Cyber manufacturing

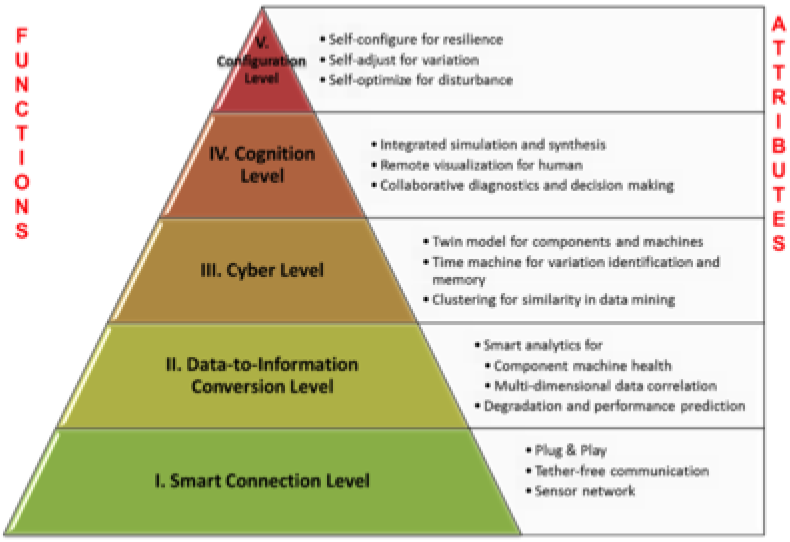
Cyber manufacturing is a concept derived from cyber-physical systems (CPS) that refers to a modern manufacturing system that offers an information-transparent environment to facilitate asset management, provide reconfigurability, and maintain productivity. Compared with conventional experience-based management systems, cyber manufacturing provides an evidence-based environment to keep equipment users aware of networked asset status, and transfer raw data into possible risks and actionable information. Driving technologies include design of cyber-physical systems, combination of engineering domain knowledge and computer sciences, as well as information technologies. Among them, mobile applications for manufacturing is an area of specific interest to industries and academia.[1]

Motivation

The idea of cyber manufacturing originates from the fact that Internet-enabled services have added business value in economic sectors such as retail, music, consumer products, transportation, and healthcare; however, compared to existing Internet-enabled sectors, manufacturing assets are less connected and less accessible in real-time. Besides, current manufacturing enterprises make decisions following a top-down approach: from overall equipment effectiveness to assignment of production requirements, without considering the condition of machines. This usually leads to inconsistency in operation management due to lack of linkage between factories, possible overstock in spare part inventory, as well as unexpected machine downtime. Such situation calls for connectivity between machines as a foundation, and analytics on top of that as a necessity to translate raw data into information that actually facilitates user decision making. Expected functionalities of cyber manufacturing systems include machine connectivity and data acquisition, machine health prognostics, fleet-based asset management, and manufacturing reconfigurability.

Technology

Several technologies are involved in developing cyber-manufacturing solutions. The following is a short description of these technologies and their involvement in cyber-manufacturing.



- **Cyber-physical system** is the foundation of cyber-manufacturing. Tools and methods within CPS enables possibility of reaching cyber-manufacturing goals.
- **Big Data Analytics** is the other significant technology participating in design and development of cyber-manufacturing systems. Connected machines in every industry raise the issue of proper data handling and

processing and cyber-manufacturing is not an exemption. Customized developments in cloud computing, artificial intelligence and predictive analytics are applicable in cyber-manufacturing.

Development

In 2013 the Office of Naval Research in the US Military has issued a proposal solicitation subjected for cyber-manufacturing.[2]

See also

- Big Data
- Industry 4.0
- Intelligent Maintenance Systems
- Computer security
- Print on demand
- Distributed manufacturing
- Prosumer
- Internet of things
- Automation
- Crowdsourcing
- In-product communication
- Cloud manufacturing
- Mass customization
- Supply chain network
- Global production network
- Computer-aided design
- Computer-aided engineering
- Resource allocation
- Peer production
- Cybernetics & feedback

References

1. "EAGER/Cybermanufacturing Systems: Fleet-Sourced Cyber Manufacturing Applications for Improved Transparency and Resilience of Manufacturing Assets and Systems" (https://www.nsf.gov/awardsearch/showAward?AWD_ID=1550433&HistoricalAwards=false). National Science Foundation (NSF). Retrieved 30 March 2016.
2. "Cyber-enabled Manufacturing Systems for Direct Digital Manufacturing (CeMS-DDM)" (http://www.onr.navy.mil/~/media/Files/Funding-Announcements/BAA/2014/14-004.ashx). The US Navy, Office of Naval Research. Retrieved 30 March 2016.

-

Digitization

Digitization[1] is the process of converting information into a digital (i.e. computer-readable) format.[2] The result is the representation of an object, image, sound, document, or signal (usually an analog signal) obtained by generating a series of numbers that describe a discrete set of points or samples.[3] The result is called *digital representation* or, more specifically, a *digital image*, for the object, and *digital form*, for the signal. In modern practice, the digitized data is in the form of binary numbers, which facilitates processing by digital computers and other operations, but digitizing simply means "the conversion of analog source material into a numerical format"; the decimal or any other number system can be used instead.[4]

Internet Archive book scanner

Digitization is of crucial importance to data processing, storage, and transmission, because it "allows information of all kinds in all formats to be carried with the same efficiency and also intermingled."[5] Though analog data is typically more stable, digital data has the potential to be more easily shared and accessed and, in theory, can be propagated indefinitely without generation loss, provided it is migrated to new, stable formats as needed.[6] This potential has led to institutional digitization projects designed to improve access and the rapid growth of the digital preservation field.[7]

