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Industry 4.0 Lexicon

Scope

The purpose of this Technical Information Paper is to provide a comprehensive definition of terminology used around the theme of Industry 4.0 in the manufacturing industries.

Safety precautions

There are no specific precautions associated with this TIP.

Goal

Manufacturing industries are in the midst of a tectonic technological shift that is profoundly changing the way industrial production is designed, produced, manufactured, shipped, serviced and sold. This era is referred to as Industrie 4.0 (or Industry 4.0 hereafter in this document).

Industry 4.0 is filled with buzzwords that have been used inconsistently to describe capabilities that can be hard to distinguish between other terms and prior technology. By speaking a common language, we can more easily share ideas and accelerate progress.

The purpose of this TAPPI TIP is to promote a better understanding of the most common terms in Industry 4.0. This is intended to be a dictionary of terminology that can be used as a reference. Consistent use of terminology will help ensure all stakeholders have the same expectations and can arrive at mutually beneficial results.

Where they exist, references to a formal definition for a term are included.

Background

Industry 4.0 is a term that was introduced by the German government (Federal Ministry for Economic Affairs and Energy) in 2011. While there is no clear definition or list of attributes for Industry 4.0, the premise of our effort in this dictionary is that each industrial era has an inflection point where a critical differentiator is at the root of a new era. For example, in Industry 0 the main driver was human or animal muscle force, with the application of hand crafts and tools to yield production.

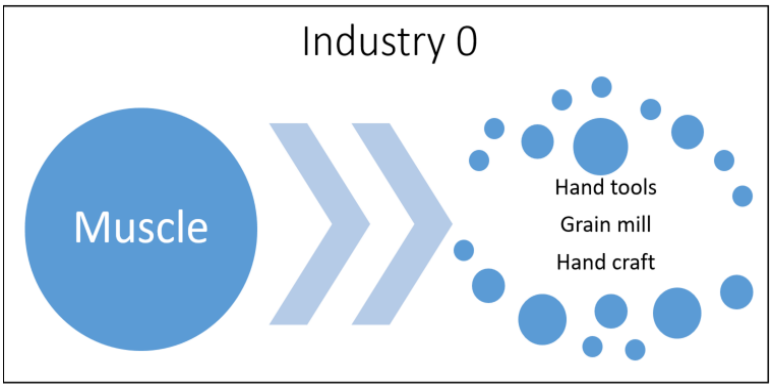


Fig. 1: Industry 0 Concept

Industry 1.0 refers to the application of steam-based energy to the manufacturing processes. Industry 2.0 refers to the application of electricity for improving efficiency and enabling scale. Industry 3.0 began in the early 1960s with automation where tasks were embedded and managed by computerized systems for further efficiency and scalability.

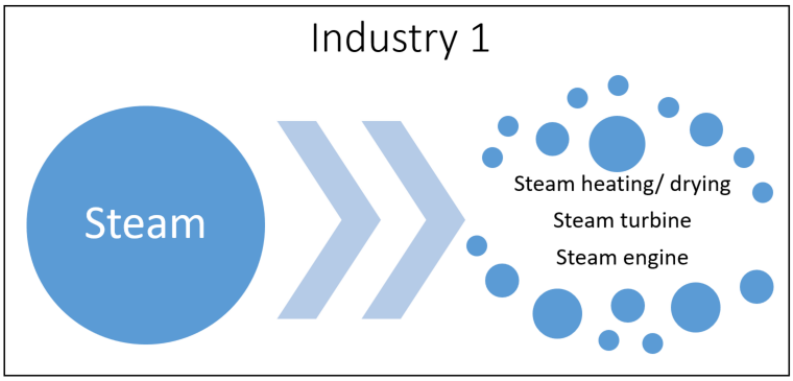


Fig. 2: Industry 1 Concept

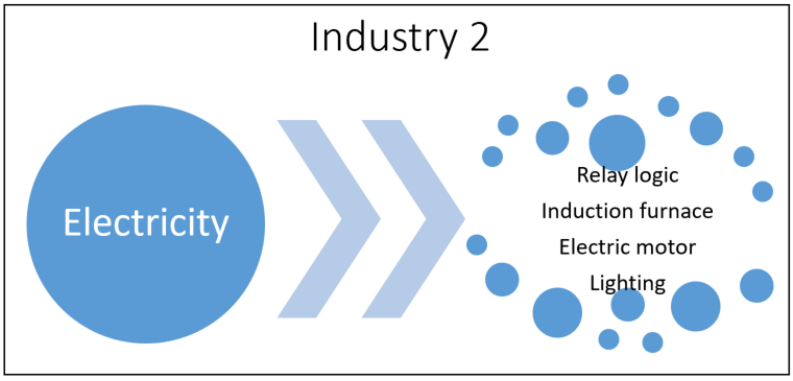


Fig. 3: Industry 2 Concept

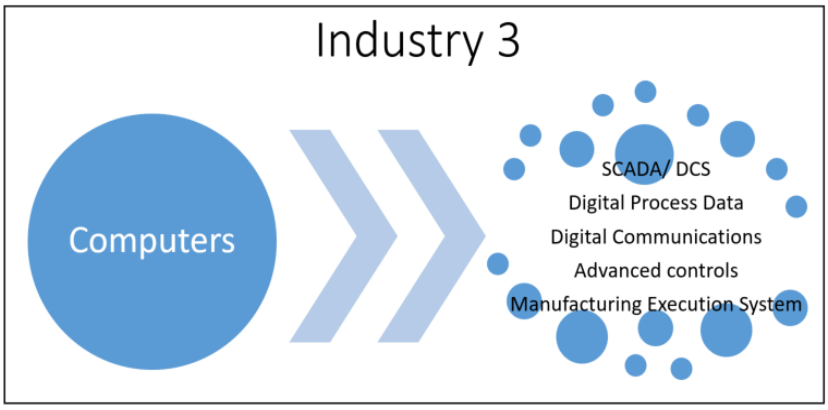


Fig. 3: Industry 3 Concept

In the prior examples is very obvious where the inflexion point between one industrial revolution and another begins. In Industry 4.0 it is more difficult to determine. Does Industry 4.0 refer to the introduction of computers into manufacturing? That happened in Industry 3.0. Does it refer to using data to improve processing? Again, process and plant engineers have been leveraging operational data for quite some time with spectacular results. Ultimately, Industry 4.0 is intelligent flexibility allowed by the internet.

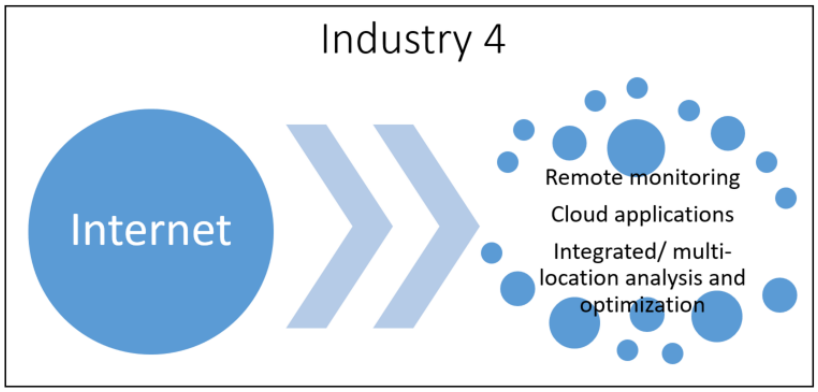


Fig. 4: Industry 4 Concept

Terms are defined by attributes. For example, a baseball has the following attributes:

- Round
- Stitches
- Circumference of about 9 inches
- Does not have fuzz like a tennis ball
- Does not have pointy ends like a football
- Does not have dimples like a golf ball

In order to clearly define the terms used in Industry 4.0, we need to list their attributes.

