are foreseen with smart manufacturing.

In order to be able to work successfully and collaboratively, across companies as well as national borders, with the enablers, enhancers and effects of smart manufacturing, standardization is key. This white paper presents the purpose of international and industrial standards and explains the role of the Smart Manufacturing Coordinating Committee (SMCC), the entity created by the ISO Technical Management Board (TMB) to coordinate these activities. The white paper presents, clearly and concisely, available definitions and standards, and states where they are missing. The white paper gives recommendations on next steps.

The overall goal of this white paper is to make it easier for companies and other stakeholders to adapt to, and benefit from, the concept of smart manufacturing.



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Introduction

"The speed of change has never before been this fast... yet it will never be this slow again."
Source: Unknown

This statement implies that there will be major shifts in our society, including in industry and production. Some refer to this as a fourth industrial revolution. Just as we find many names for those we love, there are many commonly used terms addressing this shift, including Industrie 4.0, Smart Manufacturing, Industrie du Future, Factory of the Future, Society 5.0. In this white paper, the term used is smart manufacturing.

It is assumed that the change that comes with smart manufacturing will be to our advantage. However, collaboration and coordination will be needed for the change to be as fast and successful as possible.

What is an industrial revolution ?

History repeats itself. New disruptive technologies regularly appear and pave the way for a new wave of innovations. When the effect of these new innovations is large enough, they revolutionize how things are seen and done. This repetitive process can be visualized as a circle with some cyclical steps, or by an S-curve [Open Learn (2019), Analytics Explained (2013)], see Figure 1. Some claim that we are currently undergoing a new industrial revolution.

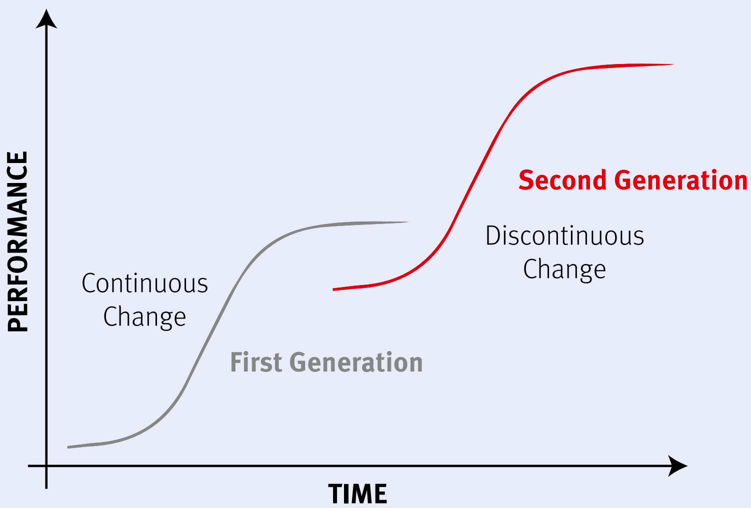
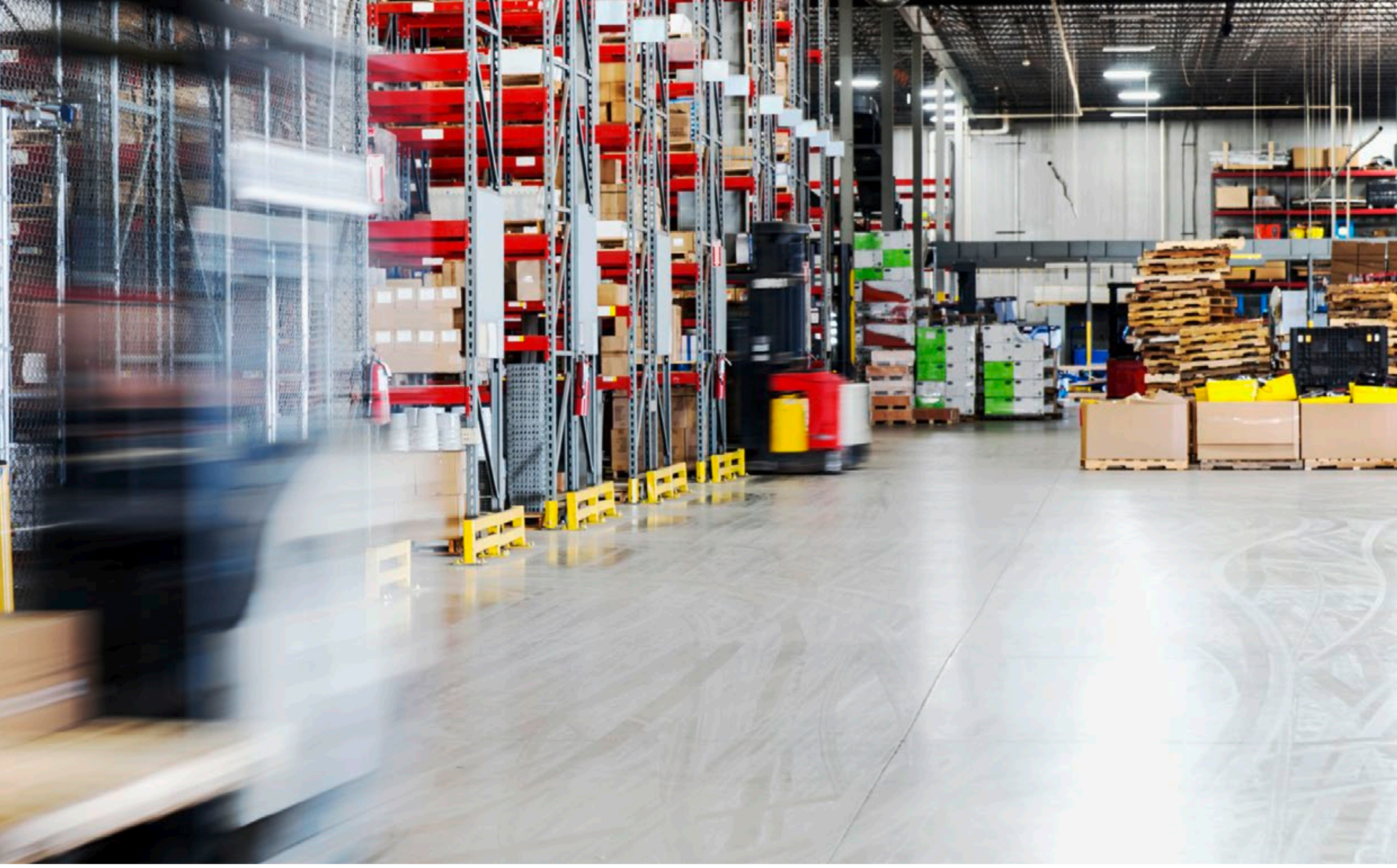


Figure 1: S-curves showing continuous versus discontinuous/disruptive changes



The first industrial revolution took place thanks to the development of steam-powered mechanical machines.

The second industrial revolution took place when the concept of electricity was stable enough to be leveraged by industry.

The third industrial revolution happened thanks to major improvements in electronics and automation.

The fourth industrial revolution is taking place as we speak and has digitalization as a critical success factor.

Each industrial revolution has brought with it fast economic growth and significant changes in living standards. It is therefore imperative for countries and societies to be part of this rapid development.

What are the technologies enabling this revolution ?

The technologies behind the current revolution are largely connected to computer power and computational capabilities, in which a drastic improvement has occurred over the past decades (Moore's law). These improvements are characterized as follows:

- *Cheap (hence abundant) data storage:* The price for storing and hosting large amounts of data no longer constitutes a hindrance; it has reached a satisfactory level of maturity. This means that collecting, storing, retrieving and managing big amounts of data is possible in a way that it was not previously and data is becoming a valuable asset for many companies. Today, storage can be outsourced and stored remotely via the Cloud concept.
- *Fast (hence responsive) computers and calculation power:* Computing capacity is increasing, and calculation power is exploding. This means

that the time required for calculations and analysis is diminishing and results can be retrieved and used in a responsive manner. Big data analytics, artificial intelligence and machine learning, blockchain and business intelligence are gaining attention.
- *Ubiquitous connectivity (hence place-independent):* Wireless technologies have matured and now allow for wireless communication in industrial contexts, while the related information security has also reached an acceptable level.

Cheap, fast and reliable data are the basis for today's accelerated digital transformation.

Enablers that have come about from this rapid development include:

- additive or 3D technologies,
- sensor and measurement technologies,
- internet of things,
- virtual and augmented reality,
- industrial and collaborative robotics,
- simulation,
- Artificial Intelligence,
- wireless connectivity,
- cloud computing,
- industrial (cyber) security,
- blockchain,
- big data analytics.

These enablers are further described in **Annex A**.

Figure 2 shows the longitudinal development of the enablers. The development started long ago and now the enablers are mature enough to be leveraged by industry.

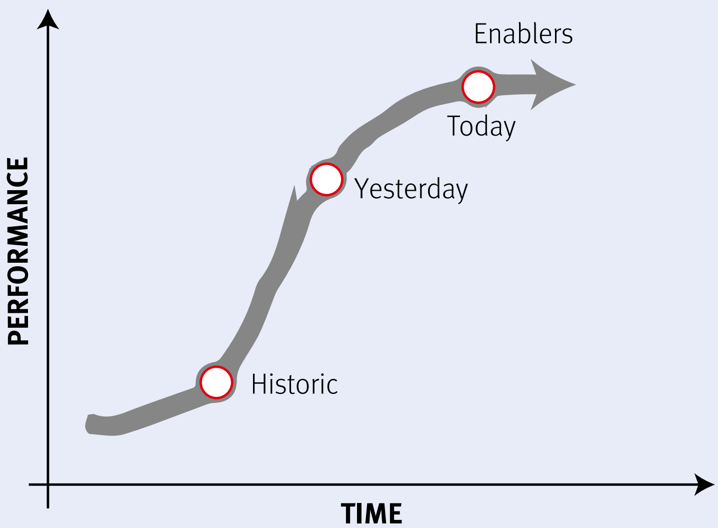


Figure 2: Longitudinal development of the enablers

What future effects will this revolution lead to?

It is most likely that the maturing of technologies will pave the way for new disruptive scenarios to form, gain acceptance and rule out current scenarios. However, no one knows for sure. Some examples of new disruptive effects that are talked about are described below.

- Circular manufacturing: the possibility to make products and production more sustainable and take advantage of retired products and their collected lifecycle information, filter out the essence, and use feedback for improving the manufacturing processes as well as the product itself.
- Model-based product and production: the ability to utilize models at every point in the product lifecycle for the optimum use of the product.
- Fully automated factories: extensive use of new technologies enable new configurations of production automated to a very high degree.
- Product personalization: the possibility to make products, that today are mass-customized, personalized, e.g. pharmaceuticals, clothing, and electronic devices.
- Predictive maintenance: the possibility to act prior to an unfavourable event, like failure, and use in-process monitoring to enable the identification of the optimum time to replace parts, and hence maximize the service life.
- Edge computing: the possibility to have all automation, including real-time control, in the edge of the cloud.
- Servitization: the possibility to augment traditional physical products with related services. Hence, the product becomes a by-product to the service.
- Data-driven business models: business models that are developed and customized based on data from the business. The more data, the better the business model.

