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SERIES Y: GLOBAL INFORMATION INFRASTRUCTURE, INTERNET PROTOCOL ASPECTS, NEXT-GENERATION NETWORKS, INTERNET OF THINGS AND SMART CITIES

Internet of things and smart cities and communities – General

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Overview of smart manufacturing in the context of the industrial Internet of things

Recommendation ITU-T Y.4003

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Recommendation ITU-T Y.4003

Overview of smart manufacturing in the context of the industrial Internet of things

Summary

Recommendation ITU-T Y.4003 provides an overview of smart manufacturing in the context of the industrial Internet of things (IIoT). The Recommendation first introduces smart manufacturing and IIoT, including the smart manufacturing capabilities with respect to the Internet of things (IoT) reference model [ITU-T Y.4000]. Then, with respect to smart manufacturing in the context of the IIoT, it identifies fundamental system characteristics and high-level requirements, specifies a reference model and provides some use cases.

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1 Scope

This Recommendation provides an overview of smart manufacturing in the context of the industrial Internet of things (IIoT).

The Recommendation first introduces smart manufacturing and IIoT, including the smart manufacturing capabilities with respect to the Internet of things (IoT) reference model [ITU-T Y.4000]. Then, with respect to smart manufacturing in the context of the IIoT, it identifies fundamental system characteristics and high-level requirements, specifies a reference model and provides some use cases.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T Y.4000] Recommendation ITU-T Y.4000/Y.2060 (2012), *Overview of the Internet of things*.

[ITU-T Y.4100] Recommendation ITU-T Y.4100/Y.2066 (2014), *Common requirements of the Internet of things.*

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following term defined elsewhere:

3.1.1 Internet of things (IoT) [ITU-T Y.4000]: A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies.

NOTE 1 – Through the exploitation of identification, data capture, processing and communication capabilities, the IoT makes full use of things to offer services to all kinds of applications, whilst ensuring that security and privacy requirements are fulfilled.

NOTE 2 – From a broader perspective, the IoT can be perceived as a vision with technological and societal implications.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 smart manufacturing: A generic term for advanced processes, systems, methods and organizations throughout the manufacturing ecosystem based on advanced computing and manufacturing technologies, as well as existing and evolving interoperable information and communication technologies, aiming to integrate this ecosystem, innovate the development of products and services and improve the efficiency and reliability of manufacturing's life-cycle management, together with increasing performance, safety and environmental sustainability.

NOTE –The concept of smart manufacturing encompasses all aspects of the manufacturing activities, from design, sales, production, logistics and service.

3.2.2 industrial Internet of things (IIoT): An Internet of things based enabling approach for industrial transformation, by taking advantage of existing and emerging information and communication technologies.

NOTE 1 – Emerging information and communication technologies include technologies for smart machines, robots, advanced industrial networks, industrial cloud computing and industrial data processing.

NOTE 2 – The industrial transformation enabled by the industrial Internet of things empowers the industry with, but not limited to, improved efficiency, intelligent production, reduced energy consumption, advanced collaboration modes and new business models. Industrial Internet of things enables smart manufacturing providing enhanced capabilities in support of manufacturing.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

3D	three-dimensional
4M1E	Man, Machine, Material, Method and Environment
CRM	Customer Relationship Management
DCS	Distributed Control System
ERP	Enterprise Resources Planning
FCS	Fieldbus Control System
HMI	Human Machine Interface
ICT	Information and Communication Technology
IIoT	Industrial Internet of things
IoT	Internet of things
MES	Manufacturing Execution System
PLC	Programmable Logic Controller
PLM	Product Life-cycle Management
QCD	Quality, Cost, Delivery
QR	Quick Response
RFID	Radio Frequency Identification
SCADA	Supervisory Control and Data Acquisition
SCM	Supply Chain Management

5 Conventions

In this Recommendation:

The keywords "is required to" indicate a requirement which must be strictly followed and from which no deviation is permitted if conformance to this Recommendation is to be claimed.

6 Introduction of smart manufacturing in the context of the industrial Internet of things

6.1 Overview of smart manufacturing from the functional layering perspective

Smart manufacturing has the potential to fundamentally change how products are designed, manufactured, supplied, used, re-manufactured and eventually retired.

As shown in Figure 1, smart manufacturing can be represented from the functional layering perspective via three layers, respectively, application layer, integration layer and life-cycle management layer.