IoT vs IIoT

It is important to distinguish these terms in the context they are used. Since many of these terms are applied in the Consumer space and Information Technology space, they can have different or conflicting meanings in the Industrial space. The Consumer space is one in which the new IoT (Internet of Things) era has the attributes of:

- Smart Devices through digital instrumentation in things such as refrigerators, homes, and vehicles
- Internet connection

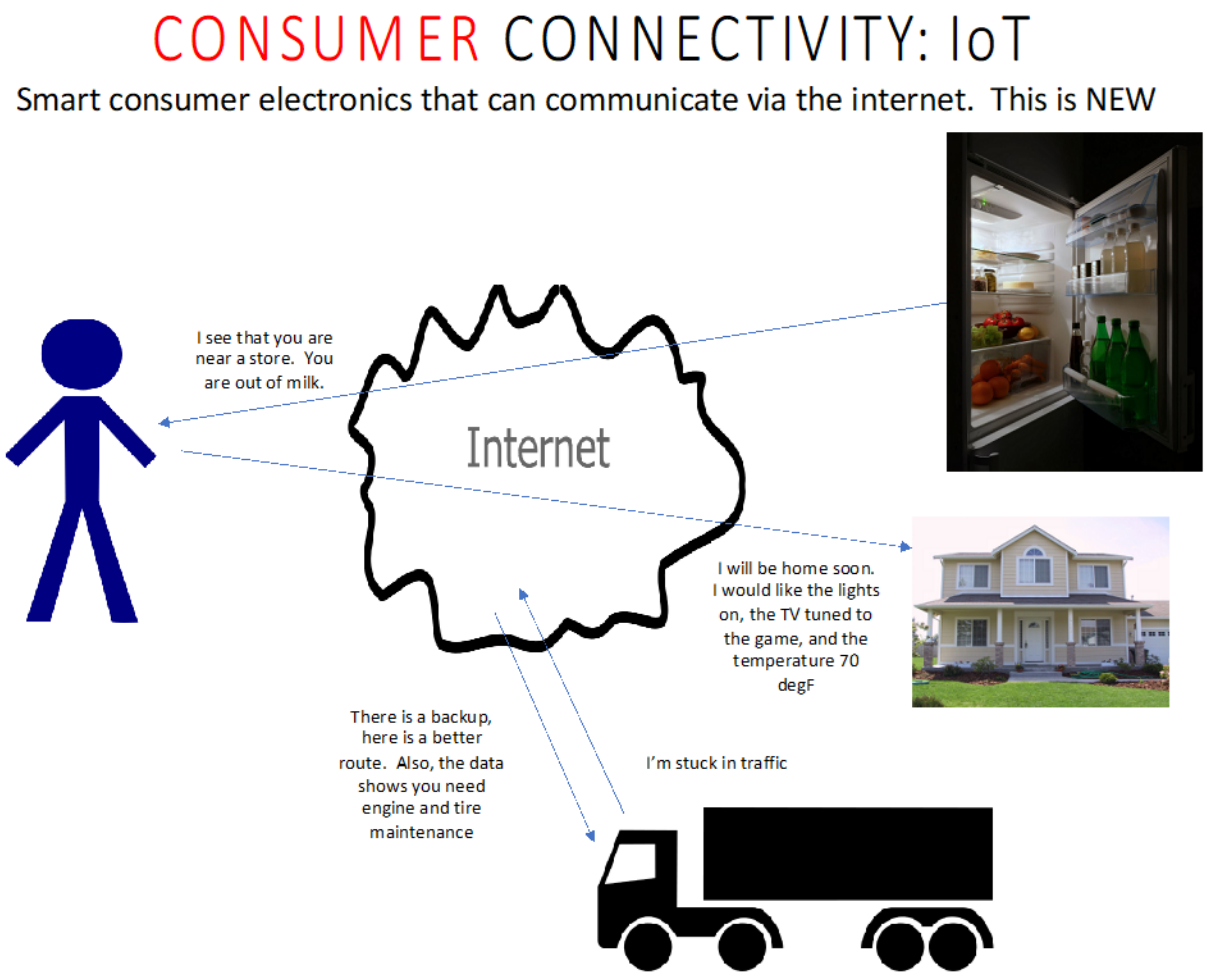


Fig. 5: Internet of Things in the Consumer Space

However, in the Industrial context, our new era is not IoT, it is IIoT (Industrial Internet of Things). Unlike the consumer space, IIoT has had instrumentation and digital data well before the term IIoT originated. In the following illustration, the instrumentation, valve, processor, and HMI represent technology that was introduce in Industry 3.0, not Industry 4.0. Therefore, the attributes of IIoT are:

- Internet connectivity of industrial automation data

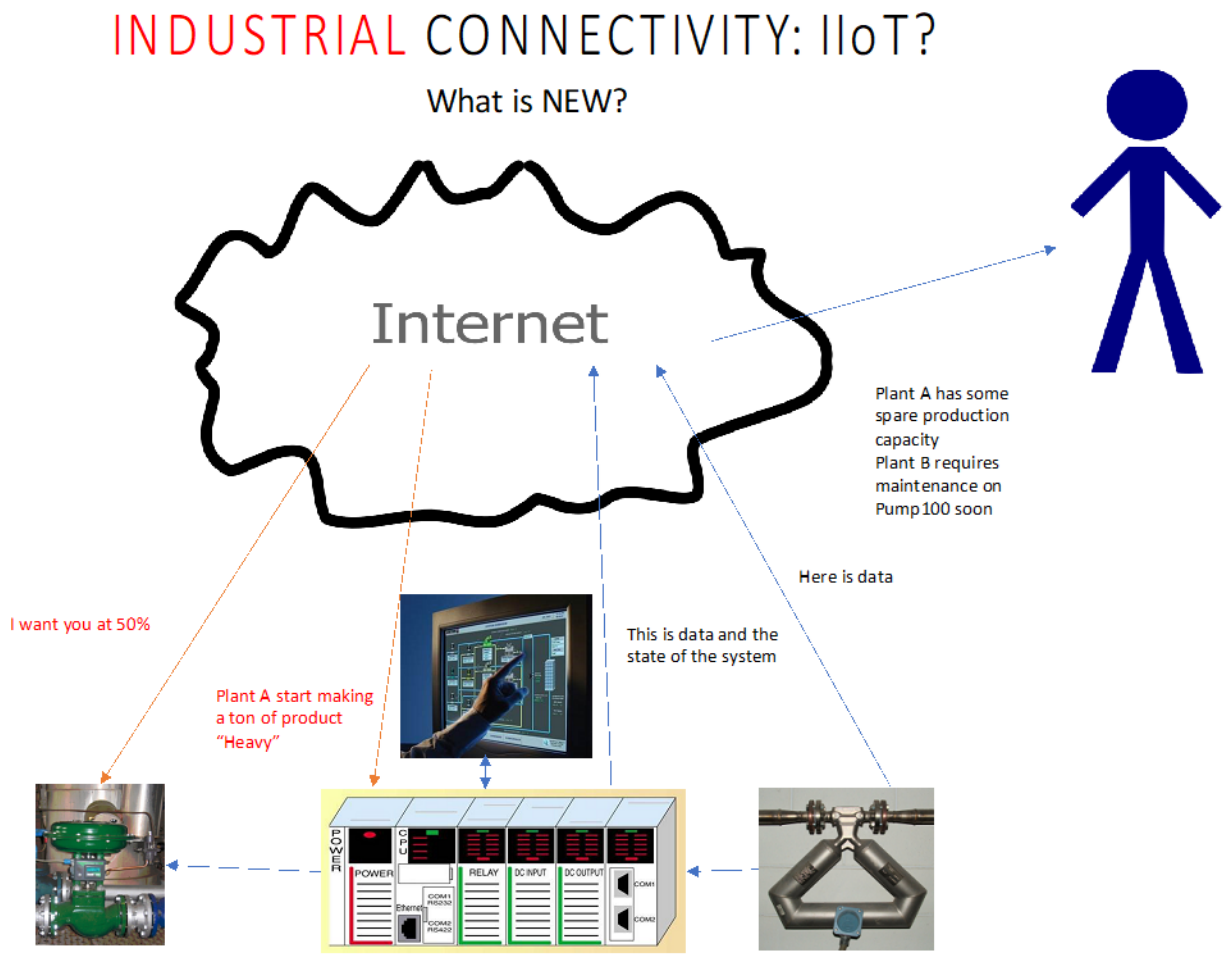


Fig. 6: Internet of Things in the Industrial Space

To summarize the differences between IoT and IIoT in a different way, the following table shows the differences in how the same technology was applied, and when.

WHEN THIS TECHNOLOGY WAS APPLIED	IoT CONSUMER	IIoT INDUSTRIAL
APPLICATION OF INTERNET CONNECTIVITY	Recent	Recent
SMART/DIGITAL "THINGS"	Recent	Pre-existing

Table 1: Comparing IoT vs IIoT

Based on this understanding of the industrial eras, we can define what is new and what is not. We can identify those attributes that uniquely define the terms we use in the new era of Industry 4.0.

For a video explanation, refer to the following recording of this TAPPI webinar: https://www.tappi.org/education/webinars/do-we-need-an-industry-4.0-lexicon/

Table of Terms

The following table lists all the terms in the lexicon, which is divided in 4 categories. Indices are also assigned, and in cases where terms have the same meaning the indices are duplicated.

Categories of terms:

- INDUSTRY: These terms apply broadly to the state of industry
- INFRASTRUCTURE: These are pertinent to elements of industrial digital infrastructure
- TECHNOLOGY: These are specific technical capabilities and techniques used in industry
- APPLICATION: These terms apply to specific application of digital technology

TERMS	CATEGORY	INDEX	GROUP
Industry 4.0	1	1	Industry
Digitization	1	2	Industry
Digitalization	1	3	Industry
Digital Transformation	1	4	Industry
IIoT	1	5	Industry
Connected Enterprise	1	5	Industry
Smart Manufacturing	1	5	Industry
Edge	2	1	Infrastructure
Cloud	2	2	Infrastructure
Virtualization	2	3	Infrastructure
Wireless	2	4	Infrastructure
Electronic Device Description Language (EDDL)	2	5	Infrastructure
Field Device Integration (FDI)	2	6	Infrastructure
OPC UA	2	7	Infrastructure
MQTT	2	8	Infrastructure
Data Analytics	3	2	Technology
Artificial Intelligence	3	3	Technology
Machine Learning	3	4	Technology
Neural Networks	3	5	Technology
Manufacturing Execution System	4	1	Application
Asset Management System	4	2	Application
Digital Twin	4	3	Application
Remote Monitoring	4	4	Application
Predictive Maintenance	4	5	Application
Virtual Sensors	4	6	Application
Virtual Online Analyzers	4	6	Application
Soft Sensors	4	6	Application
Advanced Process Control	4	7	Application

Table 2: Table of Terms in Lexicon

Lexicon

Each term has the following format. In cases where at item is not applicable, it will be marked with N/A:

FORMAL DEFINITION:

Where a formal definition exists (the term is owned by, created by, or formally recognized as defined by a specific source), the reference is given. These sources are context sensitive to industrial use, and therefore English dictionary terms lacking context are not referenced.

COMMON DESCRIPTION:

There are many references to descriptions of terms from individual or organization that do not have any formal ownership of the term. Where helpful, these are included

WHAT IT IS:

Where a formal definition is missing or lacking specificity in the context of industrial automation, the PIMA IT Infrastructure Common Interest Group (CIG) provided its description

WHAT IT ISN'T:

The PIMA IT Infrastructure Common Interest Group (CIG) included this to help clearly distinguish between examples that are or are not included under the term

ATTRIBUTES:

These are concise bullet points to list the attributes that clearly distinguish what does and does not qualify as an example of the term.

INDUSTRY TERMS

Industry 4.0

FORMAL DEFINITION:

"Industrie 4.0 refers to the intelligent networking of machines and processes for industry with the help of information and communication technology." (Federal Ministry for Economic Affairs and Energy, 2020)

"For Industrie 4.0, it is not the computer that is the core technology, but rather the Internet." (Federal Ministry for Economic Affairs and Energy, 2020)

COMMON DESCRIPTION: N/A

WHAT IT IS:

The difference between Industry 3 and Industry 4 is the Internet. It is the enabling power for Industry 4 applications. Prior to Industry 4, there was no Internet that enabled easy and cost-effective connectivity of industrial facilities to the outside world. The following table illustrates how the term applies to industrial usage:

AGE	INFLECTION POINT	CRITICAL DIFFERENTIATOR	INDUSTRIAL USAGE	PARTIALLY REPLACES
Industry 0	< 1600	Muscle	Industry was powered by humans and animals	
Industry 1	~1600	Steam	The piston engines of Newcomen, Leopold, and Watt replaced muscle power with steam	Muscle power
Industry 2	~1880	Electricity	Edison and Tesla provided the means of harnessing electrical power for industrial use	Muscle power, steam
Industry 3	~1970	Computers	Digital converters and processors enabled automation of human activities in industry (DCS, SCADA, etc.)	Human labor, pneumatic controls, electrical relay logic
Industry 4	~1990	Internet	A public network infrastructure for the entire planet enabled connectivity of industrial facilities with minimal effort and investment	Proprietary networks, human labor

Table 3: Technological Ages Comparison Table

WHAT IT ISN'T:

It is not the evolution of Industry 3 usages. The applications that existed prior to the Internet can be enhanced by Industry 4 but they are not replaced. Steam for example originated in Industry 1, yet it is alive and well, enhanced by the benefits offered by the subsequent industrial eras. Each phase in the table above partially replaces a prior means of empowerment. The evolution of a technology is not a replacement and therefore cannot be considered Industry 4. Therefore, the following are not uniquely Industry 4 applications:

- Advanced control
- Neural networks
- Data analytics

ATTRIBUTES:

- Internet connectivity
- Uses process connected data

Digitization

FORMAL DEFINITION: N/A

COMMON DESCRIPTION:

"Digitization is the process of changing from analog to digital form, also known as digital enablement. Said another way, digitization takes an analog process and changes it to a digital form without any different-in-kind changes to the process itself." (Gartner, 2020)

WHAT IT IS:

This is Industry 3.0. It was the transition from analog to digital. Dials, gauges, and indicators were replaced by transmitters that converted process data into digital representation in a computer. In the ISA-95 hierarchy, it represents levels 1 and 2, which encompasses having intelligent devices for sensing and monitoring physical processes and the control systems, which we refer to as SCADA or DCS. Digitization has been ongoing for decades with the adoption of PLCs and Control Systems.

WHAT IT ISN'T:

It is not Industry 4.0. It was the definition of Industry 3.0

ATTRIBUTES:

Digital representation of process data

Digitalization

FORMAL DEFINITION: N/A

COMMON DESCRIPTION:

"Digitalization is the use of digital technologies to change a business model and provide new revenue and value-producing opportunities; it is the process of moving to a digital business." (Gartner, 2020)

WHAT IT IS:

Digitalization covers the real-time capturing of the information for its integration with plantwide or enterprise-wide levels of connectivity, which is above the SCADA/DCS level (ISA-95 level 2). It implies having a digital representation of the process to manage the operations outside of the control systems domain. Examples include:

- Automated near real-time production reports using live/near real-time process data
- Batch executive function

WHAT IT ISN'T:

Converting manual or analog data into digital; that is Digitization.

ATTRIBUTES:

- Live or near-time deterministic information
- Does not have to be on premises

Digital Transformation

FORMAL DEFINITION: N/A

COMMON DESCRIPTION:

"Digital transformation can refer to anything from IT modernization (for example, cloud computing), to digital optimization, to the invention of new digital business models. The term is widely used in public-sector organizations to refer to modest initiatives such as putting services online or legacy modernization. Thus, the term is more like 'digitization' than 'digital business transformation.'" (Gartner, 2020)

Digital Transformation requires making change a core competency as the enterprise becomes customer-driven end-to-end. The idea is to use technology not just to replicate an existing service in a digital form, but to use technology to transform that service into something significantly better.

A customer-driven strategic business transformation that requires cross-cutting organizational change as well as the implementation of digital technologies.

WHAT IT IS:

- A new customer-driven strategic approach to designing and running a business. All processes are rethought in terms of addressing customer needs and designing products that fits those needs.
- It is not limited to manufacturing or production; accounting may be redesigned to offer more transparent, more automated billing and payments. HR may be rethought to provide a workforce with more customer-focused skills and training.
- Digitization projects are driven by this strategy, either to automate the new processes or provide the data they need to function.

WHAT IT ISN'T:

- It is not specifically industrial since it includes non-industrial business processes.
- It is not Industry 4.0, since it refers to digitization of non-industrial business operations and the digitization of industrial operations occurred in Industry 3.0

ATTRIBUTES:

- Business systems such as finance, human resources, sales
- Digitization

IIoT/ Connected Enterprise/ Smart Manufacturing

FORMAL DEFINITION: N/A

COMMON DESCRIPTION: N/A

- **WHAT IT IS:**

These are equivalent terms. There is no significant attribute to distinguish one from the others. They all refer to the ability to connect manufacturing facilities outside of their walls to the outside world using the public infrastructure of the Internet. The only technology enabler that differentiates Industry 3.0 from Industry 4.0 is the Internet. Therefore, Industry 4 is an equivalent term to all of these.

- Internet connectivity for industrial production

WHAT IT ISN'T:

- It is not conversion of process measurements to digital data. That was done 100 years ago.
- It is not connectivity without the public Internet. The IoT applications in the consumer space designate I for Internet. The Industrial Internet of Things requires the public Internet to be considered IIoT. Bringing sensor data from the field into a system is not IIoT.
- It is not replacement of paper records with digital data stored electronically. This has been an ongoing evolution that precedes Industry 4.0.
- It is not replacement of a manual process with automation. Control technology has been a continuing evolution of capability and there is nothing to clearly distinguish Industry 4.0 capabilities from Industry 3.0 capabilities

ATTRIBUTES:

- The same as Industry 4.0

INFRASTRUCTURE TERMS

Edge

FORMAL DEFINITION: N/A

COMMON DESCRIPTION:

"The edge is the physical location where things and people connect with the networked, digital world." (Gartner, 2020)

WHAT IT IS:

Any device with connectivity through the Internet that does processing local to the source and destination of data. These can be devices that connect to field IO, converts signals to digital, performs control processing, stores data, and presents a local user interface with processing in the device. This includes devices like the following:

- A server at a facility that does processing without relying upon external processing resources. These servers can often be classified either at the edge, the cloud, or in between depending on what they do and what resources they depend on.
- An operator or engineering workstation that can perform its function independent of Internet connectivity
- Programmable Logic Controllers (PLC) that process IO and control logic
- Remote Terminal Unit (RTU), that process IO
- Process Controllers in a Distributed Control System (DCS) that process IO and control logic
- A data buffering device or local historian to capture high speed data and provide it to a local user interface with minimal latency

WHAT IT ISN'T:

- It does not pertain to systems isolated from the Internet. The only meaningful use of the term is in context of an Internet connected system. The devices described above are exactly the same when they are isolated, but when they are connected, they can be called edge devices because without the connection there is no edge. In order for there to be an edge, there has to be a defined surface. That surface is the Internet.

- It is not necessarily new devices. The devices are the same as they have always been, but the connectivity of the Internet gives them a new term that helps explain to the IT world what they are. In order to be edge it has to have a direct connection to the Internet.
- It is not a network switch. While these devices do perform processing in the sense of routing and managed ports, their processing capabilities do not qualify as edge devices.

ATTRIBUTES:

- A device that performs substantive processing of data
- Is simultaneously connected to the process and the Internet

Cloud

FORMAL DEFINITION: N/A

COMMON DESCRIPTION:

"Cloud computing is a style of computing in which scalable and elastic IT-enabled capabilities are delivered as a service using internet technologies." (Gartner, 2020)

WHAT IT IS:

Data storage or processing in a central repository that outsources maintenance responsibility and reduces local hardware footprint. The cloud service is connected through the public Internet

WHAT IT ISN'T:

- It is not a deterministic, real-time resource for field IO processing and control processing such as interlocks and PID loops.
- A local server, cluster, or historian at the facility connected internally, without Internet connectivity. These existed in Industry 3.0.