Figure 3 shows the longitudinal development of the effects. The effects are just starting to be noticed in industry, and it is hard to predict what the long-term effects will be.

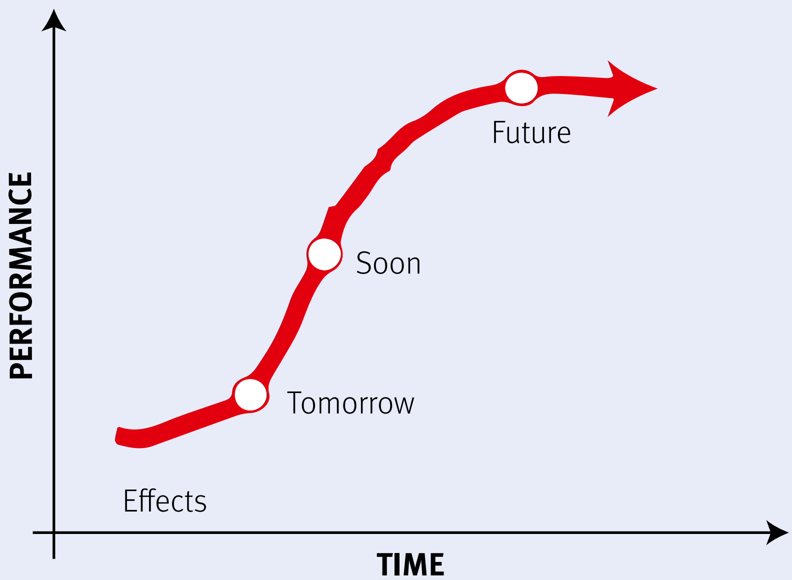


Figure 3: Foreseen longitudinal development of the effects

What principles are needed to enhance the development?

If the enablers are leveraged in a clever way, the effects will be realized. Currently, a lot of work is ongoing, at a national and international level, as well as on a company and organizational level. The aim is to find out the additional principles that are urgently needed in order to make the shift from traditional to smart industry; see **Figure 4**.

In order to realize the shift from traditional to smart industry, a majority of experts agree that collaboration is key: the era of proprietary solutions is over and replaced by the new era of shared economy. It is important to agree on underlying principles, also referred to as enhancers. Examples of enhancers that we need to agree on are as follows.

- Terminology and reference models: crucial for increasing understanding among the parties involved.
- Concepts related to decentralization, modularization and virtualization.
- Integration and interoperability vertically and horizontally, unlocking the seamless flow of data.
- Digital twin and digital thread: to be able to model the real physical world in a digital format in order to understand, analyse, optimize and predict the physical world.
- Product transparency, i.e. complete data, including sustainability data, from the lifecycle of the product.

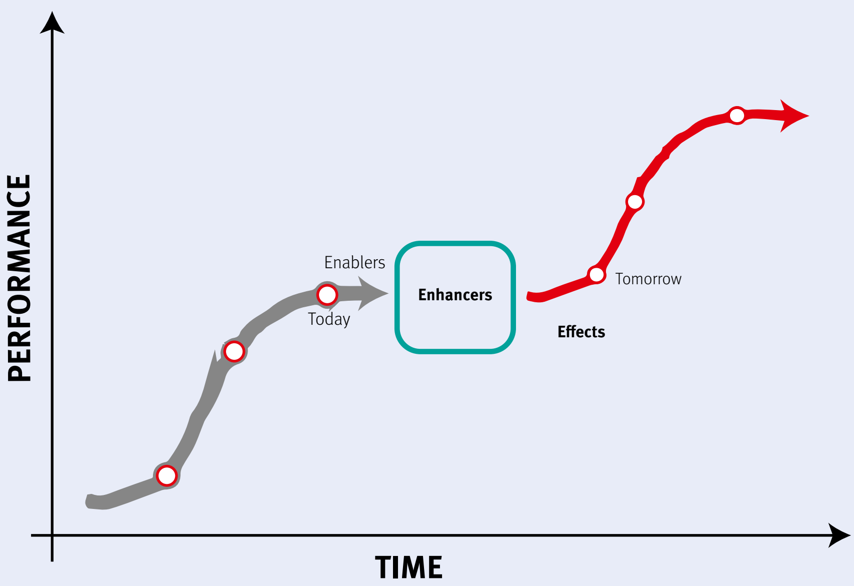
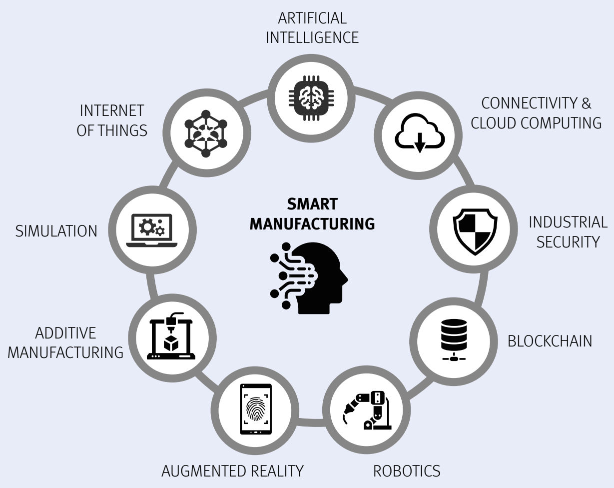


Figure 4: Graphical visualization connecting the enablers with the effects, stressing the transformation from today (grey) to tomorrow (red)



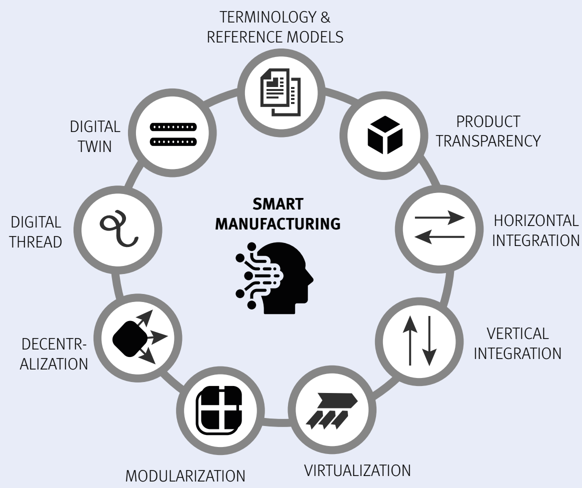


Figure 5: Enablers (left) and enhancers (right)

Enablers, enhancers and effects

Enablers have come about from recent rapid developments; cheap, fast, and ubiquitous. They are now mature enough for industry to leverage. The enablers are shown in **Figure 5** (left).

Enhancers are vital in order to enhance the development from traditional manufacturing to smart manufacturing. The enhancers are shown in **Figure 5** (right).

The intended effects are shown in **Figure 6**.

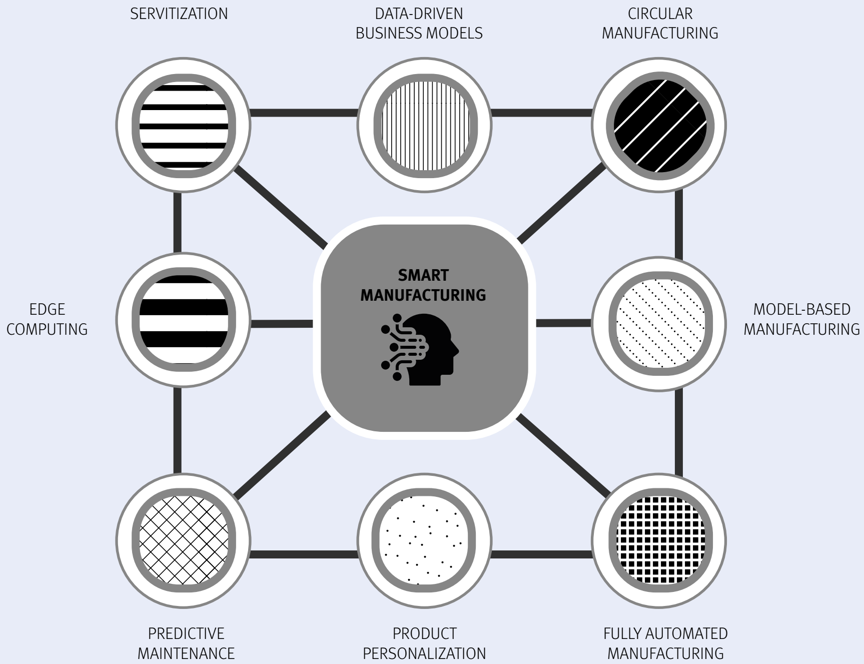


Figure 6: Effects

Benefits of standards

A suitable vehicle for this urgent collaborative work is international standards. Standards allow the development of enablers and help the enhancers to be more easily adopted within industry.

Some standards already exist for the enablers; however, a high-level description, from the perspective of smart manufacturing, can help clarify how an enabler is beneficial for the realization of smart industry.

Actions required:

- *Clarify the maturity and the potency of the enablers.*
- *Clarify the requirement that smart industry puts on the enablers.*

Standards for the effects are hard to finalize at this point since these concepts are still in their infancy. Instead the development of such standards will gradually take place in an iterative manner. Nevertheless, it is important to have a (preliminary) definition of the effect-concepts in order for all experts in smart industry to have a shared understanding of the concept and its implications.

Actions required:

- *Create clear definitions for the effects, ensuring that all stakeholders have a shared common understanding of these concepts.*

Standards treating the enhancers (design principle concepts), i.e. concepts specific to smart industry, are vital and the development is urgent. Many companies and organizations will rely on their content in their smart industry transformation journey.

Actions required:

- *Create standards for the enhancers.*

There are many organizations, clusters, groups, branch-organizations, etc., that are developing standards. Depending also on the significance of the organizations, the standards they are developing are more or less accepted in industry. Three well-known standardization organizations are:

- IEC (International Electrotechnical Commission), which develops standards related to the electrotechnical domain;
- ISO (International Organization for Standardization), an independent international organization representing more than 160 countries, which has a very broad focus, including industrial automation;
- ITU (International Telecommunication Union), the United Nations specialized agency for information and communication technologies.

Further information about standards development organizations can be found in **Annex D**.