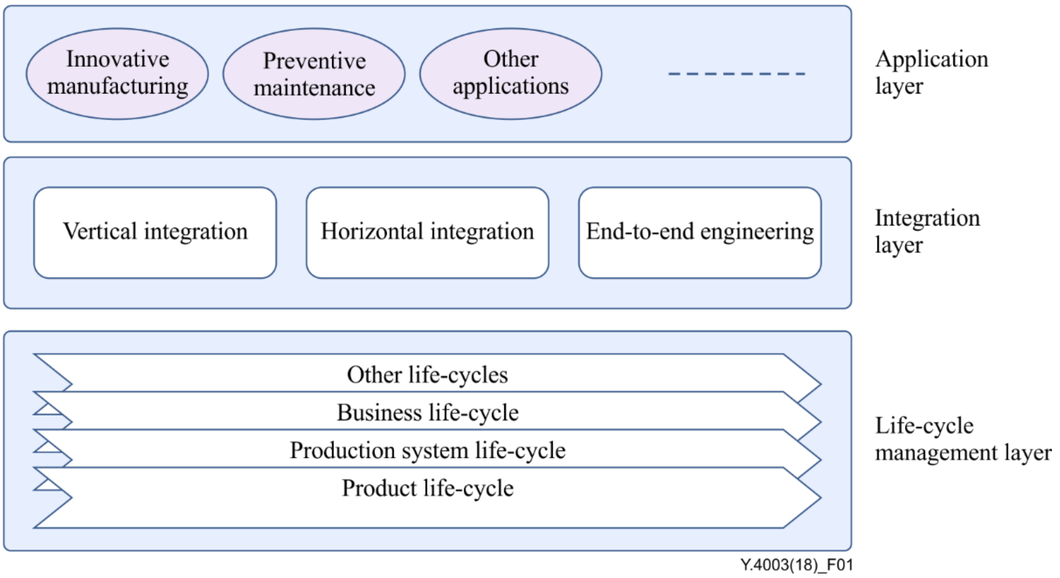

Figure 1 – Overview of smart manufacturing from the functional layering perspective

The life-cycle management layer encompasses a broad scope of systems in the manufacturing business, including those for production, management, design and engineering support.

In terms of smart manufacturing process phases and involved stakeholders, this layer addresses product life-cycle, production system life-cycle and business life-cycle. Other life-cycles, with respect to specific manufacturing business scenarios, may be addressed too.

The product life-cycle concerns the product development, the engineering of the corresponding production system, the manufacturing of the product by the production system, the use of the manufactured product by the user, and the product's recycling and/or dismantling. The product life-cycle deals with the information flows and controls from the early product design phase until the product end-of-life. All information generated over the life-cycle is linked through the entire process. The production system life-cycle focuses on design, deployment, operation and decommissioning of an entire production facility.

The business life-cycle addresses the functions related to the supplier-customer interactions.

The integration layer enables the integration of all the resources, systems and processes involved in different life-cycles associated with the value chain of the product, through the whole manufacturing system levels, for the establishment of an environment for the smart manufacturing applications.

As illustrated in Figure 1, it addresses vertical integration, horizontal integration and end-to-end engineering.

Vertical integration refers to the integration into a production system of the various manufacturing elements at the different levels of the manufacturing system (system hierarchy) e.g., from sensors and machines to control systems, production management systems and corporate planning systems.

Horizontal integration refers to the integration of the various manufacturing elements for the support of and/or execution in, the different phases of the manufacturing processes, involving exchange of materials, energy and information both within an enterprise (e.g., inbound logistics, production, outbound logistics, marketing) and between different enterprises (value networks), up to and including an end-to-end solution.

The end-to-end engineering refers to the integration of the engineering process in order to connect each phase of the product life-cycle across the product's entire value chain and across different enterprises. End-to-end engineering enables the integration of the cyber and physical spaces involved in the manufacturing process on the basis of digitization.

The application layer addresses applications of smart manufacturing, aiming to satisfy different purposes.

The applications are enabled by the integration layer capabilities.

As examples of smart manufacturing application categories, Figure 1 shows innovative manufacturing and preventive maintenance.

NOTE 1 – Innovative manufacturing, as one category of smart manufacturing applications, encompasses applications such as virtual manufacturing, flexible manufacturing and customized manufacturing. Virtual manufacturing allows the use of simulated manufacturing processes and computer models. Flexible manufacturing allows a manufacturing system to react in case of changes, whether predicted or unpredicted. Customized manufacturing supports per-customer product differentiation.

NOTE 2 – Preventive maintenance, as another category of smart manufacturing applications, aims to prevent equipment failures.

Use cases of smart manufacturing applications in the context of the IIoT are provided in Appendix I.

6.2 Support of the industrial Internet of things for smart manufacturing

In line with its definition, as described in clause 3 of this Recommendation, the IIoT can be seen as an enabling approach based on the Internet of things (IoT) reference model [ITU-T Y.4000] aiming to support industrial applications (and their industry-specific functionalities).

The IIoT is an enabler of several industries, such as manufacturing, logistics, oil and gas, transportation, utilities, mining, metallurgy, aviation and others.

With respect to smart manufacturing, the IIoT constitutes a critical foundation. As an IoT-based enabling approach, the IIoT addresses three key aspects for the support of smart manufacturing applications:

– the IIoT encompasses all kinds of sensing, measuring, controlling and actuating devices, which enable the digital transformation of manufacturing elements to meet the need of real-time data perception of the manufacturing process and at the same time, the establishment of a vast industrial data set. With respect to the IoT reference model [ITU-T Y.4000], this concerns the gateway and device capabilities of IoT;
– the IIoT concerns all networks, such as industrial control networks, enterprise networks and Internet, that form the carrier infrastructure for the end-to-end transport of the manufacturing systems data. With respect to the IoT reference model [ITU-T Y.4000], this concerns the transport and networking capabilities of IoT;
– the IIoT provides supporting capabilities for industrial data processing and management, including - but not limited to - data integration, storage, sharing and analytics. With respect

to the IoT reference model [ITU-T Y.4000], this concerns the service support and application support capabilities of IoT.