Sometimes digitization and digital preservation are mistaken for the same thing. They are different, but digitization is often a vital first step in digital preservation.[8] Libraries, archives, museums, and other memory institutions digitize items to preserve fragile materials and create more access points for patrons.[9] Doing this creates challenges for information professionals and solutions can be as varied as the institutions that implement them.[10] Some analog materials, such as audio and video tapes, are nearing the end of their life cycle, and it is important to digitize them before equipment obsolescence and media deterioration makes the data irretrievable.[11]

There are challenges and implications surrounding digitization including time, cost, cultural history concerns, and creating an equitable platform for historically marginalized voices.[12] Many digitizing institutions develop their own solutions to these challenges.[9]

Mass digitization projects have had mixed results over the years, but some institutions have had success even if not in the traditional Google Books model.[13] Although e-books have undermined the sales of their printed counterparts, a study from 2017 indicated that the two cater to different audiences and use-cases.[14] In a study of over 1400 university students it was found that physical literature is more apt for intense studies while e-books provide a superior experience for leisurely reading.[14]

Technological changes can happen often and quickly, so digitization standards are difficult to keep updated. Professionals in the field can attend conferences and join organizations and working groups to keep their knowledge current and add to the conversation.[15]

Process

The term digitization is often used when diverse forms of information, such as an object, text, sound, image, or voice, are converted into a single binary code. The core of the process is the compromise between the capturing device and the player device so that the rendered result represents the original source with the most possible fidelity, and the advantage of digitization is the speed and accuracy in which this form of information can be transmitted with no degradation compared with analog information.

Digital information exists as one of two digits, either 0 or 1. These are known as bits (a contraction of *binary digits*) and the sequences of 0s and 1s that constitute information are called bytes.[16]

Analog signals are continuously variable, both in the number of possible values of the signal *at* a given time, as well as in the number of points in the signal *in* a given period of time. However, digital signals are discrete in both of those respects – generally a finite sequence of integers – therefore a digitization can, in practical terms, only ever be an approximation of the signal it represents.

Digitization occurs in two parts:

Discretization
: The reading of an analog signal *A*, and, at regular time intervals (frequency), sampling the value of the signal at the point. Each such reading is called a *sample* and may be considered to have infinite precision at this stage;

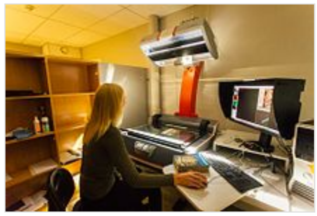
Quantization
: Samples are rounded to a fixed set of numbers (such as integers), a process known as quantization.

In general, these can occur at the same time, though they are conceptually distinct.

A series of digital integers can be transformed into an analog output that approximates the original analog signal. Such a transformation is called a digital-to-analog conversion. The sampling rate and the number of bits used to represent the integers combine to determine how close such an approximation to the analog signal a digitization will be.

Examples

The term is used to describe, for example, the scanning of analog sources (such as printed photos or taped videos) into computers for editing, 3D scanning that creates 3D modeling of an object's surface, and audio (where sampling rate is often measured in kilohertz) and texture map transformations. In this last case, as in normal photos, the sampling rate refers to the resolution of the image, often measured in pixels per inch.



Digitization of the first number of Estonian popular science magazine *Horisont* published in January 1967

Digitizing is the primary way of storing images in a form suitable for transmission and computer processing, whether scanned from two-dimensional analog originals or captured using an image sensor-equipped device such as a digital camera, tomographical instrument such as a CAT scanner, or acquiring precise dimensions from a real-world object, such as a car, using a 3D scanning device.[17]

Digitizing is central to making digital representations of geographical features, using raster or vector images, in a geographic information system, i.e., the creation of electronic maps, either from various geographical and satellite imaging (raster) or by digitizing traditional paper maps or graphs (vector).

"Digitization" is also used to describe the process of populating databases with files or data. While this usage is technically inaccurate, it originates with the previously proper use of the term to describe that part of the process involving digitization of analog sources, such as printed pictures and brochures, before uploading to target databases.[3]

Digitizing may also be used in the field of apparel, where an image may be recreated with the help of embroidery digitizing software tools and saved as embroidery machine code. This machine code is fed into an embroidery machine and applied to the fabric. The most supported format is DST file. Apparel companies also digitize clothing patterns.[18]

History

- 1957 The Standards Electronic Automatic Computer (SEAC) was invented.[19] That same year, Russell Kirsch used a rotating drum scanner and photomultiplier connected to SEAC to create the first digital image (176x176 pixels) from a photo of his infant son.[20][21] This image was stored in SEAC memory via a staticizer and viewed via a cathode ray oscilloscope.[22][21]
- 1971 Invention of Charge-Coupled Devices that made conversion from analog data to a digital format easy.[19]
- 1986 work started on the JPEG format.[19]
- 1990s Libraries began scanning collections to provide access via the world wide web.[13]

Analog signals to digital

Analog signals are continuous electrical signals; digital signals are non-continuous. Analog signals can be converted to digital signals by using an analog-to-digital converter.[23]

The process of converting analog to digital consists of two parts: sampling and quantizing. Sampling measures wave amplitudes at regular intervals, splits them along the vertical axis, and assigns them a numerical value, while quantizing looks for measurements that are between binary values and rounds them up or down.[24]

Nearly all recorded music has been digitized, and about 12 percent of the 500,000+ movies listed on the Internet Movie Database are digitized and were released on DVD.[25][26]