ATTRIBUTES:

- Data that resides on the Internet

Virtualization

FORMAL DEFINITION: N/A

COMMON DESCRIPTION:

"Virtualization is the abstraction of IT resources that masks the physical nature and boundaries of those resources from resource users. An IT resource can be a server, a client, storage, networks, applications or OSs. Essentially, any IT building block can potentially be abstracted from resource users." (Gartner, 2020)

WHAT IT IS:

- The hosting of a virtual computer inside the operating system environment of the physical host machine

WHAT IT ISN'T:

- A system that directly relies on the operating system, environment, and hardware of the host machine

ATTRIBUTES:

- Software
- Not reliant on the host hardware

Wireless

FORMAL DEFINITION: N/A

COMMON DESCRIPTION: N/A

WHAT IT IS:

- Any communication that communicates without hard wired connectivity
- This includes communication between field devices and a wireless gateway in a process control system

WHAT IT ISN'T:

- It does not necessarily utilize the Internet, therefore it is not necessarily IIoT

ATTRIBUTES:

- Real-time digital process data
- No wires

Electronic Device Description Language (EDDL)

FORMAL DEFINITION:

"Electronic Device Description Language (EDDL) is a programming language used to create Device Descriptions (DDs) to describe the attributes of field devices in an Operating System (OS) and Human Machine Interface (HMI)-neutral environment. EDDL is used to create DDs for functions such as generic digital and analog input/output modules, HMI displays and transmitters, on-off and regulating valves, and closed-loop controller diagnostics." (Fieldbus Foundation, 2006)

COMMON DESCRIPTION: N/A

WHAT IT IS: N/A (covered in the formal definition)

WHAT IT ISN'T: N/A (covered in the formal definition)

ATTRIBUTES:

- A device definition file that complies with the EDDL standard

Field Device Integration (FDI)

FORMAL DEFINITION:

"Device integration and device management technology, combining base concepts and technology aspects of Electronic Device Description Language (EDDL) according to IEC 61804 , Field Device Tool (FDT®2) According to IEC 62453, as well as in IEC 62541-1 (OPC UA)." (FieldComm Group, 2019)

COMMON DESCRIPTION: N/A

WHAT IT IS: N/A (covered in the formal definition)

WHAT IT ISN'T: N/A (covered in the formal definition)

ATTRIBUTES:

- A device integration that complies with the FDI standard

Open Platform Communications Unified Architecture (OPC UA)

FORMAL DEFINITION:

"The OPC Unified Architecture (UA), released in 2008, is a platform independent service-oriented architecture that integrates all the functionality of the individual OPC Classic specifications into one extensible framework.

This multi-layered approach accomplishes the original design specification goals of:

- Functional equivalence: all COM OPC Classic specifications are mapped to UA
- Platform independence: from an embedded micro-controller to cloud-based infrastructure
- Secure: encryption, authentication, and auditing
- Extensible: ability to add new features without affecting existing applications
- Comprehensive information modeling: for defining complex information OPC Foundation" (OPC Foundation, 2020)

COMMON DESCRIPTION: N/A

WHAT IT IS: N/A (covered in the formal definition)

WHAT IT ISN'T: N/A (covered in the formal definition)

ATTRIBUTES:

- A real-time process data communication that complies with the OPC UA standard

Message Queuing Telemetry Transport (MQTT)

FORMAL DEFINITION:

"MQTT is an OASIS standard for IoT connectivity. It is a publish/subscribe, extremely simple and lightweight messaging protocol, designed for constrained devices and low-bandwidth, high-latency or unreliable networks. The design principles are to minimize network bandwidth and device resource requirements whilst also attempting to ensure reliability and some degree of assurance of delivery. These principles also turn out to make the protocol ideal of the "Internet of Things" world of connected devices, and for mobile applications where bandwidth and battery power are at a premium." (MQTT, 2020)

COMMON DESCRIPTION: N/A

WHAT IT IS: N/A (covered in the formal definition)

WHAT IT ISN'T: N/A (covered in the formal definition)

ATTRIBUTES:

- A protocol for IoT communication compliant with the MQTT standard

TECHNOLOGY TERMS

Big Data

FORMAL DEFINITION: N/A

COMMON DESCRIPTION:

"Big data is high-volume, high-velocity and/or high-variety information assets that demand cost-effective, innovative forms of information processing that enable enhanced insight, decision making, and process automation." (Gartner, 2020)

WHAT IT IS:

While it typically refers to data sets that are too large for "traditional" computing methods, mainly utilizing cloud computing resources or enhanced computing power to derive insights, this is not a sufficient distinction. Big Data means that data sets are compiled from a variety of sources to provide enhanced insights or new levels of decision making. Just a large data set alone does necessarily qualify as Big Data as other dimensions need to be encompassed. The ability to aggregate, store, process, and take action on the data are key characteristics that are needed to be defined as big data.

The following article Jamal Khawaja (Khawaja, 2014) explains how analytics on a large Business Intelligence (BI) dataset is not Big Data unless it involves a variety of data sources: "Big Data is not a function of a single data set; it is a function of multiple data sets coming from multiple sources. Running analytics across a massive data set is (BI) on steroids; running it against multiple, disparate data sets is Big Data. A Big Data model would include information from subsurface data as well as information from public GIS records, emails from geophysicists, white papers from Gartner or Forrester, chat session between drilling engineers, and RSS feeds from this blog and others like it."

WHAT IT ISN'T:

- Data solely for BI utilization
- Not necessarily analysis run on large data sets
- Not typically utilized for basic, low-hanging fruit, problems.
- Not data for a single system/location
- It does not necessarily require Internet connectivity, and therefore is not necessarily Industry 4.0 or IIoT
- Difficult to do on-prem without significant infrastructure investment (servers, etc.)

ATTRIBUTES:

- Volume: Refers to the amount of the data and can include both unstructured and structured data. The volume of data is an arbitrary measure with ranges can be from tens of terabytes to hundreds of petabytes, depending on the context.
- Variety: Refers to the different types of data from more than one source (DCS, IIoT / Edge devices, QCS, weather , digital log, different process equipment, different locations, etc.)
- Velocity: Data that is not only acquired quickly but also processed and can be utilized at a faster rate.
- Veracity: Refers to the data quality; the biases, noise, and abnormalities within the data sets must be removed. Big Data must have preprocessed (cleaned) data that is representative of what we want to use it for.

Data Analytics

FORMAL DEFINITION: N/A

COMMON DESCRIPTION:

"Data analytics (DA) is the process of examining data sets in order to draw conclusions about the information they contain, increasingly with the aid of specialized systems and software." (Rouse, 2019)

"Data analytics focuses on processing and performing statistical analysis on existing datasets. Analysts concentrate on creating methods to capture, process, and organize data to uncover actionable insights for current problems, and establishing the best way to present this data. More simply, the field of data and analytics is directed toward solving problems for questions we know we don't know the answers to. More importantly, it's based on producing results that can lead to immediate improvements." (Liberty, 2019)

WHAT IT IS:

"The process of examining data sets to draw conclusions about the information they contain, increasingly with the aid of specialized systems and software." (Rouse, 2019)

Data Analytics refers to the science of analyzing data to make conclusions on that data. Typically used in forward looking solutions (what might happen) as opposed to traditional backward-looking (what happened in the past and why?) data analysis methods. Utilized to draw out trends and conclusions that would typically be masked in the noise or size of the data. Data analytics is the process of discovering data-driven insights that are actionable and thus create business value in both operations and strategy efforts.