6.3 Smart manufacturing-specific capabilities from the IoT infrastructure perspective

The infrastructure capabilities required for the support of smart manufacturing applications can be seen from the IoT infrastructure perspective. With respect to the IoT reference model [ITU-T Y.4000], Table 1 shows the correspondence between the IoT reference model (layers and cross-layer capabilities) and relevant smart manufacturing-specific capabilities.

Table 1 – Correspondence between IoT reference model and relevant smart manufacturing-specific capabilities

<table>
<tr><th colspan="2">IoT reference model</th><th>Smart manufacturing-specific capabilities</th></tr>
<tr><td>Application layer</td><td>IoT applications</td><td>Smart manufacturing applications. NOTE – Appendix I of this Recommendation provides a few use cases.</td></tr>
<tr><td rowspan="2">Service support and application support layer</td><td>Generic support capabilities</td><td>Data processing technologies such as cloud computing, data analytics and artificial intelligence are being adopted into smart manufacturing. For example, industrial cloud services have been provided to the market and big data and data analytics are key technologies for the predictive maintenance or condition-based maintenance of manufacturing equipment and facilities.</td></tr>
<tr><td>Specific support capabilities</td><td>Various enterprise and production management systems provide smart manufacturing-specific support capabilities. Typical examples of smart manufacturing-specific support capabilities are:
• tracking business resources such as cash, raw materials and production capacity, and business commitments such as orders, purchase orders and payroll, enterprise resources planning (ERP);
• managing the entire life-cycle of a product from design to service and disposal, which is provided by product life-cycle management (PLM);
• managing the flow of raw materials, goods and services among suppliers, company, resellers, and final consumers, which is provided by supply chain management (SCM);
• managing a company's interaction with current and potential customers, which is provided by customer relationship management (CRM):
• managing product definitions, ordering manufacturing executions, scheduling manufacturing resources and operating manufacturing processes, which are provided by manufacturing execution system (MES);
• inventory management;
• quality assurance and quality management</td></tr>
<tr><td>Network layer</td><td>Networking capabilities</td><td>The networking capabilities of smart manufacturing encompass network connectivity functions for locally and/or globally distributed manufacturing elements.
Some manufacturing-specific networking capabilities are provided by particular technologies, such as OPC-UA [b-IEC 62541] and MTConnect [b-MTConnect].
NOTE – The network-layer capabilities consisting of networking and transport capabilities correspond to the level 2 functionalities of IEC 62264 [b-IEC 62264].</td></tr>
</table>

Table 1 – Correspondence between IoT reference model and relevant smart manufacturing-specific capabilities

IoT reference model		Smart manufacturing-specific capabilities
	Transport capabilities	The transport capabilities of the smart manufacturing encompass data transport-related functions for locally and/or globally distributed manufacturing elements. Some manufacturing-specific transport capabilities are provided by particular technologies, such as SCADA [b-SCADA].
Device layer	Gateway and device capabilities	Some manufacturing-specific gateway and device capabilities are provided by particular technologies. Examples of technologies for gateway and device monitoring and control include IEC 61158-1 [b-Profibus], EtherNet/IP [b-EtherNet/IP], Modbus [b-Modbus], Fieldbus [b-Fieldbus], RAPIEnet [b-RAPIEnet], EtherCAT [b-EtherCAT]. NOTE – The provided capabilities correspond to the level 1 functionalities of [b-IEC 62264].
Management capabilities	Generic management capabilities	Device management is a key requirement of smart manufacturing. Additionally, maintenance management belongs to the generic management capabilities: • providing maintenance for existing installations; • providing a preventive maintenance program; • providing equipment monitoring to anticipate failure; and other. NOTE – OPC-UA [b-IEC 62541] can be used for device management purposes jointly with other supporting techniques.
	Specific management capabilities	Product cost accounting as a smart manufacturing-specific management capability is one key requirement for manufacturing to control all the costs of product design, manufacturing, inventory and shipping, to reduce them and increase product revenue. Tracking manufacturing status and analyzing production performance is also a smart manufacturing-specific management capability. NOTE – ISO 22400 [b-ISO 22400-2] specifies various key performance indicators to assess manufacturing performance.
Security capabilities	Generic security capabilities	Generic smart manufacturing security requirements are in line with the generic security capabilities of IoT [ITU-T Y.4100].
	Specific security capabilities	Smart manufacturing-specific security capabilities are defined in IEC/TS 62443 [b-IEC 62443].

7 System characteristics and requirements of smart manufacturing in the context of the IIoT

7.1 Fundamental characteristics

Fundamental characteristics of smart manufacturing systems are listed as follows:

Real-time: Smart manufacturing systems support real-time data in the phases of information acquisition, identification and transmission to the analysis and decision-making phases.