Smart Manufacturing Coordinating Committee (SMCC)

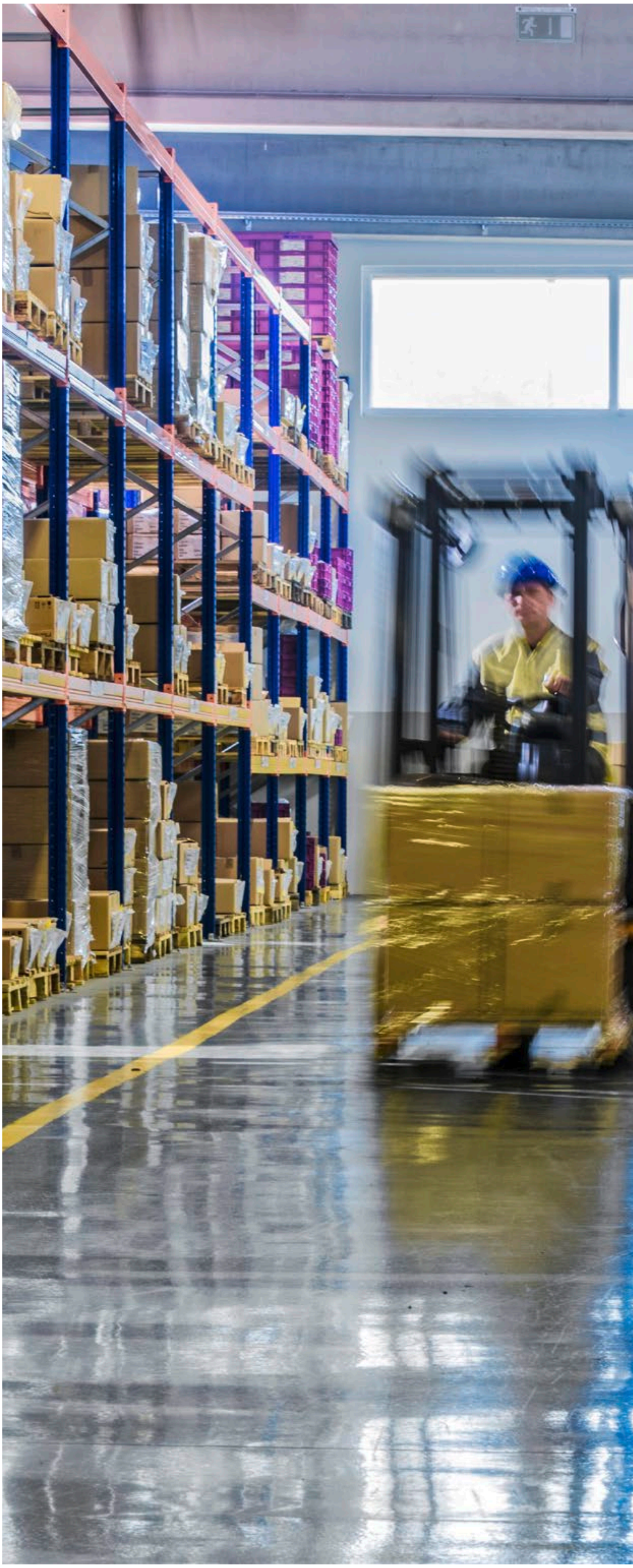
ISO, which develops standards in a broad scope of domains, including industrial applications, is well positioned to coordinate the development of standards for smart manufacturing. The Smart Manufacturing Coordinating Committee (SMCC) is made up of the chairs of more than 20 identified Technical Committees (TCs) and subcommittees (SCs). Their mandate is threefold: to coordinate across ISO committees, to coordinate with other organizations, and to advise the ISO Technical Management Board (TMB).

The first main achievement of the SMCC was to create a definition of smart manufacturing, endorsed by both ISO and IEC (ISO/TMB Resolution 31/2019):

Manufacturing that improves its performance aspects with integrated and intelligent use of processes and resources in cyber, physical and human spheres to create and deliver products and services, which also collaborates with other domains within enterprises' value chains."

Note 1: Performance aspects include agility, efficiency, safety, security, sustainability or any other performance indicators identified by the enterprise.
Note 2: In addition to manufacturing, other enterprise domains can include engineering, logistics, marketing, procurement, sales or any other domains identified by the enterprise.

Work done prior to the establishment of the SMCC had resulted in an initial list of seven standardization gaps (Strategic Advisory Group on Industry 4.0/smart manufacturing – Final report to TMB, Annex C, 2019), which will continue to be addressed by the SMCC as a roadmap develops.



Roadmap – what needs to be done

The proposal is to create a roadmap divided in three parts: enablers, enhancers and effects. The three parts need different actions and are therefore dealt with in different ways.

Enablers

The enabling technologies are sufficiently mature and have been addressed by ISO for a reasonable amount of time. It can therefore be assumed that clear definitions exist for most of the enablers, as well as for their roles and importance in smart manufacturing.

As a roadmap, the SMCC proposes:

- To make a list of the main enabling technologies for smart manufacturing, see **Figure 5** (left).
- To identify the TCs addressing these technologies as their main focus (see **Table 1**).
- If there are multiple TCs addressing the same enabler, the SMCC should recommend the appointment of one as the main TC for this enabler.
- If there is no TC addressing the enabler, the SMCC should inform the TMB.
- Ask the identified TCs to provide a short definition and a high-level description of the enabling technology and its importance for smart manufacturing (see **Annex A**).
- There might be several TCs that have included a definition of the enabling technology in their work. If so, the SMCC recommends that they also include the definition given by the main TC and explain how their definition relates to the main definition.
- Objective: Clear definitions and descriptions of the enablers and their role in smart manufacturing will help the industry to understand what technologies they can work with and why.

Table 1: List of enablers (≈enabling technologies) of smart manufacturing

Enablers	Main provider of definition	Definition/ description
Connectivity & cloud computing	3GPP ISO/IEC JTC 1/SC 38	A.1 and A.2
Industrial security (SMCC gap #5)	ISO/TC 292 Additional groups: ISO/IEC JTC 1/SC 27 IEC/TC 65/WG10	A.3
Blockchain	ISO/TC 307	A.4
Robotics	ISO/TC 299	A.5
Augmented Reality and visualization	ISO/IEC JTC 1/SC 24	A.6
Additive manufacturing	ISO/TC 261 IEC/TC 65 – ISO/TC 184 JWG 21 Additional group: ISO/IEC JTC 1/WG 12	A.7
Simulation	ISO/TC 22 ISO/TC 184/SC 5/SG 7	A.8
Internet of Things	ISO/IEC JTC 1/SC 29 ISO/IEC JTC 1/SC 41	A.9
Artificial Intelligence (AI)	ISO/IEC JTC 1/SC 42 Additional group: IEC/TC 65 – ISO/TC 184 JWG 21	A.10

Six of the nine enablers have a main TC, and hence a clear definition. Three of the nine enablers are covered by multiple TCs. None of the nine enablers is lacking a main TC.

Enhancers

Enhancers use potential provided by one or more enablers to generate new opportunities and business solutions. Enhancers are vital in order to enhance (facilitate and speed up) the development from traditional manufacturing to smart manufacturing.

As a roadmap, the SMCC proposes:

- To make a list of the enhancers that are vital to the realization of smart manufacturing [see **Figure 5** (right)].
- To identify which of the enhancers has a corresponding TC addressing the design principle as its main focus (see **Table 2**).
- The identified TC will be asked to provide a definition and a high-level description (see **Annex B**).
- For the enhancers that do not have a corresponding TC, the SMCC should make a recommendation regarding how it should be addressed (e.g. suggest which TC can be responsible).
- Objective: Clear definitions and descriptions of the enablers and their role in smart manufacturing will help the industry to understand what design principles to work with and why.

Table 2: List of the Enhancers (≈design principles) of smart manufacturing

Enhancers	Main provider of definition	Definition/ Description
Terminology (SMCC gap #1) Reference models (SMCC gap#6)	SMCC (terminology) IEC/TC 65 – ISO/TC 184 JWG 21 (reference models) Additional groups: IEC SyC SM WG 2	B.1
Product transparency	ISO/TC 184/SC 4	B.2
Horizontal integration	IEC/TC 65	B.3
Vertical integration	ISO/TC 184/SC 5 -IEC/SC 65 E JWG 5	B.4
Virtualization	-	B.5
Modularization	IEC/TC 65/SC 65 E	B.6
Decentralization (Distr./Network architecture)	IEC/TC 65/SC 65B	B.7
Digital twin	ISO/IEC JTC 1/SC 41 Additional groups: IEC/TC 65/WG 24 IEC/TC 65 – ISO/TC 184 JWG 21 ISO/TC 184/AG 2 ISO/TC 184/SC 4/WG 15 ISO/TC 184/SC 1/WG 11 IEC/TC 65/WG 23	B.8
Data quality	ISO/TC 184/SC 4 ISO/IEC JTC 1/SC 7 ISO/IEC JTC 1/SC 42	B.9

Enhancers may combine existing standardization results originating from different ISO and IEC technical committees.

Two of the nine enhancers are dealt with by one main TC and have a clear definition. One of the nine enhancers is dealt with by multiple TCs. Six of the nine enhancers are lacking a corresponding TC and do not have an ISO definition.

Effects

As a roadmap, the SMCC proposes:

- Make a list of the envisioned effects of smart manufacturing (see **Table 3**).
- If a definition is missing, the SMCC should propose a clear definition for these effects, or indicate how it should be derived.
- Objective: The idea is to ensure that all stakeholders will get a shared common understanding of the foreseen effects.

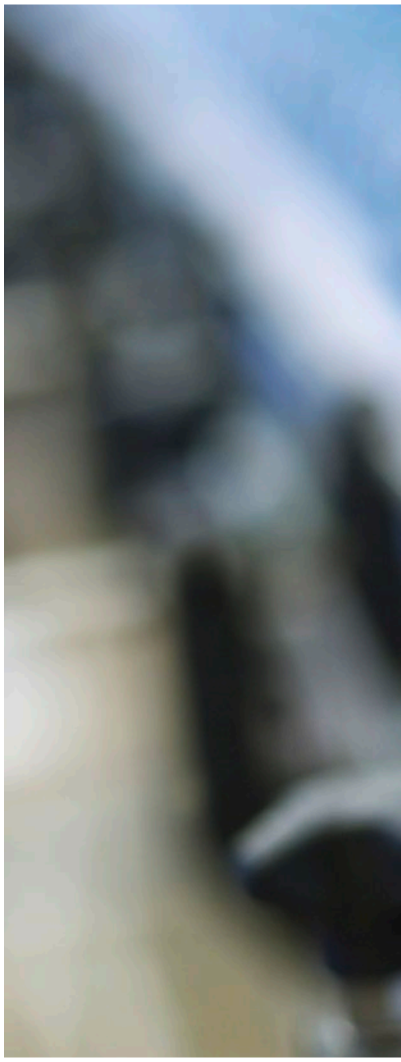


Table 3: Envisioned effects of smart manufacturing

Effects	Main provider of definition	Existing or proposed definition
Data-driven business models	-	C.1
Circular manufacturing	ISO/TC 323 ISO/TC 10/WG 20	C.2
Model-based manufacturing	ISO/TC 184/SC 4/WG 12	C.3
Fully automated factories	-	C.4
Product personalization (SMCC gap #3)	ISO/TC 184/SC 5/WG 14	C.5
Predictive maintenance	-	C.6
Edge computing	ISO/IEC JTC 1/SC 38	C.7
Servitization (SMCC gap #7)	IEC/TC 65 – ISO/TC 184 JWG 21	C.8

Seven of the nine effects are not addressed by any TC. One of the nine effects is treated by a related TC, and one has a dedicated TC and a clear definition.

The SMCC matrix

The three parts of the roadmap – enablers, enhancers, and effects – can be presented in the form of a matrix in which each column corresponds to an enabler, an enhancer or an effect, and each row corresponds to a TC or WG within ISO, IEC or joint ISO/IEC (see **Figure 7**).