Digitization of home movies, slides, and photographs is a popular method of preserving and sharing personal multimedia. Slides and photographs may be scanned quickly using an image scanner, but analog video requires a video tape player to be connected to a computer while the item plays in real time.[27][28] Slides can be digitized quicker with a slide scanner such as the Nikon Coolscan 5000ED.[29]

Another example of digitization is the VisualAudio process developed by the Swiss *Fonoteca Nazionale* in Lugano, by scanning a high resolution photograph of a record, they are able to extract and reconstruct the sound from the processed image.[30]

Digitization of analog tapes before they degrade, or after damage has already occurred, can rescue the only copies of local and traditional cultural music for future generations to study and enjoy.[31][32]

Analog texts to digital

Academic and public libraries, foundations, and private companies like Google are scanning older print books and applying optical character recognition (OCR) technologies so they can be keyword searched, but as of 2006, only about 1 in 20 texts had been digitized.[3][33] Librarians and archivists are working to increase this statistic and in 2019 began digitizing 480,000 books published between 1923 and 1964 that had entered the public domain.[34]

Book scanner in the digitization lab at the University of Liège, Belgium

Unpublished manuscripts and other rare papers and documents housed in special collections are being digitized by libraries and archives, but backlogs often slow this process and keep materials with enduring historical and research value hidden from most users (see digital libraries).[35] Digitization has not completely replaced other archival imaging options, such as microfilming which is still used by institutions such as the National Archives and Records Administration (NARA) to provide preservation and access to these resources.[36][37]

While digital versions of analog texts can potentially be accessed from anywhere in the world, they are not as stable as most print materials or manuscripts and are unlikely to be accessible decades from now without further preservation efforts, while many books manuscripts and scrolls have already been around for centuries.[31] However, for some materials that have been damaged by water, insects, or catastrophes, digitization might be the only option for continued use.[31]

Library preservation


Digitization at the British Library of a Dunhuang manuscript for the International Dunhuang Project

In the context of libraries, archives, and museums, digitization is a means of creating digital surrogates of analog materials, such as books, newspapers, microfilm and videotapes, offers a variety of benefits, including increasing access, especially for patrons at a distance; contributing to collection development, through collaborative initiatives; enhancing the potential for research and education; and supporting preservation activities.[38] Digitization can provide a means of preserving the content of the materials by creating an accessible facsimile of the object in order to put less strain on already fragile originals. For sounds, digitization of legacy analog recordings is essential insurance against technological obsolescence.[39] A fundamental aspect of planning digitization projects is to ensure that the digital files themselves are preserved and remain accessible;[40] the term "digital preservation," in its most basic sense, refers to an array of activities undertaken to maintain access to digital materials over time.[41]

The prevalent Brittle Books issue facing libraries across the world is being addressed with a digital solution for long term book preservation.[42] Since the mid-1800s, books were printed on wood-pulp paper, which turns acidic as it decays. Deterioration may advance to a point where a book is completely unusable. In theory, if these widely circulated titles are not treated with de-acidification processes, the materials upon those acid pages will be lost. As digital technology evolves, it is increasingly preferred as a method of preserving these materials, mainly because it can provide easier access points and significantly reduce the need for physical storage space.

Cambridge University Library is working on the Cambridge Digital Library, which will initially contain digitised versions of many of its most important works relating to science and religion. These include examples such as Isaac Newton's personally annotated first edition of his *Philosophiæ Naturalis Principia Mathematica*[43] as well as college notebooks[44][45] and other papers,[46] and some Islamic manuscripts such as a Quran[47] from Tipu Sahib's library.

Google, Inc. has taken steps towards attempting to digitize every title with "Google Book Search".[48] While some academic libraries have been contracted by the service, issues of copyright law violations threaten to derail the project.[49] However, it does provide – at the very least – an online consortium for libraries to exchange information and for researchers to search for titles as well as review the materials.

Digitization versus digital preservation

Digitizing something is not the same as digitally preserving it.[8] To digitize something is to create a digital surrogate (copy or format) of an existing analog item (book, photograph, or record) and is often described as converting it from analog to digital, however both copies remain.[4][50] An example would be scanning a photograph and having the original piece in a photo album and a digital copy saved to a computer. This is essentially the first step in digital preservation which is to maintain the digital copy over a long period of time and making sure it remains authentic and accessible.[51][8][6]

Digitization is done once with the technology currently available, while digital preservation is more complicated because technology changes so quickly that a once popular storage format may become obsolete before it breaks.[6] An example is a 5 1/4" floppy drive, computers are no longer made with them and obtaining the hardware to convert a file stored on 5 1/4" floppy disc can be expensive. To combat this risk, equipment must be upgraded as newer technology becomes affordable (about 2 to 5 years), but before older technology becomes unobtainable (about 5 to 10 years).[52][6]

Digital preservation can also apply to born-digital material, such as a Microsoft Word document or a social media post.[53] In contrast, digitization only applies exclusively to analog materials. Born-digital materials present a unique challenge to digital preservation not only due to technological obsolescence but also because of the inherently unstable nature of digital storage and maintenance.[6] Most websites last between 2.5 and 5 years, depending on the purpose for which they were designed.[54]

The Library of Congress provides numerous resources and tips for individuals looking to practice digitization and digital preservation for their personal collections.[55]

Digital reformatting

Digital reformatting is the process of converting analog materials into a digital format as a surrogate of the original. The digital surrogates perform a preservation function by reducing or eliminating the use of the original. Digital reformatting is guided by established best practices to ensure that materials are being converted at the highest quality.