NOTE 1 – The effective time constraints depend on the specific process and system requirements.

Decision-making for manufacturing process optimization: Smart manufacturing systems generate decision instructions for the optimization of the manufacturing process via information mining, extraction, analysis and forecasting.

Dynamic execution status adjustment: Smart manufacturing systems dynamically adjust the execution status of the manufacturing process according to the decisions made by the decision-making system, so as to support stable and safe manufacturing operations.

Data-driven closed control cycle: Smart manufacturing systems conform to a data-driven closed control cycle constituted by "perception → analysis → decision→ execution and feedback".

NOTE 2 – Sensing and measuring devices are used to collect data on running conditions. Data is transmitted to data management centre(s) in which data is stored, structured, integrated, processed and analysed. Processing may be distributed (including central and local processing) so that data can be processed at different phases of the value chain according to the specific process and system requirements. According to the results of the analysis, decisions are made (in accordance with policies) and feedbacked to the controlling and actuating devices in order to adjust the execution status.

Systematic evolution and self-learning, self-organized system: The structure of a smart manufacturing system can evolve, from the reconstruction of the workshop and factory, to the restructuring of the enterprise consortium, the crowdsourcing design and the crowdsourcing production. By capabilities of self-learning and self-organization, the structure of a manufacturing system can be adjusted at any time on demand, thus achieving the goal of effective outputs via an optimized combination of resources.

Pervasive intelligence: Smart manufacturing systems exhibit intelligence in the different elements of the system so that the different elements can work in a self-disciplined way and communicate and cooperate each other.

Integration of human and machine: Especially via the development of human-machine coordinated robots and wearable devices, more and more smart manufacturing systems exhibit an increased integration of human and machine. Although people remain a key element in smart manufacturing systems, machines more and more extend people's physical, sensory and mental systems.

Integration of cyber and physical spaces: A smart manufacturing system involves two spaces, a physical space, made up of machine and human and a cyber space, made up of digital models, status information and control information. These two spaces are more and more deeply integrated in the advanced manufacturing systems. On one hand, the design of the products and processes before the actual usage and execution in the physical space can be verified in the cyber space; on the other hand, the products and processes actually used and executed in the physical space can provide dynamic and realistic rendering of information in real-time into the cyber space.

7.2 High-level requirements

High-level requirements of smart manufacturing systems are listed as follows:

Collaboration and integration capabilities: Smart manufacturing systems are required to support capabilities of collaboration and integration as opposed to an isolated and silo-based approach of system development and deployment. It is fundamental to enable an ecosystem that includes all relevant stakeholders in the manufacturing value chain.

Compatibility: Smart manufacturing systems are required to be compatible with existing manufacturing systems.

Scalability: Smart manufacturing system are required to have the ability to be upgraded and expanded according to the changing requirements of applications and cooperation among the manufacturing value chain stakeholders.

High performance information and communication technology (ICT) infrastructure: Smart manufacturing systems are required to provide a high performance ICT infrastructure that enables high-volume, high quality, high reliability and strict latency guarantees of data exchange, these capabilities having a direct impact on the performances of applications.

Heterogeneous connectivity capabilities: Smart manufacturing systems are required to enable the appropriate interconnectivity within the system. Interworking of heterogeneous communication technologies is required to be supported.

Cross-system interoperability: Smart manufacturing systems are required to support cross-system communications and interactions for a large number of purposes. Smart manufacturing systems have to enable cross-system interoperability and exhibit it during the system operation.

Operational safety and reliability: Smart manufacturing systems are required to provide operational safety and reliability in order to exhibit low fault rates, high fault tolerance (i.e., the ability to keep correct operations even when faults occur) and robustness (i.e., the ability to guarantee basic functionalities in the event of a fault).

NOTE 1 – Operational safety refers to the aspects of safety that relate to the correct operation of a system or that are provided by the system itself.

NOTE 2 – Reliability refers to the probability that the system operates correctly for a given period of time in a given environment.

Misuse and unauthorised access: Smart manufacturing systems are required to prevent production facilities and products, e.g., data and technology features, from misuse and unauthorised access. In particular, it is required:

– protection of production facilities and products from impermissible physical influences, e.g., protection against the entry into a room from unauthorized persons;
– protection of the ICT capabilities of the system from impermissible influences via the system communication interfaces;
– protection of information from loss and misuse, insurance of its timely provision to entitled users and maintenance of its integrity and confidentiality.

8 Reference model of smart manufacturing in the context of the IIoT

8.1 Reference model in the product life-cycle view

This clause describes a reference model of smart manufacturing in the context of the IIoT as a foundational framework.

The reference model of smart manufacturing in the context of the IIoT described in this Recommendation is built according to the three dimensions of system hierarchy, intelligence and life-cycle.

NOTE – This model, via the representation of key dimensions of smart manufacturing systems, aims to identify the working context of smart manufacturing standardization.