According to Gartner's four stage model (Sapuntzis, 2019) the types include:

- Descriptive analytics: visualize what's going on in the data
- Diagnostic analytics: determine why it's going on
- Predictive analytics: determine what's going to happen or what will likely happen
- Prescriptive analytics (includes adaptive applications): determine actions / what you should do about it

Examples include:

- Using a model to predict behavior
- Troubleshooting process problems, such as sheet breaks
- Analyzing equipment failures
- Understanding / troubleshooting sources of process variability and shifts

WHAT IT ISN'T:

"Data Analytics is not data analysis which refers to the process of collecting and analyzing data. It also is not Data Science. While data science is macro in scope (we do not have a particular problem to solve, we are looking for insights, data mining) with the goal to ask the right questions, data analytics is micro in scope with the goal to find actionable insights (finding the answer to a specific problem). Therefore, Data Analytics is not data mining." (Rouse, 2019)

Both Data Analytics and Data Science use big data.

ATTRIBUTES:

- Micro in scope (seeks to answer a defined question with the goal to produce improvements)
- Uses big data

Artificial Intelligence (AI)

FORMAL DEFINITION: N/A

COMMON DESCRIPTION:

Artificial Intelligence (AI) is the study of enabling intelligent behavior in machines. (Marr, 2018) Like mathematics or chemistry, it is a broad term that encompasses specific sub-fields (ex. Machine Learning) and methodologies (ex. Neural Networks). (Serokell, 2020) While there is disagreement regarding the precise nature of intelligence, the overarching goal of AI remains the same — to create synthetic systems that exhibit human-like intelligence.

WHAT IT IS:

The term "artificial intelligence" has become increasingly commonplace yet meaningless over the past decade. Technologies and products that have existed for decades are often re-branded as "AI," making it difficult to distinguish what is truly novel and impactful versus what is hype. Similar to any study or profession, there is a gradient of sophistication with AI — not all AI is made equal.

Sophistication in AI is distinguished by the ability to generalize. The simplest AI solutions are custom-made to perform narrow tasks (ex. prediction, anomaly detection) on narrow domains (ex. a single piece of equipment). They often break in applications of higher complexity or dynamism.

Sophisticated AI solutions will apply to systems both large and small (ex. they can scale from a single piece of equipment to an entire interconnected plant) and can be trained to handle multiple tasks without significant rework or customization. Sophisticated AI solutions may also involve decision-making, which requires a deeper understanding of the underlying domain than prediction (ex. tell me how to operate the plant to maximize product quality vs predict the product quality).

Examples include:

- Expert systems: Capturing the knowledge of an expert to provide a digital representation of the response from a human expert
- Fuzzy logic: Utilizing the way humans use statistical estimates to make decisions

WHAT IT ISN'T:

AI is not the same as automation. Intelligence and automation are two separate concepts that are sometimes but not always paired together. For example, industrial systems since the 1980s have been largely automated with the advent of digital controllers; however, they have been programmed according to a static set of rules and heuristics that do not evolve over time. The adoption of AI within the industrial sector is about making existing automated systems more intelligent, not necessarily more automated.

AI is also not about consciousness. There is no evidence that intelligence and consciousness are related, or if intelligence is even a prerequisite for consciousness. Unfortunately, decades of Hollywood tropes have led a large fraction of the general population to conflate AI with autonomy or rogue behavior. Experts believe Artificial General Intelligence (AGI, commonly defined as human-level intelligence) is likely 30-100 years away. However, a human-level of intelligence does not necessarily imply a human-level of consciousness.

The following examples lack the human behavior characteristics of AI:

- Offline what-if analysis
- Online virtual sensors
- Multivariable Predictive Control (MPC)

ATTRIBUTES:

- Uses process data
- Uses mathematical techniques to turn data into information or action
- Creates a system that mimics human behavior
- It does not have to be adaptive

Machine Learning (ML)

FORMAL DEFINITION: N/A

COMMON DESCRIPTION:

Machine Learning (ML) is a sub-field of AI that enables computers to automatically learn from experience rather than being explicitly programmed. (Ng, 2020) Whereas traditional computer systems utilize static rules and heuristics, ML-based systems learn and adapt directly from the data.

WHAT IT IS:

The ability to learn from data makes ML well-suited for applications of immense complexity and dynamism. Many real-world systems are simply too complex and fluid to define precisely (ex. explicitly programming a self-driving car would require billions of lines of code, if at all possible). In these situations, it is often much easier and more accurate to design programs that can learn and adapt over time, rather than relying upon explicit instructions.

WHAT IT ISN'T:

The defining characteristic of ML is the ability to automatically learn and adapt from data. A solution that relies upon embedded human knowledge (in form of rules and heuristics) or physics-based models (ex. a process simulator) is not ML. In practice, the most successful ML solutions use a hybrid approach of combining domain expertise and explicit models with data-based learning.

Machine Learning is not a once-trained system that produces predictions on prior training without continuous data analysis, training, and adaptation.

ATTRIBUTES:

- Meets the definition under the umbrella of AI
- Adaptive

Neural Networks

FORMAL DEFINITION: N/A

COMMON DESCRIPTION:

Neural Networks (NNs) are a specific mathematical tool that enables machine learning. While many other tools also enable programs to learn directly from data (ex. support vector machines, polynomial regression, etc.), NNs have become increasingly popular due to their ability to model systems of immense complexity. (Ng, 2020) Strictly speaking, a NN is a mathematical framework that converts a set of data inputs into a set of outputs via artificial neurons. The structure of a NN, and the data transformations that occur within, are loosely inspired by the structure and functionality of the human brain.

WHAT IT IS:

The term "Neural Networks" is often used in relation to "Deep Learning." A deep learning system is simply a neural network that has many hidden layers. However, there is no precise definition as to the number of hidden layers required for a system to qualify as deep learning.

- A model-free mathematical technique inspired by brain design to learn process patterns and relationships
- It may be steady state, dynamic, or both

WHAT IT ISN'T:

NNs are not new - they are a specific mathematical tool that was invented in the 1950s, primarily for scientific research. However, the usefulness of NNs for business applications was realized relatively recently (early 2010s), driven by an exponential increase in data availability and computational power.