Digital reformatting at the Library of Congress

The Library of Congress has been actively reformatting materials for its American Memory project and developed best standards and practices pertaining to book handling during the digitization process, scanning resolutions, and preferred file formats.[56] Some of these standards are:

- The use of ISO 16067-1 and ISO 16067-2 standards for resolution requirements.
- Recommended 400 ppi resolution for OCR'ed printed text.

- The use of 24-bit color when color is an important attribute of a document.
- The use of the scanning device's maximum resolution for digitally reproducing photographs
- TIFF as the standard file format.
- Attachment of descriptive, structural, and technical metadata to all digitized documents.

A list of archival standards for digital preservation can be found on the ARL website.[57]

The Library of Congress has constituted a Preservation Digital Reformatting Program.[58] The Three main components of the program include:

- Selection Criteria for digital reformatting
- Digital reformatting principles and specifications
- Life cycle management of LC digital data

Audio digitization and reformatting

Audio media offers a rich source of historic ethnographic information, with the earliest forms of recorded sound dating back to 1890.[59] According to the International Association of Sound and Audiovisual Archives (IASA), these sources of audio data, as well as the aging technologies used to play them back, are in imminent danger of permanent loss due to degradation and obsolescence.[60] These primary sources are called “carriers” and exist in a variety of formats, including wax cylinders, magnetic tape, and flat discs of grooved media, among others. Some formats are susceptible to more severe, or quicker, degradation than others. For instance, lacquer discs suffer from delamination. Analog tape may deteriorate due to sticky shed syndrome.[61]

1/4" analog tape being played back on a Studer A810 tape machine for digitization at Smithsonian Folkways Recordings

Archival workflow and file standardization have been developed to minimize loss of information from the original carrier to the resulting digital file as digitization is underway. For most at-risk formats (magnetic tape, grooved cylinders, etc.), a similar workflow can be observed. Examination of the source carrier will help determine what, if any, steps need to be taken to repair material prior to transfer. A similar inspection must be undertaken for the playback machines. If satisfactory conditions are met for both carrier and playback machine, the transfer can take place, moderated by an analog-to-digital converter.[62] The digital signal is then represented visually for the transfer engineer by a digital audio workstation, like Audacity, WaveLab, or Pro Tools. Reference access copies can be made at smaller sample rates. For archival purposes, it is standard to transfer at a sample rate of 96 kHz and a bit depth of 24 bits per channel.[59]

Challenges

Many libraries, archives, museums, and other memory institutions, struggle with catching up and staying current regarding digitization and the expectation that everything should already be online.[63][64] The time spent planning, doing the work, and processing the digital files along with the expense and fragility of some materials are some of the most common.

Time spent

Digitization is a time-consuming process, even more so when the condition or format of the analog resources requires special handling.[65] Deciding what part of a collection to digitize can sometimes take longer than digitizing it in its entirety.[66] Each digitization project is unique and workflows for one will be different from every other project that goes through the process, so time must be spent thoroughly studying and planning each one to create the best plan for the materials and the intended audience.[67]

Expense

Cost of equipment, staff time, metadata creation, and digital storage media make large scale digitization of collections expensive for all types of cultural institutions.[68]

Ideally, all institutions want their digital copies to have the best image quality so a high-quality copy can be maintained over time.[68] In the mid-long term, digital storage would be regarded as the more expensive part to maintain the digital archives due to the increasing number of scanning requests.[69] However, smaller institutions may not be able to afford such equipment or manpower, which limits how much material can be digitized, so archivists and librarians must know what their patrons need and prioritize digitization of those items.[70] To help the information institutions to better decide the archives worth of digitization, Casablancas and other researchers used a proposed model to investigate the impact of different digitization strategies on the decrease in access requests in the archival and library reading rooms.[69] Often the cost of time and expertise involved with describing materials and adding metadata is more than the digitization process.[31]

Fragility of materials

Some materials, such as brittle books, are so fragile that undergoing the process of digitization could damage them irreparably.[66][70] Despite potential damage, one reason for digitizing fragile materials is because they are so heavily used that creating a digital surrogate will help preserve the original copy long past its expected lifetime and increase access to the item.[9]

Copyright

Copyright is not only a problem faced by projects like Google Books, but by institutions that may need to contact private citizens or institutions mentioned in archival documents for permission to scan the items for digital collections.[68] It can be time consuming to make sure all potential copyright holders have given permission, but if copyright cannot be determined or cleared, it may be necessary to restrict even digital materials to in library use.[31][68]

Solutions

Institutions can make digitization more cost-effective by planning before a project begins, including outlining what they hope to accomplish and the minimum amount of equipment, time, and effort that can meet those goals.[9] If a budget needs more money to cover the cost of equipment or staff, an institution might investigate if grants are available.[9][68]

Collaboration

Collaborations between institutions have the potential to save money on equipment, staff, and training as individual members share their equipment, manpower, and skills rather than pay outside organizations to provide these services.[10] Collaborations with donors can build long-term support of current and future digitization projects.[71][64]

Outsourcing

Outsourcing can be an option if an institution does not want to invest in equipment but since most vendors require an inventory and basic metadata for materials, this is not an option for institutions hoping to digitize without processing.[64][68]

Non-traditional staffing

Many institutions have the option of using volunteers, student employees, or temporary employees on projects. While this saves on staffing costs, it can add costs elsewhere such as on training or having to re-scan items due to poor quality.[64][72]

MPLP

One way to save time and resources is by using the More Product, Less Process (MPLP) method to digitize materials while they are being processed.[63] Since GLAM (Galleries, Libraries, Archives, and Museums) institutions are already committed to preserving analog materials from special collections, digital access copies do not need to be high-resolution preservation copies, just good enough to provide access to rare materials.[66] Sometimes institutions can get by with 300 dpi JPGs rather than a 600 dpi TIFF for images, and a 300 dpi grayscale scan of a document rather than a color one at 600 dpi.[68][73]

Digitizing marginalized voices

Digitization can be used to highlight voices of historically marginalized peoples and add them to the greater body of knowledge. Many projects, some community archives created by members of those groups, are doing this in a way that supports the people, values their input and collaboration, and gives them a sense of ownership of the collection.[74][12] Examples of projects are Gi-gikinomaage-min and the South Asian American Digital Archive (SAADA).