The system hierarchy dimension concerns the different levels of a manufacturing system, from a specific equipment to different interconnected manufacturing enterprises.

The intelligence dimension concerns the enablement of different layers of intelligence (smart capabilities) in the manufacturing system, from intelligence in (physical) resources to intelligence in services.

As mentioned in clause 6.1, the life-cycle dimension concerns the different phases of the smart manufacturing process (including for – but not limited to – products, production systems and business processes). This Recommendation, however, deals with the product life-cycle as described below.

Details of these three dimensions are provided in the clauses 8.1.1 to 8.1.3.

The reference model integrates the intelligence enablement with the smart manufacturing process life-cycles at the different levels of the smart manufacturing system.

With respect to life-cycles, the product life-cycle is the basic life-cycle which affects all other life-cycles. All the resources associated to smart manufacturing, including materials, machines, methods, human resources and environment, are involved in the product life-cycle. The major contribution of IIoT to smart manufacturing is directly reflected on the product life-cycle (and on the other life-cycles via the product life-cycle). For this reason, the scope of the smart manufacturing reference model in the context of the IIoT described in this Recommendation is limited to the representation of the product life-cycle in the life-cycle axis.

NOTE – The scope limitation of the smart manufacturing reference model described in this Recommendation does not intend to prevent further studies also taking into consideration other life-cycles.

Figure 2 illustrates the reference model of smart manufacturing in the context of the industrial IoT in the product life-cycle view.

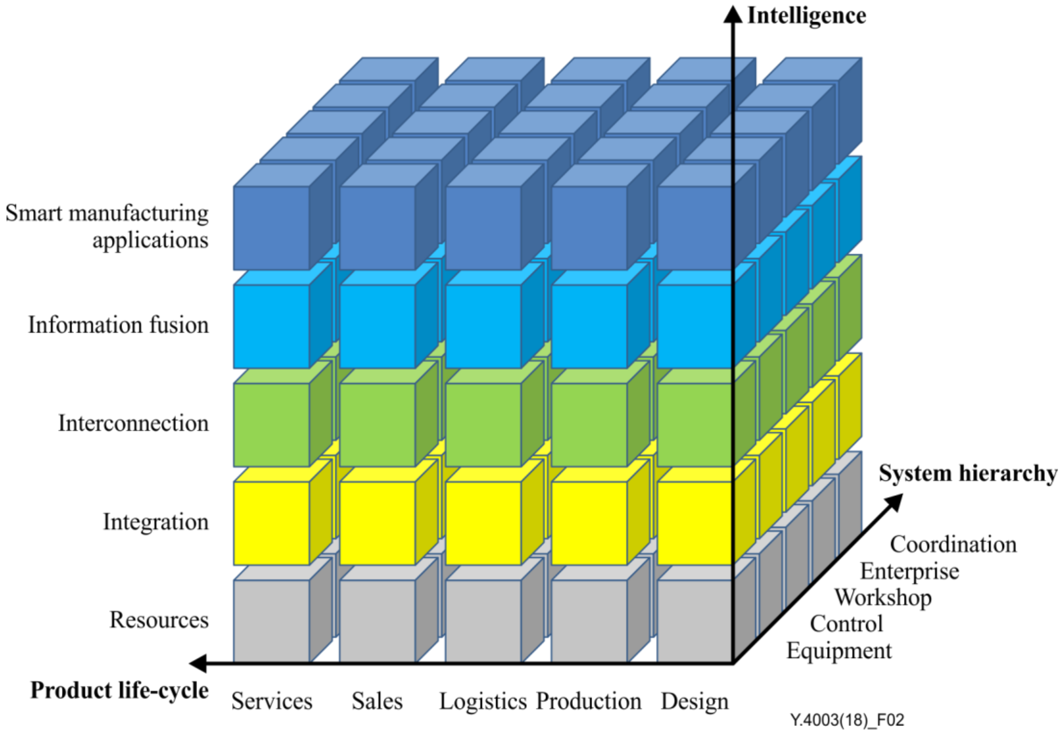

Figure 2 – Reference model of smart manufacturing in the context of the industrial IoT in the product life-cycle view

The following clauses describe, respectively, the three axes of the reference model.

8.1.1 Product life-cycle

As indicated in clause 6.1, the product life-cycle deals with the information flows and controls from the early product design phase until the product end-of-life.

The product life-cycle is composed by multiple phases of value creation activities, all of them being correlated and interactive. The composition of the product life-cycle may vary depending on the specific manufacturing sector. In smart manufacturing, it typically includes the phases of design, production, logistic, sales and service:

1) the "design" phase refers to the process of forming a product type, including design documentation and process simulation;

2) the "production" phase refers to the process of realizing products according to the product type, including manufacturing, testing and sales preparation;

3) the "sales" phase refers to the processes related to customer's ordering, including online ordering, contract establishment and payment collection, as well as other sales related activities, including advertising, promotion, exhibition activities and others;

4) the "logistics" phase refers to the distribution of raw materials, parts and products, including their procurement, delivery and storage;

5) the "service" phase refers to the customer support activities of providing support to the customer after the product and/or service have been delivered until the product and/or service end-of-life, including monitoring, diagnosis, maintenance, data analysis, creation of service-related decision-making, etc.