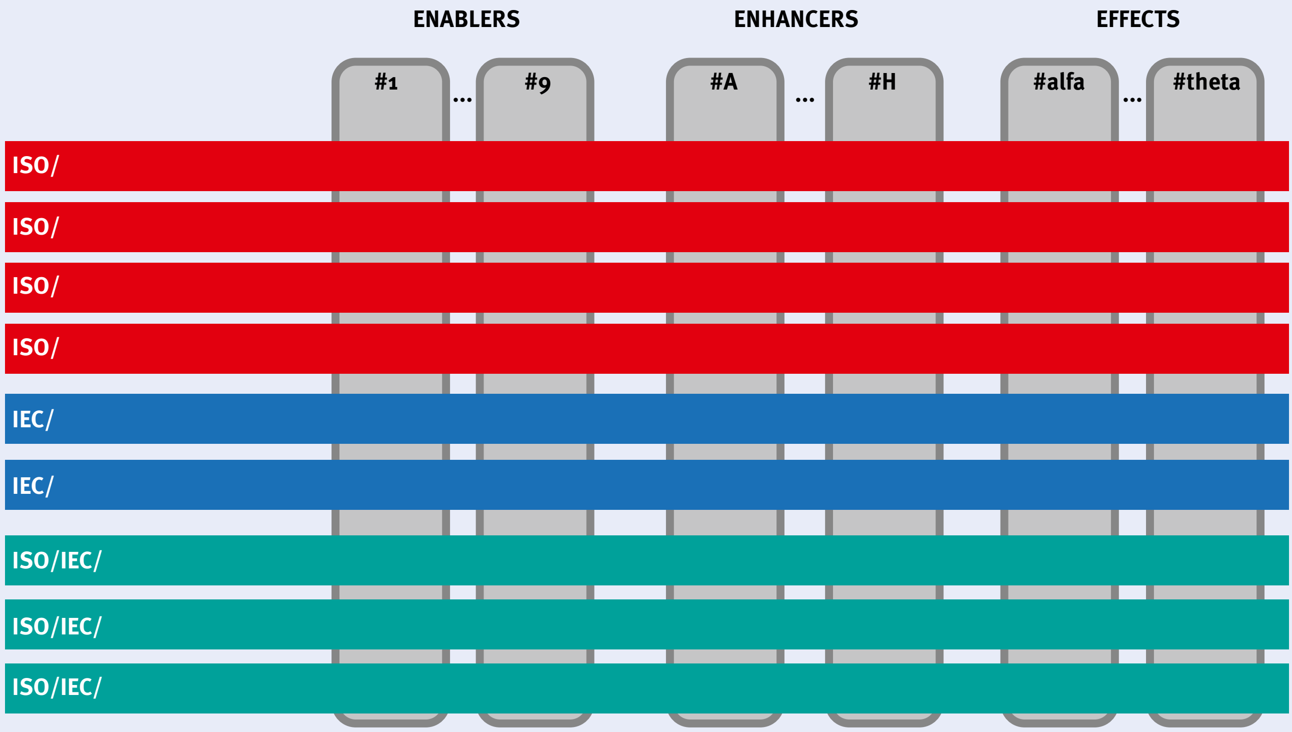
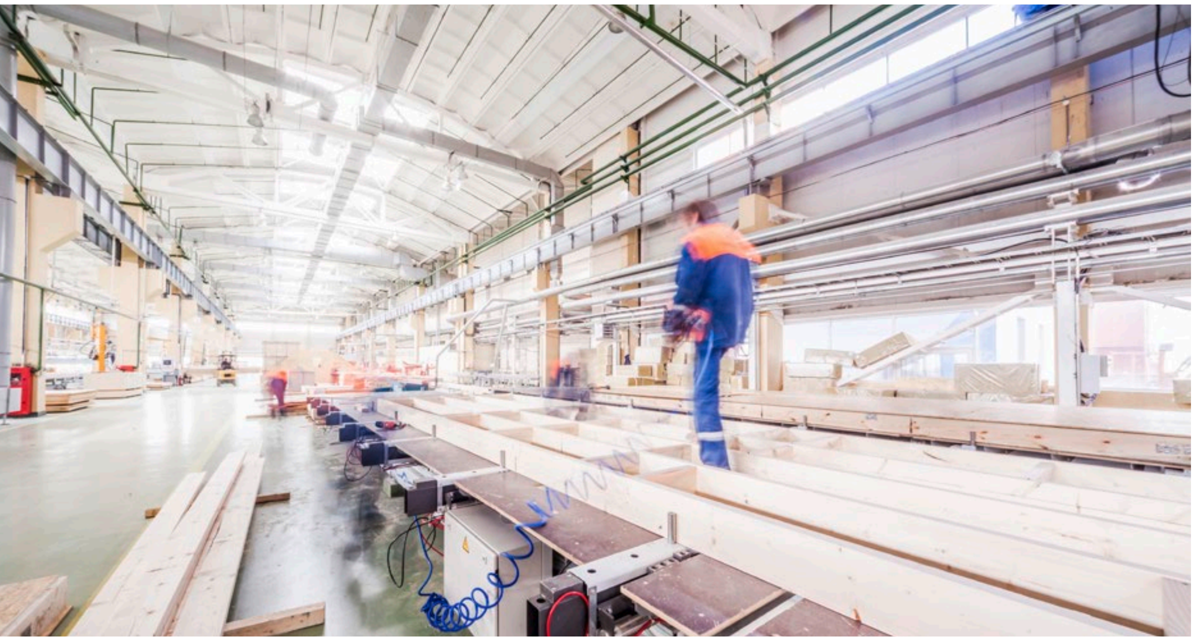
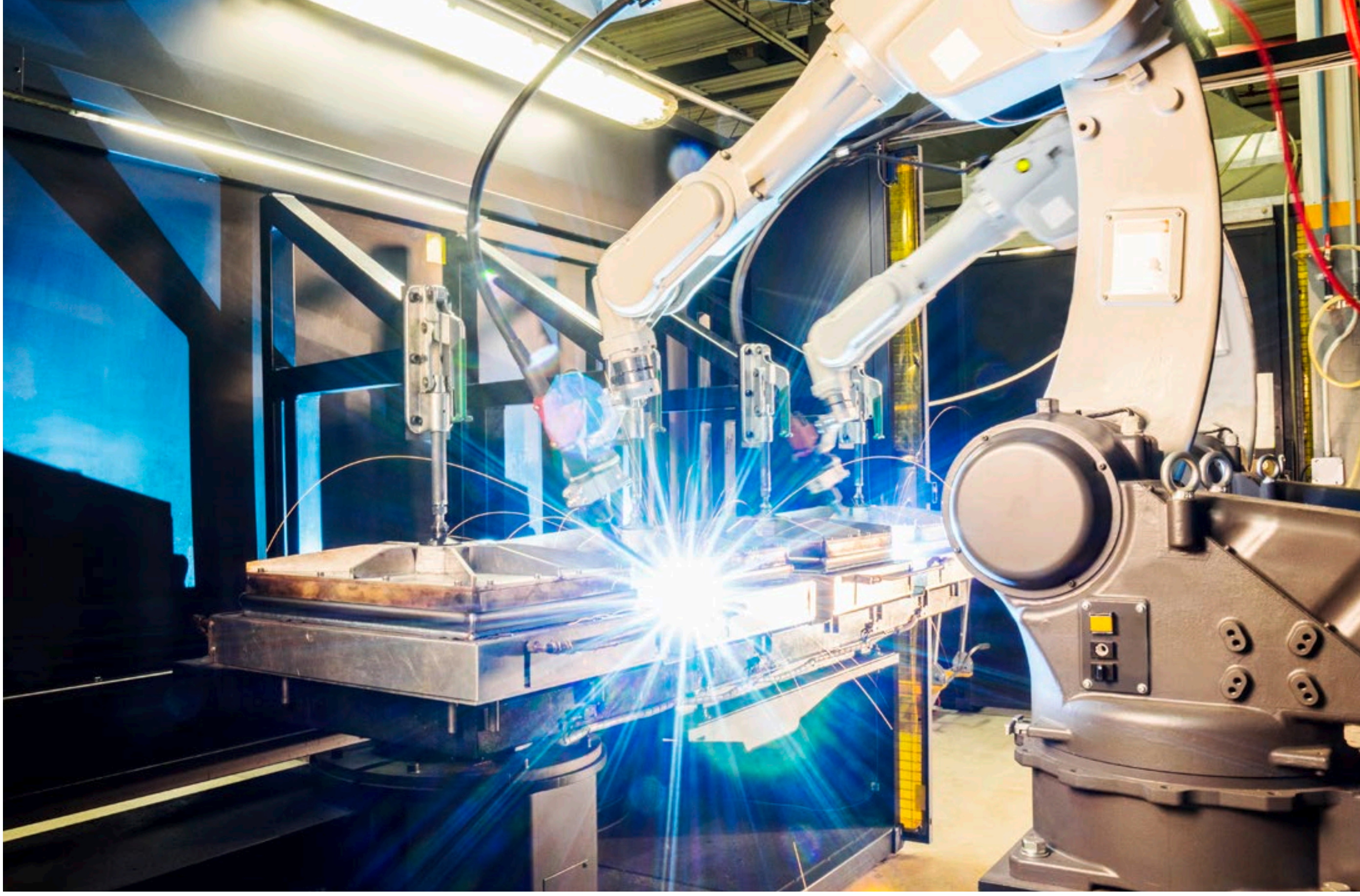


Figure 7: SMCC matrix

A list of standards relevant to smart manufacturing can be found in ISO/IEC TR 63306-2.





Additional information

This white paper has presented smart manufacturing from the perspective of enablers, enhancers and effects. There are, of course, alternative ways in which the concept can be presented. Two of them are briefly mentioned here.

Lifecycles

Another way of presenting the work done by ISO regarding smart manufacturing is to present it according to the set of lifecycles that are included in smart manufacturing, i.e. product lifecycle, asset lifecycle, order-to-cash lifecycle, supply chain lifecycle, security lifecycle.

Each lifecycle is composed of a set of sequential steps. Each lifecycle has its own set of steps, however, the step "operation (make)" is present in all of them. This means that all lifecycles converge in the step "operation (make)". In smart manufacturing, the aim is to increase the level of integration in three ways: integration between the steps within each lifecycle, integration between the various lifecycles, as well as integration between the early and late steps of the lifecycles.

This way of presenting smart manufacturing is highlighted in Figure 8 in which traditional manufacturing is visualized on the left part of the figure, and smart manufacturing is visualized on the right part (reference).