Gi-gikinomaage-min

Gi-gikinomaage-min is Anishinaabemowin for "We are all teachers" and its main purpose is "to document the history of Native Americans in Grand Rapids, Michigan."[75] It combines new audio and video oral histories with digitized flyers, posters, and newsletters from Grand Valley State University's analog collections.[75] Although not entirely a newly digitized project, what was created also added item-level metadata to enhance context. At the start, collaboration between several university departments and the Native American population was deemed important and remained strong throughout the project.[75]

SAADA

The South Asian American Digital Archive (SAADA) has no physical building, is entirely digital and everything is handled by volunteers.[76] This archive was started by Michelle Caswell and Samip Mallick and collects a broad variety of materials "created by or about people residing in the United States who trace their heritage to Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, Sri Lanka, and the many South Asian diaspora communities across the globe."[76] (Caswell, 2015, 2). The collection of digitized items includes private, government, and university held materials.[76]

Black Campus Movement Collection (BCM)

Kent State University began its BCM collection when it acquired the papers of African American alumnus Lafayette Tolliver, which included about 1,000 photographs that chronicled the black student experience at Kent State from 1968-1971.[12] The collection continues to add materials from the 1960s up to and including the current student body and several oral histories have been added since it debuted.[12] When digitizing the items, it was necessary to work with alumni to create descriptions for the images. This collaboration created changes in local controlled vocabularies the libraries used to create metadata for the images.[12]

Mass digitization

The expectation that everything should be online has led to mass digitization practices, but it is an ongoing process with obstacles that have led to alternatives.[66] As new technology makes automated scanning of materials safer for materials and decreases need for cropping and de-skewing, mass digitization should be able to increase.[66]

Obstacles

Digitization can be a physically slow process involving selection and preparation of collections that can take years if materials need to be compared for completeness or are vulnerable to damage.[77] Price of specialized equipment, storage costs, website maintenance, quality control, and retrieval system limitations all add to the problems of working on a large scale.[77]

Data privacy and security

Digitization presents significant challenges related to data privacy and security.[78] As organizations increasingly depend on electronic databases and information systems, their vulnerability to security threats also rises.[79] The risk of data loss rises and cyberattacks can result in significant financial losses and damage the company’s reputation .[79] Therefore, there is a need for better cybersecurity measures and protection of data security and privacy to decrease the risks associated with digitization.[79]

Successes

Digitization on demand

Scanning materials as users ask for them, provides copies for others to use and cuts down on repeated copying of popular items. If one part of a folder, document, or book is asked for, scanning the entire object can save time in the future by already having the material access if someone else needs the material.[66][77] Digitizing on demand can increase volume because time spent on selection and prep has been used on scanning instead.[77]

Google Books

From the start, Google has concentrated on text rather than images or special collections.[77] Although criticized in the past for poor image quality, selection practices, and lacking long-term preservation plans, their focus on quantity over quality has enabled Google to digitize more books than other digitizers.[66][77]

Standards

Digitization is not a static field and standards change with new technology, so it is up to digitization managers to stay current with new developments.[15] Although each digitization project is different, common standards in formats, metadata, quality, naming, and file storage should be used to give the best chance of interoperability and patron access.[80] As digitization is often the first step in digital preservation, questions about how to handle digital files should be addressed in institutional standards.[7]

A standard for still images adapted from the Smithsonian digitization standards might include the following:[81]

Still Image Digitization Standards							
Filename format	**Analog Material Type**	**Color or B&W**	**Resolution of Scan**	**RGB Setting for Scan**	**Digital File Format**	**File Compression**	**Metadata**
YYYYMMDD_CollectionID#_Image#	35 mm print	Color	600 ppi	24 bit; 8 bits per color channel	TIFF	None	Follow Local Controlled Vocabularies and LC SH and NAF
YYYYMMDD_CollectionID#_Image#	35 mm slide	Color	1400 ppi	24 Bit; 8 bits per color channel	TIFF	None	Follow Local Controlled Vocabularies and LC SH and NAF
YYYYMMDD_CollectionID#_Image#	microform	B&W	300 ppi	24 Bit	TIFF	None	Follow Local Controlled Vocabularies and LC SH and NAF

Resources to create local standards are available from the Society of American Archivists, the Smithsonian, and the Northeast Document Conservation Center.[82][81][15]

Implications

Cultural heritage concerns

Digitization of community archives by indigenous and other marginalized people has led to traditional memory institutions reassessing how they digitize and handle objects in their collections that may have ties to these groups.[74] The topics they are rethinking are varied and include how items are chosen for digitization projects, what metadata to use to convey proper context to be retrievable by the groups they represent, and whether an item should be accessed by the world or just those who the groups originally intended to have access, such as elders.[74] Many navigate these concerns by collaborating with the communities they seek to represent through their digitized collections.[74]

Lean philosophy

The broad use of internet and the increasing popularity of lean philosophy has also increased the use and meaning of "digitizing" to describe improvements in the efficiency of organizational processes. Lean philosophy refers to the approach which considers any use of time and resources, which does not lead directly to creating a product, as waste and therefore a target for elimination. This will often involve some kind of Lean process in order to simplify process activities, with the aim of implementing new "lean and mean" processes by digitizing data and activities. Digitization can help to eliminate time waste by introducing wider access to data, or by the implementation of enterprise resource planning systems.