8.1.2 System hierarchy

The system hierarchy consists of five levels, equipment, control, workshop, enterprise and coordination:

1) the "Equipment" level represents sensors, instruments and meters, bar codes, radio frequency identification tags, machines, tools, devices, etc. It is the physical technical foundation of the manufacturing activities;

2) the "Control" level represents programmable logic controllers (PLCs), data acquisition equipment, supervisory control and data acquisition (SCADA) equipment, distributed control systems (DCS), fieldbus control systems (FCS), etc.;

3) the "Workshop" level represents the workshop or factory-oriented manufacturing operations. It includes manufacturing execution systems (MES), etc.;

4) the "Enterprise" level represents the enterprise-oriented manufacturing operations and management. It includes enterprise resource planning (ERP), product life-cycle management, supply chain management (SCM), customer relationship management (CRM), etc.;

5) the "Coordination" level represents the cooperative manufacturing process through information sharing via the interconnection of different enterprises in the smart manufacturing value chain.

8.1.3 Intelligence

The intelligence dimension consists of five layers, resources, system integration, interconnection, information fusion and smart manufacturing applications:

1) the "resources" layer enables the digitalization of the manufacturing resources, including design and construction drawings, product technical documents, raw materials, manufacturing equipment, workshops, factories. Personnel can also be included in this layer.

2) the "system integration" layer enables the integration of manufacturing resources by the connection of resources with QR code, radio frequency identification (RFID), human machine interface (HMI), software, network and other technologies, provision of information on the resources, generation of events from the resources, etc. The integration concerns the whole manufacturing system, from equipment and products to production line, workshop, factory, etc.;

3) the "interconnection" layer enables the realization of interconnection between manufacturing resources and enterprises via communication technologies;

4) the "information fusion" layer enables the realization of information sharing and coordination via appropriate technologies such as cloud computing, big data and other emerging information technologies, on the premise of information security. It includes data

processing, event related modelling, run time environment for smart manufacturing applications and other technical functionalities.

5) the "smart manufacturing applications" layer enables value chain integration among the different enterprises in order to create innovative industrial patterns, such as personalized customization, industrial cloud services and other manufacturing service patterns.

8.1.4 Support of the industrial Internet of things from the smart manufacturing reference model viewpoint

As an IoT-based enabling approach, the IIoT addresses three key sets of capabilities for the support of smart manufacturing, in line with the IoT reference model: gateway and device capabilities, transport and networking capabilities and generic support and specific support capabilities.

From the smart manufacturing reference model viewpoint, the IIoT supports all the manufacturing activities concerned by both the system hierarchy and product life-cycle axes. By means of the IIoT, the intelligence dimension enables smart capabilities in each of the product life-cycle phases and system hierarchy levels.

Appendix I

Use cases of smart manufacturing in the context of the IIoT

(This appendix does not form an integral part of this Recommendation.)

I.1 Factory visualization for production management

This system enables timely and appropriate decision-making at every level of enterprise management and factory management and unified visualization of information collected from multiple factories.

From the perspective of global expansion of production bases, supply chains and partner enterprises, it is important to improve production efficiency and to quickly respond to demand fluctuation and other situation changes in manufacturing processes. In addition, quick recovery when a factory loses its manufacturing ability is also important.

In this use case, a given product is manufactured in multiple factories. The factories can be located in various regions, including overseas and are interconnected.

The following information, categorized into five types – man, machine, material, method and environment (4M1E), is collected from multiple factories in real time:

– Man related information: operation of factory workers;

– Machine related information: equipment (repair history, process status);

– Material related information: expiration date, procurement information;

– Method related information: production time, maintenance time;

– Environment related information: power consumption.

This information is collected at one place in real time and analysed and visualized during the manufacturing process. The visualization enables timely decision making.

The overall system is required to handle various pieces of information, but some pieces of information should be provided to specific levels of the manufacturing enterprise.

Via real-time visualization, appropriate information for every level of the manufacturing enterprise can be provided. For example, summary information for planning of a new factory set up or for making management decisions is provided to the enterprise manager. Production information for factory operation such as line-operating ratio, load factor and so on, is provided to the managers of the factories. Detailed information for improvement of the manufacturing sites is provided to individual factories. This system enables timely decision making by providing in real time the necessary information for every level of the manufacturing enterprise.

In addition, when a factory loses its manufacturing ability, this system enables quick recovery by using alternative production lines in other factories. It also enables adjustment of equipment parameters in the production lines according to the analysed information and enables a production line to be stopped by the prediction of malfunctions before production equipment is actually broken.

As a result, this system enables not only greater production efficiency but also strengthens quality, cost, delivery (QCD) competitiveness on the global stage.