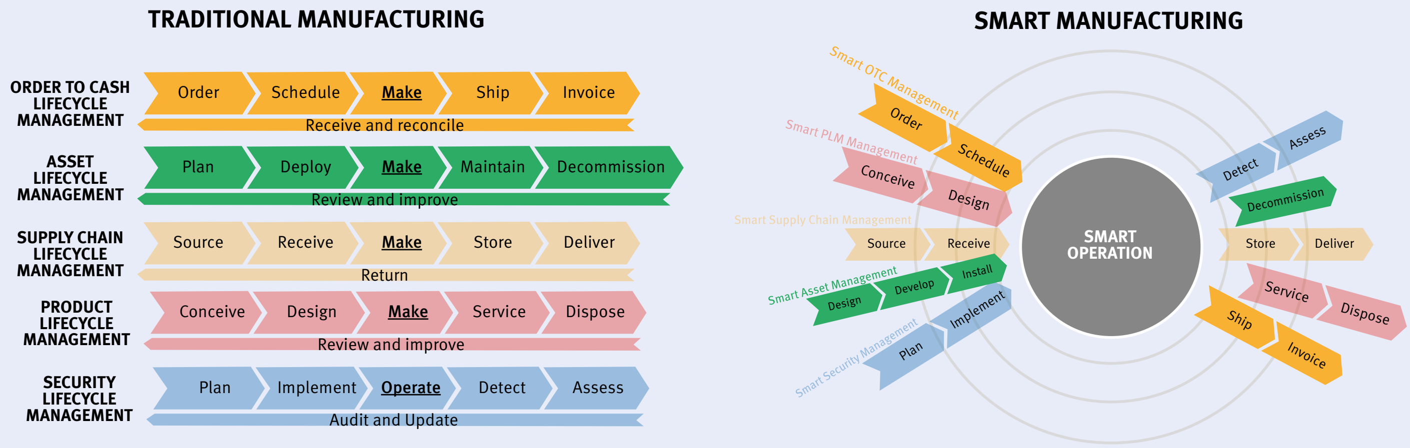


Figure 8 : Visualization of traditional manufacturing compared with smart manufacturing

Smart Manufacturing Standards Mapping (SM2)

International and regional standards development organizations (SDOs), as well as consortia and national initiatives, identified the need for clarifying the standards landscape of the thousands of publications related to smart manufacturing.

Based on the recommendations of some ISO initiatives (e.g. ISO/TMB Strategic Advisory Group Industry 4.0/Smart Manufacturing), ISO and IEC established the Smart Manufacturing Standards Map Task Force (SM2TF), which reports jointly to the SMCC and IEC/SyC SM.

The goals of the SM2TF are to provide a systematic and reliable classification method for sorting, classifying and comparing standards.

In order to be able to make a quick and accurate selection from the vast number of standards for smart manufacturing, without having to read thousands of pages of text, the SM2TF used reference architecture models and other systematics that have emerged in recognized national initiatives for structuring.

The results were published in a two-part ISO/IEC Technical Report:

- ISO/IEC TR 63306-1, *Smart manufacturing standards map (SM2) – Part 1: Framework. This document describes the framework and the vocabulary that are used for the development of entries in ISO/IEC TR 63306-2.*
- ISO/IEC TR 63306-2, *Smart manufacturing standards map (SM2) – Part 2: Catalogue. This document lists smart manufacturing related standards with their characteristics as specified in ISO/IEC TR 63306-1.*

Currently, SM2TF is working on mapping the results on a platform that allows a graphical representation. First promising test results have already been achieved in the **IEC mapping tool**.

Conclusions/next steps

Smart manufacturing is vital for economic growth and improved living standards. In this white paper, it has been explained by utilizing models from innovation. With certain regularity new disruptive technologies become available and pave the way for a new wave of innovations. When the effect of the new innovations is large enough, they revolutionize how things are seen and done.

In this white paper we have presented new disruptive technologies that are mature enough for industry to leverage (the enablers of smart manufacturing). We have also presented a set of design principles (the enhancers of smart manufacturing) that are currently under development and of high relevance for successfully implementing smart manufacturing. We have also presented the effects that are foreseen with smart manufacturing.

Standards related to smart manufacturing, i.e. to the enablers, enhancers and effects, are vital, and their development is urgently needed. Many companies and organizations rely on their content in the company's transformation journey towards smart manufacturing.

Therefore, it is important to understand which standards are already available, which are under development and, if any are missing, to identify where new ISO working groups should be established.

All the enablers are covered by at least one TC. Six of the nine enablers are addressed by one main TC and have a clear definition. Three of the nine enablers are addressed by multiple TCs, and a clarification would be beneficial for stakeholders. This white paper contains a concise presentation of the enabler by its ISO definition, as well as a short description of its relevance for smart manufacturing.

Only two of the nine enhancers are addressed by one dedicated TC and have a clear definition. One of the nine enhancers is addressed by multiple TCs. Six of the nine enhancers are lacking a corresponding TC and do not have an ISO definition. There is a need for additional working groups addressing the missing enhancers.

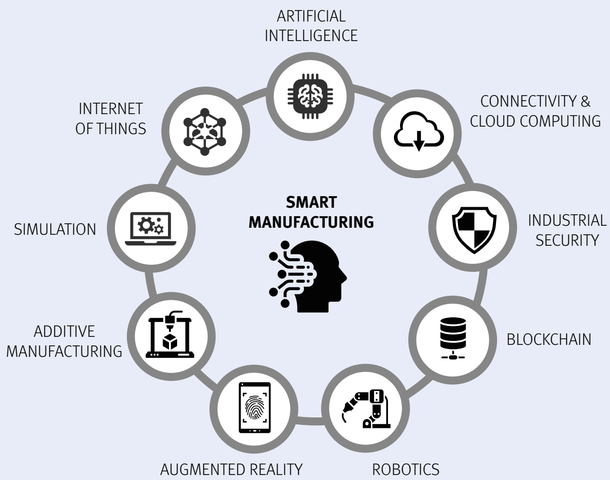
Seven of the nine effects are not addressed by any TC. One of the nine effects is addressed by a related TC, and one has a dedicated TC and a clear definition. There is a lack of ISO initiatives related to the effects.

The landscape of existing, as well as non-existent, standards is an important finding by the SMCC which will be brought forward to the ISO/TMB, together with additional recommendations.

The overall goal of this white paper – as well as for the SMCC and the related ISO working groups – is to make it easier for companies and other stakeholders to adapt to, and benefit from, the concept of smart manufacturing.

Annex A – Enablers, their definitions and relevance for smart manufacturing

Enablers have benefited from the recent rapid development in computer power and computational capabilities, and are now mature enough for industry to leverage.



Below is a list of enablers, their definitions and relevance for smart manufacturing.
Where there is no relevant ISO or IEC definition, a tentative definition was given.

A.1 Connectivity

Definition

5G is the fifth generation of wireless communications technologies supporting cellular data networks
[SOURCE: 3GPP]

Relevance

Connectivity, such as wireless connectivity through 5G, is an enabler for smart manufacturing since its speed, stability and reliability are high enough to fit industrial applications. This implies that intelligence/ tasks, that traditionally have resided locally within the factory, now can be moved into the cloud and managed remotely. This is foreseen to increase performance, cost-efficiency and flexibility in the factories.

The performance of 5G's predecessors (i.e. 4G, 3G etc.) was suitable for personal applications such as voice and videos on mobile platforms, but it was insufficient for industrial applications. With the new advancements in wireless connectivity, industrial applications can leverage wireless technology and connectivity.

A.2 Cloud computing

Definition

cloud computing: paradigm for enabling network access to a scalable and elastic pool of shareable physical or virtual resources with self-service provisioning and administration on-demand
Note 1 to entry: Examples of resources include servers, operating systems, networks, software, applications, and storage equipment.
[SOURCE: ISO/IEC 17788:2014, 3.2.5 (JTC1/SC38)]

Relevance

Just as Moore's Law has continually expanded the calculation power of individual computing devices, the parallel advances in distributing computing over the last several decades have expanded the capacity, power and efficiency of working across these devices as a collective.

Cloud computing is the most recent advancement in distributed computing. It has emerged as the most efficient and powerful form of distributed computing yet and it is still improving and expanding. Cloud computing enables network access to a scalable and elastic pool of shareable physical or virtual resources with self-service provisioning and administration on-demand. This flexible distribution of data and computation provides new efficiencies across a spectrum of devices located on-premise, on the edge, or in high capacity data centers—using private, public or hybrid cloud deployment models. This enables one to choose the most efficient place to process their data, whether it be local data emerging from devices at the edge, or central collections of data in a data center. This powerful new paradigm allows wider access to modern sophisticated computing platforms without upfront capital investment, and with a pay-as-you-go flexibility.

Cloud computing itself has enabled the emergence of other powerful enablers like Big Data and Artificial Intelligence, which themselves drive further abilities in smart manufacturing. From product design, to supply chains, to factory floor automation, cloud computing plays a role in expanding the capacity, efficiency and power of all aspects of smart manufacturing.

A.3 Industrial security

Definition 1
security: state of being free from danger or threat
[SOURCE: ISO 22300:2021, 3.1.239, modified (ISO/TC 292)]

Definition 2
Information security: preservation of confidentiality, integrity and availability of information.
[SOURCE: ISO/IEC 27000 :2018, 3.28 (ISO/IEC JTC 1/SC 27)]

Definition 3
cybersecurity: preservation of confidentiality, integrity and availability of information in the Cyberspace
[SOURCE: ISO/IEC 27032:2012, 4.20, modified (ISO/IEC JTC 1/SC 27)]

Relevance
Security is, as an enabler, a basic requirement for smart manufacturing and trustworthy cooperation along industrial value chains. "Industrial security" denotes the holistic protection of information technology in production systems, as well as of machines and plants against sabotage, espionage, or manipulation. The expectation of trustworthiness has become increasingly important along the value creation chain. This heightens the importance of protection and proof of the integrity of data, systems, and processes along a "supply chain", which will be reflected in future standards. Also, data protection (privacy/IPR protection) and functional security are typical protection goals within the industrial environment.

The various security requirements also are determined by real-time and robustness requirements, and requirements for the continuous availability of industrial plants. At the same time, it is essential for industrial security to implement end-to-end security architectures that cover both the IT areas and the OT areas of a company (or an entire smart manufacturing application scenario across company boundaries). Thus, there is an increasing need to protect industrial applications and systems directly (i.e. at application level) rather than relying on network security mechanisms alone.

Also, the protection of applications supported by artificial intelligence mechanisms creates new requirements and needs for standards: Here, security functions should ensure that an application delivers exactly the functionality that the user expects in terms of trustworthiness, without the result being falsified by manipulation of input data or function components. The classic integrity protection of data or components and systems is faced with completely new challenges.

The development principle "Security by Design" is generally accepted, i.e. security functions are integrated into the planning, development and manufacturing process from the beginning, which means that appropriate process and technical standards, as well as requirement and certification standards are particularly necessary.

International standardization activities in the field of industrial security that also support future quality assurance processes are taking place especially in ISO/TC 292, ISO/IEC JTC1 (WG13, SC17, SC27, SC41, SC42), IEC/TC65, and IECEE CMC WG31.