Fiction

Works of science-fiction often include the term digitize as the act of transforming people into digital signals and sending them into digital technology. When that happens, the people disappear from the real world and appear in a virtual world (as featured in the cult film *Tron*, the animated series *Code: Lyoko*, or the late 1980s live-action series *Captain Power and the Soldiers of the Future*). In the video game *Beyond Good & Evil*, the protagonist's holographic friend digitizes the player's inventory items. One Super Friends cartoon episode showed Wonder Woman and Jayna freeing the world's men (including the male super heroes) onto computer tape by the female villainess Medula.[83]

Mind uploading

Mind uploading is the (as of 2023) speculative process of copying a human mind into a digital computer so it can be emulated there. This would require some form of advanced brain scan far more detailed than what is currently possible.

See also

- Book scanning
- Digital audio
- Digital library
- Economics of digitization
- ENUMERATE
- Fourth Industrial Revolution
- Frame grabber
- Newspaper digitization
- Optical character recognition
- Raster to vector
- Scannebago

References

1. "What is digitization?" (https://www.techtarget.com/whatis/definition/digitization). *WhatIs.com*. Retrieved 2023-04-14.
2. Collins Dictionary. (n.d.). Definition of 'digitize'. Retrieved December 15, 2021, from https://www.collinsdictionary.com/dictionary/english/digitize
3. Mirzagayeva, Shamiya; Aslanov, Heydar (2022-12-15). "The digitalization process: what has it led to, and what can we expect in the future?" (https://web.archive.org/web/20221112173332/https://metafizikajurnali.az/storage/images/site/files/Metafizika-20/Metafizika.Vol.5,No.4,Serial.20,pp.10-21.pdf) (PDF). *Metafizika*. **5** (4): 10–21. eISSN 2617-751X (https://www.worldcat.org/issn/2617-751X). ISSN 2616-6879 (https://www.worldcat.org/issn/2616-6879). OCLC 1117709579 (https://www.worldcat.org/oclc/1117709579). Archived from the original (https://metafizikajurnali.az/storage/images/site/files/Metafizika-20/Metafizika.Vol.5%2CNo.4%2CSerial.20%2Cpp.10-21.pdf) (PDF) on 2022-11-12. Retrieved 2022-10-14.
4. Bloomberg, Jason. "Digitization, Digitalization, And Digital Transformation: Confuse Them At Your Peril" (https://www.forbes.com/sites/jasonbloomberg/2018/04/29/digitization-digitalization-and-digital-transformation-confuse-them-at-your-peril/). *Forbes*. Retrieved 2023-04-14.
5. McQuail, D. (2000). *McQuail's mass communication theory* (4th edition). Sage.
6. Brown, A. (2013). *Practical digital preservation: A how-to guide for organizations of any size*. Neal Schuman.
7. Daigle, Bradley J. (2012). "The Digital Transformation of Special Collections". *Journal of Library Administration*. **52** (3–4): 244–264. doi:10.1080/01930826.2012.684504 (https://doi.org/10.1080%2F01930826.2012.684504). S2CID 56527894 (https://api.semanticscholar.org/CorpusID:56527894).