It is not a method that relies on a-priori mathematical forms, models, or statistical rules, such as:

- First-principles models
- Expert systems
- Statistical (Bayesian, ANOVA) systems

ATTRIBUTES:

- Ability to model systems of unpredictable complexity
- A mathematical modeling/pattern recognition technique
- Predicts behavior based on training data
- No a-priori model form

APPLICATION TERMS

Manufacturing Execution System (MES)

FORMAL DEFINITION: N/A

COMMON DESCRIPTION:

"Manufacturing execution systems (MES) are computerized systems used in manufacturing, to track and document the transformation of raw materials to finished goods. MES provides information that helps manufacturing decision makers understand how current conditions on the plant floor can be optimized to improve production output.[1] MES works in real time to enable the control of multiple elements of the production process (e.g., inputs, personnel, machines and support services)." (Wikipedia, 2020)

WHAT IT IS:

- It is a broad range of supervisory functionality.
- An application that resides above deterministic field devices, communicates to these devices, tracks production and reports it to upper-level systems, and sends commands to process equipment
- MES acts as a conduit for production data into the Enterprise Resource Planning (ERP). It gives real-time resource utilization data context for transfer to the ERP.
- Batch executive control can be considered an MES application, as it schedules and sequences actions of process equipment and provides reports of the batch execution

WHAT IT ISN'T:

- It does not require deterministic processing, such as in the field device. Latency will not create instability or disruption.
- It is not a dynamic control application, such as Model Predictive Control (MPC) or supervisory level regulatory control. Control that depends on identification of the dynamic response of the process is not an MES application

ATTRIBUTES:

- Near real-time processing to ensure functions can be used during production
- Use process data as inputs to produce site wide operational information
- Supervisory functions that drive the process from site wide or enterprise-wide inputs

Asset Management System (AMS)

FORMAL DEFINITION: N/A

COMMON DESCRIPTION: N/A

WHAT IT IS:

- A digital system to maintain process equipment and instrumentation
- It is digitally connected to the actual process devices in order to enable online configuration and maintenance of the devices, including revisions of configuration files

WHAT IT ISN'T:

- It is not a disconnected, stand-alone system. For example, a spreadsheet or database that lists all devices, revision levels, and configuration data requiring manual update of data is not an AMS
- It is not a communication device to configure one single device at a time

ATTRIBUTES:

- Connected to the process
- A repository of information about process assets

Digital Twin

FORMAL DEFINITION:

"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" (ISO, 2020)

COMMON DESCRIPTION:

- "Imagine looking at your computer screen and seeing reality--an image of your city, for instance, complete with moving traffic patterns, or a picture that sketches the state of an entire far-flung corporation at this second. These representations are called Mirror Worlds" or in today' s case Digital Twin. (Gelernter, 1992)
- "elements of the Digital Twin: real space, virtual space, the link for data flow from real space to virtual space, the link for information flow from virtual space to real space and virtual sub-spaces." (Grieves, Digital Twin: Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems (Excerpt), 2016)

WHAT IT IS:

- A very broad term, which applies to any digital representation of a physical thing.
- It may include real-time process data for adapting or otherwise augmenting process models
- It may include the following:
- A dataset of process data
- An HMI
- Any digitally simulated process which allows prediction of process behavior based on simulated inputs, such as:
  - A hot standby control system with process simulation but no connectivity to the actual process
  - Tie-back of IO to produce a simple feedback for loops without accounting for dynamics or gain
  - An offline simulation of a process

WHAT IT ISN'T: N/A

ATTRIBUTES:

- Digital data that represents the physical process

Remote Monitoring

FORMAL DEFINITION: N/A

COMMON DESCRIPTION: N/A

WHAT IT IS:

The ability to access live process data off premises for analysis and monitoring.

WHAT IT ISN'T:

Accessing non-real-time process data, such as historical data or reports

ATTRIBUTES:

- Internet connectivity
- View of real-time process data

Predictive Maintenance

FORMAL DEFINITION: N/A

COMMON DESCRIPTION: N/A

WHAT IT IS:

A system that predicts the probability of equipment failure. It may include:

- Alarms on motor runtimes
- Online mathematical predictions of equipment failure probability

WHAT IT ISN'T: N/A

ATTRIBUTES:

- Provides digital indication of equipment health

Virtual Sensors/Virtual Online Analyzers/Soft Sensors

FORMAL DEFINITION: N/A

COMMON DESCRIPTION:

"Soft sensors are inferential estimators, drawing conclusions from process observations when hardware sensors are unavailable or unsuitable; they have an important auxiliary role in sensor validation when performance declines through senescence or fault accumulation." (Luigi Fortuna, 2007)

WHAT IT IS:

There is no single formal definition of soft sensors. Soft sensor refers to a software application that utilizes a set of process and/or product variables, both online and/or offline measurements to infer a crucial measurement that are physically measurable or unmeasurable for monitoring or control purposes.

Use of online mathematical models to infer process measurements when an instrument for a direct physical measurement is not available.

WHAT IT ISN'T: N/A

ATTRIBUTES:

- Real-time prediction
- Infer a process related parameter

Advanced Process Control (APC)/ Advanced Control/ Supervisory Control

FORMAL DEFINITION: N/A

COMMON DESCRIPTION:

"In advanced process control, process knowledge by way of process models is used to make the control system more intelligent. The process modeling topic (Chapter 17) shows how quantitative process models can provide process knowledge and inferential measurements, such as stream compositions, that can be less expensive, faster, and more reliable than the measurements from field analyzers. The quantitative models from Chapter 17 are used in this chapter

to provide better tuning settings, set points, and models and algorithms for feedback and feedforward control." (McMillan, 2018)

"In control theory, Advanced process control (APC) refers to a broad range of techniques and technologies implemented within industrial process control systems. Advanced process controls are usually deployed optionally and in addition to basic process controls. Basic process controls are designed and built with the process itself, to facilitate basic operation, control and automation requirements. Advanced process controls are typically added subsequently, often over the course of many years, to address particular performance or economic improvement opportunities in the process." (wikipedia, 2020)

WHAT IT IS:

A real-time, continuous, closed loop process control technique.

There is no single formal source or definition of Advanced Process Control. Advanced Process Control often refers to techniques or solutions that focus on overall control operation and/or optimization of industrial processes within given constraints on the top of basic process control loops like PID's

APC can be of any of the following forms:

MODEL: One form of APC uses a sophisticated process model for predictive control. Since PID is model based (2nd order differential equation), the sophistication of the model has to be distinguished. A sophisticated model has to have at least one of the following characteristics:

- Deadtime (Dahlin, IMC, Smith Predictor, etc.)
- Multiple input, multiple outputs (MPC, Relative Gain Array, etc.)
- Nonlinear relationship

MIMO: A PID loop controls only one measurement and final control element. Any technique that controls more than one measurement or final control element can be considered APC, such as :

- MPC
- Relative Gain Array

ADVANCED REGULATORY: Another form of APC is often referred to as Advanced Regulatory Control. These are techniques that enhance PID. These include:

- Feedforward
- Ratio
- Cascade
- Split range
- Adaptive gain

REPLACEMENT: Any form of realtime, continuous closed loop control that replaces PID can be considered APC, such as:

- Fuzzy Logic
- IMC

CASCADE: Any form of realtime, continuous closed loop control of PID setpoints can be considered APC, such as:

- An optimizer (to achieve operational and/or productional objectives within given constraints)

WHAT IT ISN'T:

- It is not an Industry 4.0 application; APC applications existed prior to the Internet. However, if APC is integrated with other Industry 4.0 technologies such as remote monitoring or cloud-based computing, it may be classified as an Industry 4.0 application
- Not a PID controller, because the process model used for tuning lacks the sophistication to be considered advanced
- It is not discrete (such as interlocks or motor logic) or sequential (such as batch) control

ATTRIBUTES:

- Realtime, deterministic closed loop control
- Not discrete
- Has at least one of the following attributes:
  - Model
  - MIMO
  - Advanced Regulatory
  - PID replacement
  - Cascade

Terms in Industry 4.0

This table reflects whether a term applies to a capability that is new in Industry 4.0.