A.4 Blockchain

Definition
blockchain: distributed ledger with confirmed blocks organized in an append-only, sequential chain using cryptographic links
Note 1 to entry: Blockchains are designed to be tamper resistant and to create final, definitive and immutable ledger records.
[SOURCE: ISO 22739:2020, 3.6 (ISO/TC 307)]

Relevance
A blockchain is, succinctly, an encrypted and sequential encrypted interlinked set of records (ledgers) that is usually duplicated and distributed across multiple storage units or nodes. Blockchains can be implemented in either a private, closed system with pre-approved users, or as open public systems where anonymous users can manipulate the ledgers using a distributed

authentication algorithm. A blockchain-based application, if properly implemented and operated, is tamper-proof since, once a block of data is recorded on a blockchain ledger, it is practically impossible to change or remove. Blockchain technologies can be used for any transactional and document/information management systems.

In smart manufacturing, blockchains can be used, for instance, to further automate in a secure fashion the supply chain, to implement tamper-proof digital threads (for life cycle asset and product management) and to enable secure automated registration and software update of IoT devices.

A.5 Robotics

Definition 1
robotics: science and practice of designing, manufacturing, and applying robots
[SOURCE: ISO 8373:2012, 2.16 (ISO/TC 184/SC 2, which was replaced by ISO/TC 299)

Definition 2
robot: actuated mechanism programmable in two or more axes with a degree of autonomy, moving within its environment, to perform intended tasks
Note 1 to entry: A robot includes the control system and the interface of the control system.
Note 2 to entry: the classification of robot into industrial robot or service robot is done according to its intended application.
[SOURCE: ISO 8373:2012, 2.6 (ISO/TC 184/SC 2)]

Definition 3
industrial robot: automatically controlled, reprogrammable multi-purpose manipulator, programmable in three or more axes, which can be either fixed in place or mobile for use in industrial automation applications
Note 1 to entry: The industrial robot includes: the manipulator, including actuators, the controller, including teach pendant and any communication interface (hardware and software).
Note 2 to entry: This includes any integrated additional axes.
[SOURCE: ISO 8373:2012, 3.10 (ISO/TC 184/SC 2)]

Relevance
Robotics has been a core pillar in manufacturing for several decades and is a hugely valuable industry today. As statistics reveal, growth in the robotics industry continues to be explosive. Since the installation of the first industrial robot in the 1970s, the sector has continuously expanded into new markets and developed new applications. Today robotics is no longer a technology for only manufacturing but has evolved to also address much wider range of applications and domains where a variety of services are provided to different end users. Robot and robot systems can also be part of Integrated Machine Systems where such IMS should be considered as a new and different machine rather than simply its parts combined.

A.6 Augmented Reality

Definition 1
augmented reality: interactive experience of a real-world environment whereby the objects that reside in the real world are augmented by computer-generated perceptual information
[SOURCE: ISO/IEC 18038:2020, 3.2 (ISO/IEC JTC1/SC 24)]

Definition 2
visualization: technique for creating images, diagrams, or animations to communicate a message
[SOURCE: ISO/TR 24464:2020, 3.1.14 (ISO/TC 184/SC 4)]

Relevance
Augmented Reality (AR) characterizes an interactive experience of a real-world environment where the objects that reside in the real world are augmented by computer-generated perceptual information. Mixed Reality (MR) merges real and virtual worlds to generate a new environment where physical and synthetic objects co-exist and interact (ISO/IEC 18038).

Smart manufacturing employs computer-integrated manufacturing and digital information technology. It provides interoperable systems, multi-scale dynamic modeling and simulation for manufacturing. It includes intelligent automation, cyber security, networked sensors, and big data processing capabilities. Industrial connectivity devices and services support smart manufacturing, and robotics plays a key role in its advancement. In summary, smart manufacturing is based on automation, sensors, intelligent machines, big data, AR/MR, digital twin, and robotics.

For smart manufacturing to function, information access and simulation to/from machines should be provided as part of device usage. This requires connectivity with real world sensors and simulation in a virtual world for sensor representation, control and management. AR and MR provide the functionalities between real and virtual worlds to achieve smart manufacturing.

For smart manufacturing, AR/MR provides design capabilities for manufacturing objects and facilities, visualization of sensor functions and manufacturing objects and facilities, and simulation of sensor-generated data and functions. It provides connectivity and communication between real and virtual worlds, and monitoring of sensor functions with data visualization, and management of manufacturing objects and facilities.

Applications for smart manufacturing with AR/MR include smart factory, facility management and security, manufacturing data visualization, manufacturing process visualization, manufacturing data monitoring, etc.

A.7 Additive manufacturing

Definition 1

additive manufacturing: process of joining materials to make parts from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies

[ISO/ASTM 52900:2015, 2.1.2 (ISO/TC 261)

Definition2

additive manufacturing: various processes in which material is joined or solidified under computer control to create a three-dimensional object

[SOURCE: IEC 63339, (IEC/TC 65 – ISO/TC 184 JWG 21]

Relevance

Additive manufacturing is within the scope of ISO/TC 261, *Additive manufacturing*, in cooperation with ASTM F42, *Additive Manufacturing Technologies*, on the basis of a partnership agreement between ISO and ASTM International with the aim to create a common set of ISO/ASTM standards on additive manufacturing. From ISO/ASTM 52900, additive manufacturing is the general term for those technologies that based on a geometrical representation create physical objects by addition of material. These technologies are undergoing a rapid rate of development and expansion in material properties, machine tool enhancements and production processes. Multiple material systems are being enhanced in metals, polymers, ceramics and composites.

Additive manufacturing is defined by process categories and is used to provide a general, structural distinction between different AM processes, based on the process architecture and typical process characteristics.

In the additive process, entire paradigms of engineering design are challenged. New and never-before imagined designs are emerging from the optimization methods for structural design that are not limited by the removal of materials found in subtractive processes. In this fashion, smart manufacturing and additive are highly complementary concepts where the information technology enhancements from a smart system are used to provide information to the additive design itself. Further, additive technologies bring the ability to create customized product based on the detailed information at the point of design. With smart machines embedded within the additive manufacturing process, smart products tailored to the individual use are possible.

A.8 Simulation

Definition 1

simulation: approximated imitation of selected behavioural characteristics of one physical or abstract system by a static or dynamic model

[SOURCE: ISO/TR 4804:2020, 3.56 (ISO/TC 22)]

Definition 2

modeling and simulation: discipline that comprises the development and/or use of models and simulations

Note 1 to entry: The use of models – physical, mathematical, or otherwise logical representations – as a basis for simulations – to develop data for managerial or technical decision making covering analysis, experimentation, and training enables understanding a system's behaviour without actually testing the system in the real world.

[SOURCE: DoD 5000.61:2009-12-09, (Modeling and Simulation Verification, Validation, and Accreditation), modified – Note 1 to entry has been added].

Relevance

A simulation is, succinctly, the dynamic execution of a model of a real or abstract system. A simulation can be used to virtually prototype a system and compare alternative designs. Simulations are also at the core of digital twins.

In smart manufacturing, in addition to the implementation of digital twin, simulation can be used not only in the engineering of products, but also to engineer and optimize all the processes such as the supply chain.

A.9 Internet of Things

Definition 1

Internet of Things: infrastructure of interconnected objects, people, systems and information resources together with intelligent services to allow them to process information of the physical and the virtual world and to react
[SOURCE: ISO/IEC 23093-1:—, 3.2.9 (ISO/IEC JTC 1/SC 29)]

Relevance

The Internet of Things (IoT) is a system concept that uses many technologies that are standardized by other ISO/IEC JTC 1 entities and other SDOs ranging from networking, big data, digital twin to cloud computing and AI.

IoT systems are software and data intensive as well as network centric. They can be quite complex, ranging from simple architecture to multi-tier distributed computing cyberphysical systems. IoT sensor data is used for analytic applications, to train AI systems, build and synchronize digital twins and in implementing cyber-physical systems.

In an industrial setting, the convergence of operational technologies (OT) and information technologies (IT) is giving rise to the Industrial Internet of Things.

The IoT is thus a key enabler for smart manufacturing since it enables an entity (human or machine) to make a decision using 'real-time' sensor data and historical data and act on it, either through human intervention or directly in a machine-to-machine mode using actuators.

A.10 Artificial Intelligence (AI)

Definition 1

artificial intelligence: <engineered system> set of methods or automated entities that together build, optimize and apply a model so that the system can, for a given set of predefined tasks, compute predictions, recommendations, or decisions
Note 1 to entry: AI systems are designed to operate with varying levels of automation.
Note 2 to entry: Predictions can refer to various kinds of data analysis or production (including translating text, creating synthetic images or diagnosing a previous power failure). It does not imply anteriority.
[SOURCE: ISO/IEC 22989:—, 3.1.2 (ISO/IEC JTC 1/SC 42)]

Definition 2

artificial intelligence: <discipline> study of theories, mechanisms, developments and applications related to artificial intelligence <engineered system>
[SOURCE: ISO/IEC 22989:—, 3.1.3 (ISO/IEC JTC 1/SC 42)]

Relevance

This section covers the horizontal work related to artificial intelligence, big data and the data ecosystem related to AI, big data and analytics. The work is being developed in ISO/IEC JTC 1/SC 42.

Artificial Intelligence is an enabler for smart manufacturing since it provides an ability to compute large amounts of data to produce insights. For example:

- AI technologies will enable insights and analytics that go far beyond what legacy analytic systems could provide in terms of both efficiency, speed and applications that have yet to be envisioned. This is a radical departure from the way analytic systems have traditionally been designed akin to the "plug and play" approach over a decade ago in enterprise and consumer applications.
- Big data technologies will streamline and, in many cases, enable analytics to be performed on massive data sets by architecting compute systems around how the data sets will be generated and used in a particular application. This is a departure from applying the same compute system to an application regardless of what the data looks like such as its variety, volume, variability etc.

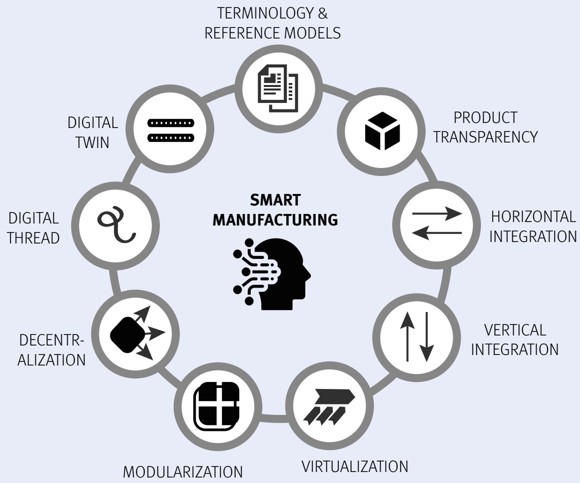
In addition to enabling the services that are at the cornerstone of digital transformation, the work of ISO/IEC JTC 1/SC 42 goes further in addressing some of the concerns, usage and application of them. For instance:

- Data quality standards for machine learning and analytics are crucial in ensuring that the applied technologies produce useful insights and eliminate faulty ones.
- Governance standards in the areas of AI and business process framework for big data analytics address how the technologies can be governed and managed from a management perspective.
- Standards that address trustworthiness, ethics and societal concerns will ensure rapid deployment while addressing such concerns from the start.

ISO/IEC JTC 1/SC 42 is also working on a novel approach to help ensure confidence when technologies like AI are used in areas like smart manufacturing through a management systems standard. Together, these technologies and standards will enable smart manufacturing applications. It should be noted that these technologies will not operate in isolation but together with emerging operational technologies and other IT technologies.