8. LeFurgy, Bill (2011-07-15). "Digitization is Different than Digital Preservation: Help Prevent Digital Orphans! | The Signal" (https://blogs.loc.gov/thesignal/2011/07/digitization-is-different-than-digital-preservation-help-prevent-digital-orphans/). *The Library of Congress*. Retrieved 2023-04-14.
9. Riley-Reid, Trevar D. (2015). "The hidden cost of digitization – things to consider". *Collection Building*. **34** (3): 89–93. doi:10.1108/CB-01-2015-0001 (https://doi.org/10.1108%2FCB-01-2015-0001).
10. "Collaboration between libraries, archives and museums (LAMS) in the digitisation of information in South Africa" (https://scholar.google.com/citations?view_op=view_citation&hl=en&user=3phltK0AAAAJ&citation_for_view=3phltK0AAAAJ:d1gkVwhDpl0C). *scholar.google.com*. Retrieved 2023-04-14.
11. "Moving pictures and sound - Digital Preservation Handbook" (https://www.dpconline.org/handbook/moving-pictures-and-sound?Itemid=501). *www.dpconline.org*. Retrieved 2023-04-14.
12. Hughes-Watkins, Lae'l (2018-05-16). "Moving Toward a Reparative Archive: A Roadmap for a Holistic Approach to Disrupting Homogenous Histories in Academic Repositories and Creating Inclusive Spaces for Marginalized Voices" (https://elischolar.library.yale.edu/jcas/vol5/iss1/6). *Journal of Contemporary Archival Studies*. **5** (1). ISSN 2380-8845 (https://www.worldcat.org/issn/2380-8845).
13. Verheusen, A. (2008). Mass digitization by libraries: Issues concerning organisation, quality and efficiency. *LIBER Quarterly*, 18(1), 28-38.
14. Yoo, Dong Kyoon; Roh, James Jungbae (2019-03-04). "Adoption of e-Books: A Digital Textbook Perspective" (https://www.tandfonline.com/doi/full/10.1080/08874417.2017.1318688). *Journal of Computer Information Systems*. **59** (2): 136–145. doi:10.1080/08874417.2017.1318688 (https://doi.org/10.1080%2F08874417.2017.1318688). ISSN 0887-4417 (https://www.worldcat.org/issn/0887-4417).
15. "Session 7: Reformatting and Digitization" (https://www.nedcc.org/preservation101/session-7/7digitization). *Northeast Document Conservation Center*. Retrieved 2023-04-14.
16. Flew, Terry. 2008. New Media An Introduction. South Melbourne. 3rd Edition. South Melbourne: Oxford University Press.
17. "Digimation | 3D Training and Simulation" (https://digimation.com/). Retrieved 2023-04-14.
18. Hedstrom, Margaret (1997-05-01). "Digital Preservation: A Time Bomb for Digital Libraries" (https://deepblue.lib.umich.edu/bitstream/2027.42/42573/1/10579_2004_Article_153071.pdf) (PDF). *Computers and the Humanities*. **31** (3): 189–202. doi:10.1023/A:1000676723815 (https://doi.org/10.1023%2FA%3A1000676723815). hdl:2027.42/42573 (https://hdl.handle.net/2027.42%2F42573). ISSN 1572-8412 (https://www.worldcat.org/issn/1572-8412). S2CID 15327062 (https://api.semanticscholar.org/CorpusID:15327062).
19. "What is the History of Digitization?" (https://kodakdigitizing.com/blogs/news/what-is-the-history-of-digitization). *Kodak Digitizing*. Retrieved 2023-04-14.
20. "Square Pixel Inventor Tries to Smooth Things Out" (https://www.wired.com/2010/06/smoothing-square-pixels/). *Wired*. ISSN 1059-1028 (https://www.worldcat.org/issn/1059-1028). Retrieved 2023-04-14.
21. Kirsch, R. A. (2001, January). Computer development at the National Bureau of Standards. *A Century of Excellence in Measurements, Standards, and Technology: A Chronicle of Selected NBS/NIST Publications, 1901-2000.* https://nistdigitalarchives.contentdm.oclc.org/digital/collection/p15421coll5/id/1386
22. Kirsch, R. A. (1988). Earliest image processing. *IEEE Annals of the History of Computing, 20*(2). https://tsapps.nist.gov/publication/get_pdf.cfm?pub_id=821701
23. ICT Technologies. (2004, February 3). *Analog vs. digital signals*. Chapter 3: Module 2: Communication Systems. Archived from the original on March 3, 2008. Retrieved on December 15, 2021, from https://tsapps.nist.gov/publication/get_pdf.cfm?pub_id=821701
24. "How do we convert audio from analogue to digital and back?" (https://www.sciencefocus.com/science/how-do-we-convert-audio-from-analogue-to-digital-and-back/). *BBC Science Focus Magazine*. Retrieved 2023-04-14.
25. Lee, K.H.; Slattery, O.; Lu, R.; Tang, X.; McCrary, V. (2002). "The state of the art and practice in digital preservation" (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4865277). *Journal of Research of the National Institute of Standards and Technology*. **107** (1): 93–106. doi:10.6028/jres.107.010 (https://doi.org/10.6028%2Fjres.107.010). PMC 4865277 (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4865277). PMID 27446721 (https://pubmed.ncbi.nlm.nih.gov/27446721).
26. Waldfogel, Joel (2017). "How Digitization Has Created a Golden Age of Music, Movies, Books, and Television" (https://doi.org/10.1257%2Fjep.31.3.195). *Journal of Economic Perspectives*. **31** (3): 195–214. doi:10.1257/jep.31.3.195 (https://doi.org/10.1257%2Fjep.31.3.195).
27. "Good-bye, VHS; Hello, DVD" (https://www2.computerworld.co.nz/article/89569/good-bye_vhs_hello_dvd/). *Computerworld New Zealand*. Retrieved 2023-04-14.
28. Moses, Jeanette D. (2021-02-20). "How to digitize VHS tapes" (https://www.tomsguide.com/how-to/digitize-vhs-tapes). *Tom's Guide*. Retrieved 2023-04-14.
29. "Super COOLSCAN 5000 ED | Nikon" (https://www.nikonusa.com/en/nikon-products/product-archive/film-scanners/super-coolscan-5000-ed.html). *www.nikonusa.com*. Retrieved 2023-04-14.
30. "Swiss National Sound Archives" (https://www.fonoteca.ch/index_en.htm). *www.fonoteca.ch*. Retrieved 2023-04-14.
31. Breeding, Marshall (2014-11-01). "Ongoing Challenges in Digitization" (https://librarytechnology.org/document/20128). *Computers in Libraries*. **34** (9): 16–18.
32. Champion, N. (2013, February/March). Delivering music digitisation projects: Issues and challenges. *Crescendo, 92*, 12-18.
33. Google. (2004, December 14). *Google checks out library books* [Press release]. http://googlepress.blogspot.com/2004/12/google-checks-out-library-books.html
34. "Libraries & Archivists Are Digitizing 480,000 Books Published in 20th Century That Are Secretly in the Public Domain | Open Culture" (https://www.openculture.com/2019/09/libraries-archivists-are-digitizing-480000-books.html). Retrieved 2023-04-14.
35. Tam, Marcella (2017). "Improving Access and "Unhiding" the Special Collections". *The Serials Librarian*. **73** (2): 179–185. doi:10.1080/0361526X.2017.1329178 (https://doi.org/10.1080%2F0361526X.2017.1329178). S2CID 196043867 (https://api.semanticscholar.org/CorpusID:196043867).
36. "Microfilm" (https://www.archives.gov/preservation/formats/microfilming.html). *National Archives*. 2016-08-15. Retrieved 2023-04-14.
37. CMCCONNELL (2013-08-16). "1. Microforms in Libraries and Archives" (https://www.ala.org/alcts/resources/collect/serials/microforms01). *Association for Library Collections & Technical Services (ALCTS)*. Retrieved 2023-04-14.
38. Hughes, Lorna M. (2004). *Digitizing Collections: Strategic Issues for the Information Manager*. London: Facet Publishing. ISBN 1-85604-466-1. Chapter 1, "Why digitize? The costs and benefits of digitization", p. 3-30; here, especially p. 9-17.
39. "Guidelines on the Production and Preservation of Digital Audio Objects (web edition)" (http://www.iasa-web.org/tc04/audio-preservation). *iasa-web.org*.
40. Hughes (2004), p. 204.
41. Caplan, Priscilla (February–March 2008). "What is Digital Preservation?" (https://journals.ala.org/ltr/article/view/4224/4808). *Library Technology Reports*. **44** (2): 7. Retrieved 2016-10-26.
42. Cloonan, M.V. and Sanett, S. "The Preservation of Digital Content," Libraries and the Academy. Vol. 5, No. 2 (2005): 213–37.
43. Newton, Isaac. "Philosophiæ Naturalis Principia Mathematica" (http://cudl.lib.cam.ac.uk/view/PR-ADV-B-00039-00001/). Cambridge University Digital Library. Retrieved 10 January 2012.