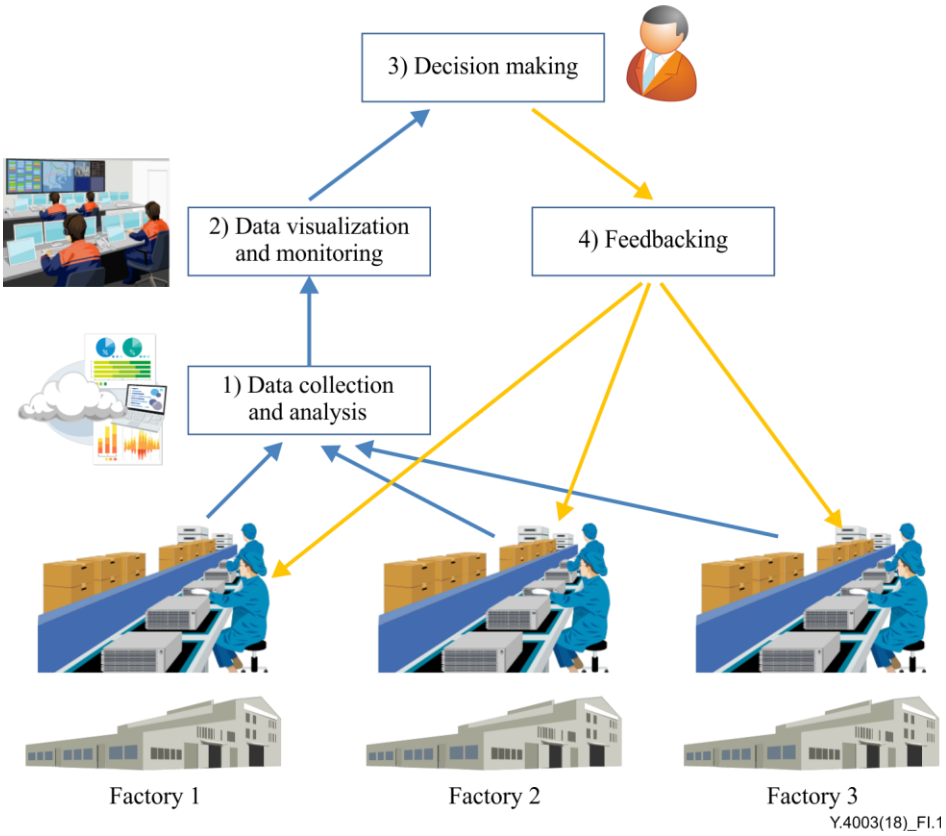

Figure I.1 – Factory visualization system for production management

The following illustrates the different operational phases of the factory visualization system as shown in Figure I.1:

(1) The manufacturing related data are collected from each factory and analysed;

(2) The analysed data are visualized at one place for real-time monitoring;

(3) An appropriate person (e.g., the enterprise manager) makes a timely decision regarding production management;

(4) Instructions based on the decision are transferred to each factory.

I.2 Flexible manufacturing

This use case shows how one clothing enterprise can produce customized suits and personalized services according to the orders of each specific customer.

Flexible manufacturing realizes customized suits and personalized service by mass production in order to improve production efficiency, reduce production cost, shorten delivery time and also reduce the number of errors.

In this use case, a customer inputs his/her body-size data into the clothing enterprise's platform and selects the suit details from it, such as colour, size, fabric, buttons style, collar type, sleeve type, pocket design and so on. The platform automatically compares the customer's personal information with its stored data concerning specification sheet and available fabric pieces, converts into standard customization information and outputs a personalized order for the customer. At the same time, a three-dimensional (3D) model of the customized suit is displayed on the platform website, and the customers can there observe the suit's details. The customer can modify every detail of the output suit as he/she likes in real time. After this, each suit's production process is split into specific production lines by the intelligent production management software provided by clothing enterprise's platform, and the production lines are distributed to a given number of enterprise workers.

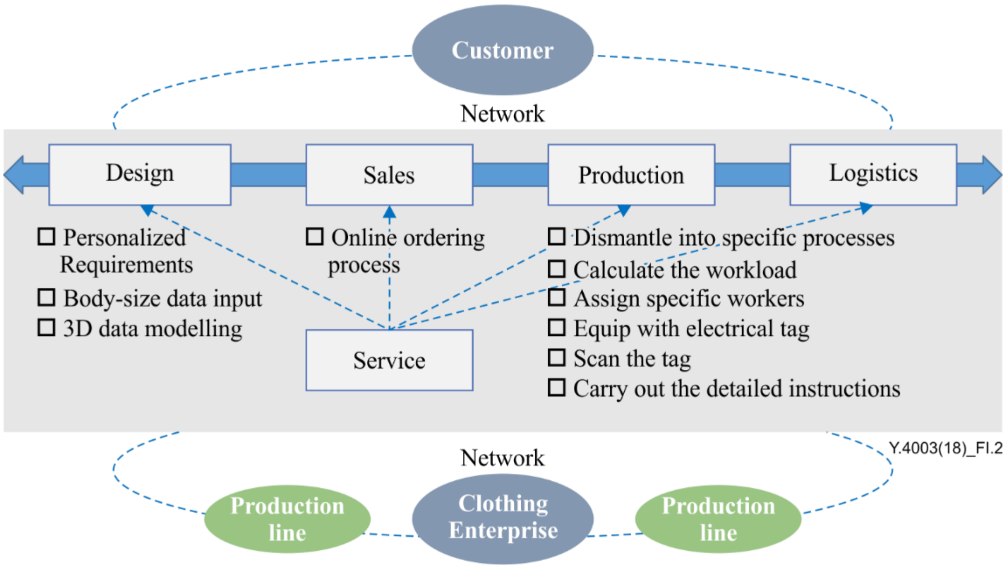

Figure I.2 – Summary view of flexible manufacturing

In this use case, shown in Figure I.2, the steps of suit customization include design, sales, production and logistics procedures.