Annex B – Enhancers their definitions and relevance to smart manufacturing

Enhancers are vital in order to enhance the development from traditional manufacturing to smart manufacturing.



Below is a list of enhancers, their definitions and relevance to smart manufacturing.
Where there is no relevant ISO or IEC definition, a tentative definition was given.

B.1 Terminology and reference models

Definition 1

terminology: a new term is defined by a short description explaining its meaning

Note to entry: Many ISO working groups are defining terms that are of relevance for smart manufacturing. The work is coordinated by ISO SMCC. Similar work is done in IEC SyC SM WG2.
[SOURCE: SMCC definition]

Definition 2

reference model : a framework for understanding significant relationships among the entities of some environment, and for the development of consistent standards or specifications supporting that environment. A reference model is based on a small number of unifying concepts and may be used as a basis for education and explaining standards to a non-specialist.
[SOURCE: ISO 14721:2012, 1.7.2 (ISO/TC 20/SC 13)]

Relevance

A smart manufacturing system is a complex system of systems, where many collaborating, competing and possibly conflicting systems are connected in federated and/or integrated ways. The system development and maintenance activities are also complex and require appropriate standardized interfaces and harmonized business processes to reduce that complexity. Modelling provides systematic methods supporting the whole life cycle of system development, usage and retirement, allowing all the SM benefits while managing the complexity. A SMRM thus provides a framework for preparation of interoperability as well as guidance for architecture derivation and system design. To summarize, SMRM can be used by SM system developers and users to support the development process, and by SM standard developers to ensure coherence and compatibility in the developed body of standards.

Modeling is a very effective approach to systematize system development and operation activities by use of advanced information technology. A reference model provides insight into the aspects of a system to consider when developing a new system or modifying an existing system and provides mechanisms for conducting that development or modification. Reference models provide a common basis for the development of individual systems and enable their interpretation as a whole system by reuse of the common characteristics of the individual systems.

The intent of the meta-model is to provide a meta-language for representing concepts and relationships to be used by standards developers as they identify and document a SMRM. The meta-model specified here is an abstraction of the concepts and relationships evident in the contributions for SMRMs. Because the meta-model needs to be useful for discussing this wide range of models, the meta-model is rather abstract and imprecise, sometimes stretching our conventional word meaning to extend coverage for different situations.

Use cases are a critical approach to understanding the ways in which processes, information, resources, and organizations operate for successful manufacturing, today and in the future. In addition to capturing the utility of use cases, using guides similar to those created using IEC 62559, the meta-model utilizes concepts from ISO/IEC/IEEE 42010 and ISO 15704.

B.2 Product transparency

Definition missing.

B.3 Horizontal integration

Definition
horizontal integration: integration within a functional/ organizational hierarchical level across system boundaries
[SOURCE: IEC/TR 63283-1:—(IEC/TC 65)]

B.4 Vertical integration

Definition missing.

B.5 Virtualization

Definition
virtualization: act of creating a virtual (rather than actual) version of something, including virtual computer hardware platforms, storage devices, and computer network resources
[SOURCE: www.wikipedia.uk]

B.6 Modularization

Definition missing.

Relevance
Modularization is a concept that originates in product strategy that seeks to maximize the investment made in product engineering. Leveraging the fundamental concept of subdivision, modularization relies on a modular design approach where components or elements are reusable across product offerings.

Modularization relies on reusable components that can be used in multiple scenarios. From a standards perspective, the standardization of the part geometry and the product information is critical. Two standards provide functionality to address the modularization use case. ISO 10303, Product data representation and exchange, defines a computer interpretable data schema for the product geometry and associated engineering requirements. ISO 13584, Parts library, defines the requirements for a reusable product library that can be used by modern computing systems to contain the product design content and supporting characteristics of a design intended for reuse.

B.7 Decentralization

Definition missing.

Relevance
IEC 61499 defines a generic architecture and presents guidelines for the use of function blocks in distributed industrial-process measurement and control systems (IPMCSs). This architecture is presented in terms of implementable reference models, textual syntax and graphical representations

B.8 Digital twin

Definition 1
digital twin: digital representation of a particular entity or process with data connections that (1) enable convergence between the physical and digital states at an appropriate rate of synchronization, (2) has the capabilities of connection, integration, analysis, simulation, visualization, optimization and (3) provides an integrated view throughout the lifecycle of the entity or the process
[SOURCE: ISO/IEC 30173:—, ISO/IEC JTC 1/SC 41]

Definition 2

digital twin: compound model composed of a physical asset, an avatar and an interface
[SOURCE: ISO/TR 24464:2020, 3.1.4 (ISO/TC 184/SC 4)]

Definition 3

digital twin: digital asset on which services can be performed that provide value to an organization
Note 1 to entry: The descriptions comprising the digital twin can include properties of the described asset, IIOT collected data, simulated or real behavior patterns, processes that use it, software that operates on it, and other types of information.
Note 2 to entry: The services can include simulation, analytics such as diagnostics or prognostics, recording of provenance and service history.
[SOURCE: ISO/TS 18101-1:2019, 3.9 (ISO/TC 184/SC 4)]

Definition 4

digital twin: ‹manufacturing› fit for purpose digital representation of an observable manufacturing element with a means to enable convergence between the element and its digital representation at an appropriate rate of synchronization
[SOURCE: ISO 23247-1:—, (ISO/TC 184/SC4/WG15)]

Definition 5

digital twin: digital replica of physical assets (physical twin), processes and systems that can be used for various purposes
[SOURCE: IEC/TC 65 – ISO/TC 184 JWG 21]

Definition 6

digital twin: fit for purpose digital representation of some realized thing(s) or process(es) with a means to enable convergence between the realized instance and digital instance at an appropriate rate of synchronisation
[SOURCE: ISO/TC184/AG 2)]

Relevance

Digital twin is a concept that will enhance the development and realization of smart manufacturing since, being based on measurements that create an evolving profile of the object or process in the digital world, it provides important insights on system performance, leading to actions in the physical world such as a change in product design or manufacturing process. It can thus also help optimize business performance.

According to consultancies Gartner and Deloitte, a digital twin is a digital representation of a real-world entity or system. It is an evolving digital profile of the historical and current behaviour of a physical object or process.

The implementation of a digital twin is an encapsulated software object or model that mirrors a unique physical object, process, organization, person or other abstraction. The digital twin is thus based on massive, cumulative, real-time, real-world data measurements across an array of dimensions.

Data from multiple digital twins can be aggregated for a composite view across a number of real-world entities, such as a building, a factory or a supply-chain.

Mirroring is done through synchronization using data streams. The data streams are generated by sensors, but also transactions and other sources.

B.9 Data quality

Definition 1

data quality: degree to which a set of inherent characteristics of data fulfils requirements
[SOURCE: ISO 8000-2:2020, 3.8.1 (TC 184/SC 4)]

Definition 2

data quality: degree to which the characteristics of data satisfy stated and implied needs when used under specified conditions
[SOURCE: ISO/IEC 25024:2015, 4.11 (ISO/IEC JTC 1/SC 7)]

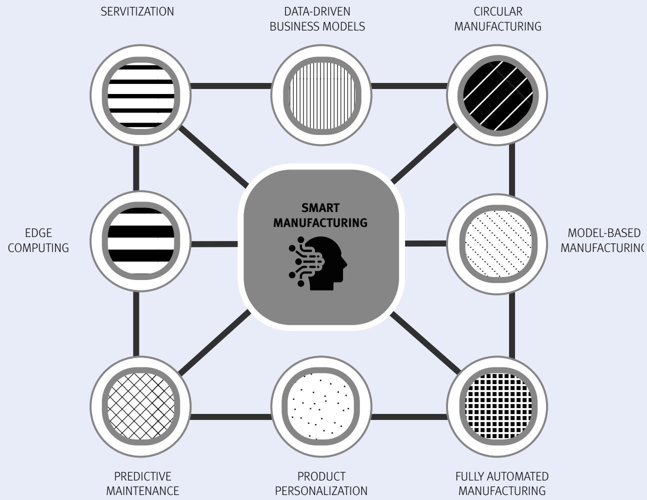
Relevance

ISO 8000-1, *Data quality – Part 1: Overview, provides a framework for data quality and lays out the requirements for a data quality system*.

Note: ISO/IEC JTC 1/SC 42 is developing the ISO/IEC 5259 series on data quality for analytics and ML (machine learning).

Annex C – Effects and their definitions

Effects indicate new disruptive scenarios that will form, gain acceptance and rule out current scenarios.



Below is a list of effects, their definitions and relevance to smart manufacturing.
Where there is no relevant ISO or IEC definition, a tentative definition was given.

C.1 Data-driven business models

Definition
data-driven business models: business models that are developed based on data from the business
[SOURCE: SMCC working definition]

C.2 Circular manufacturing

Definition 1
circular manufacturing: possibility to take advantage of retired products and their collected lifecycle information, filter out the essence, and use feedback for improving the manufacturing processes as well as the product itself
[SOURCE: SMCC working definition]

Definition 2
circular manufacturing: manufacturing system that is designed intentionally for closing the loop of products/components preferably in their original form, through multiple lifecycles

Note 1 to entry: This is a value management approach which includes value creation, delivery, use, recovery, and reuse in a systemic perspective.
[SOURCE: SMCC working definition]

C.3 Model-based manufacturing

Definition 1
model-based manufacturing: the conveyance of product design data from the engineering domain to the manufacturing domain
[SOURCE: ISO 10303-238:2020 (ISO/TC 184/SC 4)]

Definition 2
model-based enterprise (MBE): a term used in manufacturing, to describe a strategy where an annotated digital three-dimensional (3D) model of a product serves as the authoritative information source for all activities in that product's lifecycle
[SOURCE: **www.wikipedia.uk**]

C.4 Fully automated factories

Definition
fully automated factories: extensive use of new technologies making the human worker obsolete, and thus allowing for factories where conditions such as light are of no importance

Note to entry: Fully automated factories can also be known as lights-out factories or dark factories.
[SOURCE: SMCC working definition]

C.5 Product personalization

Definition 1
product personalization: ability to make each individual product customized for a specific person
[SOURCE: SMCC working definition]

Definition 2
product personalization: ability to make the right product, for the right person, at the right time
[SOURCE: SMCC working definition]

C.6 Predictive maintenance

Definition 1
predictive maintenance: possibility to act prior to an unfavourable event, like failure
[SOURCE: SMCC working definition]

Definition 2
predictive maintenance: techniques, [which] are designed to help determine the condition of in-service equipment in order to estimate when maintenance should be performed
[SOURCE: **www.wikipedia.uk**]

Definition 3
condition-based maintenance: maintenance performed as governed by condition monitoring programmes
[SOURCE: ISO 13372:2012, 1.2 (ISO/TC 108)]

C.7 Edge computing

Definition 1
edge computing: eistributed computing in which processing and storage takes place at or near the edge, where the nearness is defined by the system's requirements
[SOURCE: ISO/IEC TR 23188:2020, 3.1.3 (ISO/IEC JTC 1/SC 38)]

Definition 2
distributed computing: model of computing in which a set of nodes coordinates its activities by means of digital messages passed between the nodes
[ISO/IEC TR 23188:2020, 3.1.1 (ISO/IEC JTC 1/SC 38)]

Definition 3
edge computing: methods for optimizing computing systems by placing control in applications/services that directly contact the physical world, rather than in central nodes
[SOURCE: IEC 63339:— (IEC/TC 65 JWG 21)]

C.8 Servitization

Definition 1
servitization: manufacturing capability results from supplier-based integration of production systems and devices with value adding services often provided in real-time and based on analytics of measured data
[SOURCE: IEC 63339:— (IEC/TC 65 JWG 21)]

Definition 2
servitization: the act of selling the outcome of a product as a service rather than selling the product itself
[SOURCE: SMCC working definition]

Annex D – Standards development organizations

ISO, IEC and ITU are three separate standards development organizations, which cooperate under the banner of the World Standards Cooperation.