TERMS	CATEGORY	INDEX	GROUP	NEW IN INDUSTRY 4.0
Industry 4.0	1	1	Industry	YES
Digitization	1	2	Industry	NO
Digitalization	1	3	Industry	NO
Digital Transformation	1	4	Industry	NO
IIoT	1	5	Industry	YES
Connected Enterprise	1	5	Industry	YES
Smart Manufacturing	1	5	Industry	YES
Edge	2	1	Infrastructure	YES
Cloud	2	2	Infrastructure	YES
Virtualization	2	3	Infrastructure	NO
Wireless	2	4	Infrastructure	NO
Electronic Device Description Language (EDDL)	2	5	Infrastructure	NO
Field Device Integration (FDI)	2	6	Infrastructure	NO
OPC UA	2	7	Infrastructure	NO
MQTT	2	8	Infrastructure	YES
Big Data	3	1	Technology	NO
Data Analytics	3	2	Technology	NO
Artificial Intelligence	3	3	Technology	NO
Machine Learning	3	4	Technology	NO
Neural Networks	3	5	Technology	NO
Manufacturing Execution System	4	1	Application	NO

Asset Management System	4	2	Application	NO
Digital Twin	4	3	Application	NO
Remote Monitoring	4	4	Application	YES
Predictive Maintenance	4	5	Application	NO
Virtual Sensors	4	6	Application	NO
Virtual Online Analyzers	4	6	Application	NO
Soft Sensors	4	6	Application	NO
Advanced Process Control	4	7	Application	NO

Table 4: Terms new or not in Industry 4.0

Keywords

Control systems, Automation, Information systems, Digital control

Additional Information

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References

Federal Ministry for Economic Affairs and Energy. (2020). *Plattform Industrie 4.0*. Retrieved from Indsutrie 4.0: https://www.plattform-i40.de/PI40/Navigation/EN/Industrie40/WhatIsIndustrie40/what-is-industrie40.html

Fieldbus Foundation. (2006). *EDDL*. Retrieved from Foundation Technology: http://www.fieldbus.org/index.php?option=com_content&task=view&id=140&Itemid=316

FieldComm Group. (2019, June 21). *TS62769-1 Field Device Integration (FDI) – Part 1: Overview*. Retrieved from FieldComm Group Library: https://library.fieldcommgroup.org/62769/TS62769-1/1.2/#page=8

Gartner. (2020). *Information Technology Glossary Big Data*. Retrieved from Gartner Glossary: https://www.gartner.com/en/information-technology/glossary/big-data

Gartner. (2020). *Information Technology Glossary Cloud Computing*. Retrieved from Gartner Glossary: https://www.gartner.com/en/information-technology/glossary/cloud-computing

Gartner. (2020). *Information Technology Glossary Digital Transformation*. Retrieved from Gartner Glossary: https://www.gartner.com/en/information-technology/glossary/digital-transformation

Gartner. (2020). *Information Technology Glossary Digitalization*. Retrieved from Gartner Glossary: https://www.gartner.com/en/information-technology/glossary/digitalization

Gartner. (2020). *Information Technology Glossary Digitization*. Retrieved from Gartner Glossary: https://www.gartner.com/en/information-technology/glossary/digitization

Gartner. (2020). *Information Technology Glossary Edge*. Retrieved from Gartner Glossary: https://www.gartner.com/en/information-technology/glossary/edge

Gartner. (2020). *Information Technology Glossary Virtualization*. Retrieved from Gartner Glossary: https://www.gartner.com/en/information-technology/glossary/virtualization

Gelernter, D. (1992). *Mirror Worlds.* Newy York: Oxford University Press.

Grieves, M. (2003). PLM - Beyond lean manufacturing. *Manufacturing Engineering*(130), 23-23.

Grieves, M. (2016, August). *Digital Twin: Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems (Excerpt).* Retrieved from ResearchGate: https://www.researchgate.net/publication/307509727_Origins_of_the_Digital_Twin_Concept

ISO. (2020). *ISO/DIS 23247-1(en). Automation systems and integration — Digital Twin framework for manufacturing — Part 1: Overview and general principles*. Retrieved from ISO: https://www.iso.org/obp/ui/#iso:std:iso:23247:-1:dis:ed-1:v1:en

Khawaja, J. (2014, August 21). *Five Things Big Data Isn't*. (Dataconomy Media Gmbh) Retrieved September 14, 2020, from Dataconomy: https://dataconomy.com/2014/08/five-things-big-data-isnt-2/

Liberty, D. (2019, January 2). *Data Science vs. Data Analytics — What's the Difference?* (Sisense) Retrieved September 14, 2020, from Business Perspectives: https://www.sisense.com/blog/data-science-vs-data-analytics/

Luigi Fortuna, S. G. (2007, January). *Soft Sensors for Monitoring and Control of Industrial Processes.* Retrieved from ResearchGate: https://www.researchgate.net/publication/321610308_Soft_Sensors_for_Monitoring_and_Control_of_Industrial_Processes

Marr, B. (2018, February 14). *Bernard Marr*. Retrieved 2020, from forbes: https://www.forbes.com/sites/bernardmarr/2018/02/14/the-key-definitions-of-artificial-intelligence-ai-that-explain-its-importance/#7905d2dc4f5d

McMillan, G. K. (2018). *A Guide to the Automation Body of Knowledge - 3rd edition.* Retrieved from ISA: https://www.isa.org/getmedia/b02b4a74-dcfd-4e01-b59a-c2cc51207650/ABoK-3rd-061318_Excerpt-final-1.pdf

MQTT. (2020). *FAQ*. Retrieved from MQTT: https://mqtt.org/faq/

Ng, A. (2020). *About this course*. Retrieved from Coursera: https://www.coursera.org/learn/machine-learning

OPC Foundation. (2020). *Unified Architecture*. Retrieved from About OPC Technologies: https://opcfoundation.org/about/opc-technologies/opc-ua/

Rouse, M. (2019, July). *data analytics (DA)*. (C. Stedman, Producer) Retrieved September 14, 2020, from SerachData Management TechTarget: https://searchdatamanagement.techtarget.com/definition/data-analytics

Sapuntzis, T. (2019, September 09). *IT Decision-Making Through the Lens of Gartner's Analytics Maturity Model*. Retrieved September 14, 2020, from numerify blog: https://www.numerify.com/blog/it-decision-making-through-the-lens-of-gartners-analytics-maturity-model/

Serokell. (2020, April 11). *Artificial Intelligence vs. Machine Learning vs. Deep Learning: What's the Difference*. Retrieved 2020, from Medium: https://medium.com/ai-in-plain-english/artificial-intelligence-vs-machine-learning-vs-deep-learning-whats-the-difference-dccce18efe7f

wikipedia. (2020, February 22). *Advanced process control.* Retrieved from wikipedia article: https://en.wikipedia.org/wiki/Advanced_process_control

Wikipedia. (2020, august 28). *Manufacturing execution system*. Retrieved from wiki article: https://en.wikipedia.org/wiki/Manufacturing_execution_system

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