– During the design procedure, customer's body-size data and personalized requirements are at first collected into the clothing enterprise's platform and then the platform automatically matches the most appropriate version of the body size and forms a 3D model that is exclusive to the customer's personalized requirements. The platform then displays the 3D model of the customized suit on the website so that the customer can modify every detail of the suit to his/her satisfaction.

– During the sales procedure, the customer clicks on the platform website's order button. After this step, each ordered product acquires its own exclusive electronic tag.

  NOTE – As described in clause 8.1.1, the online ordering process can be considered part of the sales procedure.

– During the production procedure, the clothing enterprise's platform decomposes each suit's production into specific processes, i.e. suit materials' preparation process, specific cutting process, specific ironing process, specific sewing process, etc. Then it calculates the workload and the working hours for each process through the platform's analysis capabilities. After this step, each suit's production process is split into a number of production lines and the production lines are distributed to a specific set of workers based on the platform's analysis results. After this step, each cutting piece is equipped with an electrical tag and each working place is equipped with a tablet computer. Workers on the working place scan the tags of each piece of suit, then read the customer's requirements and carry out the detailed instructions according to the tablet computer instructions, e.g., sewing suits by hand or by machine for the lining, buttons, sleeve edge and so on.

– During the logistics procedure, the customized suit is transported to the customer after verification and packing of the completed suit.

During the whole suit customization process, each of the above procedures can be real-time monitored. With respect to the reference model of smart manufacturing in the context of the industrial IoT in the product life-cycle view (as described in clause 8.1), the set of the above procedures constitutes the service which is provided throughout the entire product life-cycle.

I.3 Smart products in smart manufacturing

Smart products are enabled by the integration of interoperable information and communication technologies with traditional products. Smart products are an essential component of smart manufacturing. In the context of typical manufacturing scenarios, smart products can enable different applications, as shown in Figure I.3.

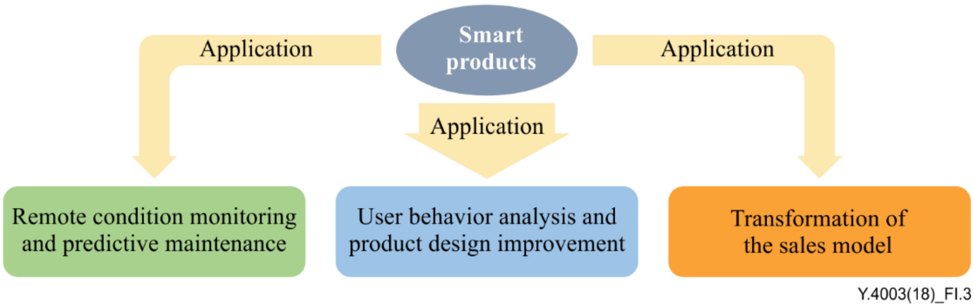

Figure I.3 – Examples of applications enabled by smart products

One application example is remote condition monitoring and predictive maintenance. Taking an enterprise offering predictive maintenance for aviation engines as an example, the enterprise can use sensors to instrument the production equipment and gather the data for enabling users to monitor the data in real-time. It can then adopt proactive maintenance and repair procedures rather than fixed schedule-based procedures, potentially saving money on maintenance and repair and on productivity losses due to downtime of failed production equipment. Further, combining sensor data from multiple equipment and multiple industrial processes, it can provide deeper insight into the production equipment, enabling identification and resolution of problems before they effectively impact the operations and improving the efficiency of the industrial processes.

Another application example is user behaviour analysis and product design improvement. Taking one air-conditioning enterprise as an example, the enterprise can evaluate an existing and well-sold competing product through gathering online and offline reviews and feedbacks and in-depth understanding of user requirements and can then identify some features of its own product which are not appreciated on the market. The good features identified in a competing product can also be fed into the next generation of its own product's design process as potential user requirements. Also, part of the gathered feedback information can be incorporated in the next generation of its own product.

Another application example is the transformation of the sales model from selling products to selling services. One digital printing enterprise can offer custom-made reproduction services instead of just selling photocopiers; an enterprise of passenger car engine oils can sell an engine oil quality monitoring service instead of engine oil; a heavy machinery manufacturing enterprise can sell the services of crane safety monitoring and management instead of selling cranes. They can sell a quality monitoring service instead of just the production itself.

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