Every country in the world can participate in the standardization work of these organizations. This is normally done by setting up a national mirror committee which can a) provide input to the standards developed by ISO, IEC and ITU, and b) vote on the draft standards before they are published. This process ensures that the standards delivered by ISO, IEC and ITU are consensus driven and globally relevant.

The technical work in ISO and IEC is overseen by the Technical Management Board (TMB) and the Standardization Management Board (SMB), respectively. ISO has more than 250 technical committees, and IEC has more than 100. Each TC is dedicated to a certain area of expertise, e.g. ISO/TC 184 is Automation systems and integration, IEC/TC 65 is Industrial-process measurement, control and automation. In order to take care of overlapping work in the field of Information Technology, IEC and ISO have a Joint Technical Committee (JTC1).

Technical committees may be broken down into subcommittees (SCs), and then further into working groups (WGs). Technical experts, appointed by national mirror committees and certain approved liaison organizations, participate in the development process in the WGs.

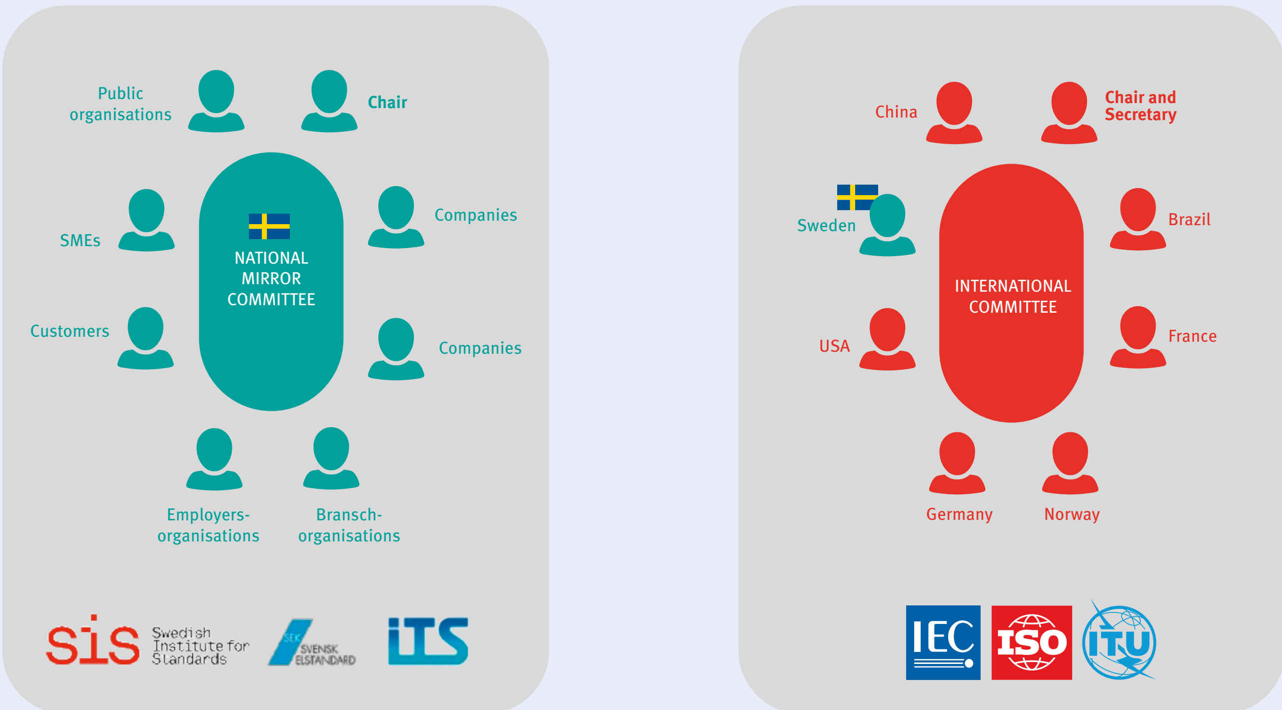


Figure 8: Typical composition of national mirror committees, exemplified by Sweden (left) and of international technical committees (right)

Annex E – About the authors (listed in alphabetical order)

1. **Coallier, François (Canada):** *Chair of ISO/IEC JTC1/SC41 (Internet of Things and Digital Twin) as well as actively participating in many other JTC 1 and IEC entities. Dr Coallier is also full professor at the Department of Software and IT Engineering at the École de technologie supérieure (ÉTS) in Montréal, Québec, Canada.*
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11. **Wennblom, Philip (USA):** *Chair ISO/IEC JTC1 (Information Technology). P. Wennblom is also Senior Director for Standards Policy at Intel Corporation.*

References

1. **ISO/TR 4804,** *Road vehicles — Safety and cybersecurity for automated driving systems — Design, verification and validation*
2. **ISO/IEC 5259,** *Data quality for analytics and ML*[1)]
3. **ISO 8000-1,** *Data quality – Part 1: Overview*
4. **ISO 8000-2,** *Data quality — Part 2: Vocabulary*
5. **ISO 8373,** *Robotics — Vocabulary*
6. **ISO 10303-1,** *Industrial automation systems and integration — Product data representation and exchange — Part 1: Overview and fundamental principles*
7. **ISO 10303-209,** *Industrial automation systems and integration — Product data representation and exchange — Part 209: Application protocol: Multidisciplinary analysis and design*
8. **ISO 10303-233,** *Industrial automation systems and integration — Product data representation and exchange — Part 233: Application protocol: Systems engineering*
9. **ISO 10303-238,** *Industrial automation systems and integration — Product data representation and exchange — Part 238: Application protocol: Model based integrated manufacturing*
10. **ISO 10303-239,** *Industrial automation systems and integration — Product data representation and exchange — Part 239: Application protocol: Product life cycle support*
11. **ISO 10303-242,** *Industrial automation systems and integration — Product data representation and exchange — Part 242: Application protocol: Managed model-based 3D engineering*
12. **ISO 10303-243,** *Industrial automation systems and integration — Product data representation and exchange — Part 243: Application protocol: For modelling and simulation information in a collaborative systems engineering context (MoSSEC)*[2)]
13. **ISO 13372,** *Condition monitoring and diagnostics of machines — Vocabulary*
14. **ISO 14721,** *Space data and information transfer systems — Open archival information system (OAIS) — Reference model*
15. **ISO 15704,** *Enterprise modelling and architecture — Requirements for enterprise-referencing architectures and methodologies*
16. **ISO/IEC 17788,** *Information technology — Cloud computing — Overview and vocabulary*
17. **ISO/IEC 18038,** *Information technology — Computer graphics, image processing and environmental representation — Sensor representation in mixed and augmented reality*
18. **ISO/TS 18101-1,** *Automation systems and integration — Oil and gas interoperability — Part 1: Overview and fundamental principles*
19. **ISO 22300,** *Security and resilience — Vocabulary*
20. **ISO 22739,** *Blockchain and distributed ledger technologies — Vocabulary*
21. **ISO/IEC 22989,** *Information technology — Artificial intelligence — Artificial intelligence concepts and terminology*[3)]
22. **ISO/IEC 23093-1,** *Information technology — Internet of media things — Part 1: Architecture*[4)]
23. **ISO/IEC TR 23188,** *Information technology — Cloud computing — Edge computing landscape*
24. **ISO 23247-1,** *Automation systems and integration — Digital Twin framework for manufacturing — Part 1: Overview and general principles*[5)]
25. **ISO/TR 24464,** *Automation systems and integration — Industrial data — Visualization elements of digital twins*
26. **ISO/IEC 25024,** *Systems and software engineering — Systems and software Quality Requirements and Evaluation (SQuaRE) — Measurement of data quality*
27. **ISO/IEC 27000,** *Information technology — Security techniques — Information security management systems — Overview and vocabulary*

1) Under development.
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5) To be published.

28. ISO/IEC 27032, *Information Technology — Cybersecurity — Guidelines for Internet Security*

29. ISO/IEC 30173, *Digital twin – Concepts and terminology*[6)]

30. ISO/IEC/IEEE 42010, *Software, systems and enterprise — Architecture description*

31. ISO/ASTM 52900, *Additive manufacturing — General principles — Fundamentals and vocabulary*

32. IEC 62559, *Use case methodology*

33. IEC/TR 63283-1, *Industrial-process measurement, control and automation – Smart Manufacturing – Part 1: Terms and definitions*[7)]

34. ISO/IEC TR 63306-1, *Smart manufacturing standards map (SM2) — Part 1: Framework*

35. ISO/IEC TR 63306-2, *Smart manufacturing standards map (SM2) — Part 2: Catalogue*[8)]

36. IEC 63339, *Unified reference model for smart manufacturing*[9)]

37. DoD 5000.61:2009-12-09, Modeling and Simulation (M&S) Verification, Validation, and Accreditation

38. Digital Thread for Smart Manufacturing, NIST Systems Engineering Group at https://www.nist.gov/programs-projects/digital-thread-smart-manufacturing

39. OpenLearn (2019): Free course “Organisations, environmental management and Innovation”, https://www.open.edu/openlearn/nature-environment/organisations-environmental-management-and-innovation/content-section-1.7

40. AnalyticsExplained (2013): Article in press https://analyticsexplained.com/the-s-curve-pattern-of-innovation-a-full-analysis/

41. Moore (xxxx): https://en.wikipedia.org/wiki/Moore%27s_law

42. IT/OT convergence: https://www.cigref.fr/wp/wp-content/uploads/2020/02/Cigref-IT-OT-Convergence-Fruitful-integration-information-operational-systems-December-2019-EN.pdf

43. Additive Manufacturing: ISO/ASTM 52900

44. DIN and DKE ROADMAP German Standardization Roadmap Industrie 4.0, V.4: https://www.din.de/en/innovation-and-research/industry-4-0/german-standardization-roadmap-on-industry-4-0-77392

45. Strategic Advisory Group on Industry 4.0/smart manufacturing – Final report to TMB, Annex C, 2019

46. https://etech.iec.ch/issue/2019-06/ai-standards-help-accelerate-digitalization-of-smart-manufacturing

47. https://blog.iec.ch/2020/01/important-questions-around-ai-technologies-in-smart-manufacturing/

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