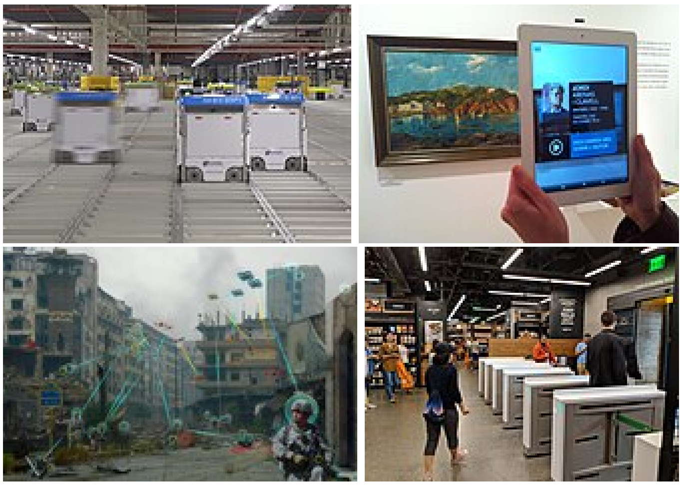
44. Newton, Isaac. "Trinity College Notebook" (http://cudl.lib.cam.ac.uk/view/MS-ADD-03996/). Cambridge University Digital Library. Retrieved 10 January 2012.
45. Newton, Isaac. "College Notebook" (http://cudl.lib.cam.ac.uk/view/MS-ADD-04000/). Cambridge University Digital Library. Retrieved 10 January 2012.
46. Newton, Isaac. "Newton Papers" (http://cudl.lib.cam.ac.uk/collections/newton). Cambridge University Digital Library. Retrieved 10 January 2012.
47. "al-Qurʾān" (http://cudl.lib.cam.ac.uk/view/MS-NN-00003-00075/). Cambridge University Digital Library. Retrieved 10 January 2012.
48. *Google Books* (https://books.google.com/).
49. Baksik, C. "Fair Use or Exploitation? The Google Book Search Controversy," Libraries and the Academy. Vol. 6, No. 2 (2006): 399–415.
50. "Definition of Digitization - Gartner Information Technology Glossary" (https://www.gartner.com/en/information-technology/glossary/digitization). *Gartner*. Retrieved 2023-04-14.
51. Ross, S. (2000). *Changing trains at Wigan: Digital Preservation and the future of scholarship (1st ed.)*. National Preservation Office (British Library). Retrieved December 15, 2021, from https://www.researchgate.net/publication/31869566_Changing_Trains_at_Wigan_Digital_Preservation_and_the_Future_of_Scholarship
52. "Fundamentals of AV Preservation - Chapter 4" (https://www.nedcc.org/fundamentals-of-av-preservation-textbook/chapter-4-introduction/chapter-4-section-6). *Northeast Document Conservation Center*. Retrieved 2023-04-14.
53. "SAA Dictionary: born digital" (https://dictionary.archivists.org/entry/born-digital.html). *dictionary.archivists.org*. Retrieved 2023-04-14.
54. Crestodina, Andy (2017-04-25). "What is the average website lifespan? 10 Factors In Website Life Expectancy" (https://www.orbitmedia.com/blog/website-lifespan-and-you/). *Orbit Media Studios*. Retrieved 2023-04-14.
55. Library of Congress. (n.d.). *Digital preservation*. Retrieved December 15, 2021, from https://www.digitalpreservation.gov/
56. "Library of Congress. (2007). Technical Standards for Digital Conversion of Text and Graphic Materials" (http://memory.loc.gov/ammem/about/techStandards.pdf) (PDF).
57. "Search Publications – Association of Research Libraries® – ARL®" (https://web.archive.org/web/20120505032857/http://www.arl.org/bm~doc/digi_preserv.pdf) (PDF). *www.arl.org*. Archived from the original (http://www.arl.org/bm~doc/digi_preserv.pdf) (PDF) on 2012-05-05. Retrieved 2016-11-06.
58. Library of Congress, (2006). Preservation Digital Reformatting Program. https://www.loc.gov/preserv/prd/presdig/presintro.html
59. "ARSC Guide to Audio Preservation" (http://www.clir.org/wp-content/uploads/sites/6/pub164.pdf) (PDF).
60. Casey, Mike (January 2015). "Why Media Preservation Can't Wait: The Gathering Storm" (https://www.avpreserve.com/wp-content/uploads/2015/04/casey_iasa_journal_44_part3.pdf) (PDF). *IASA Journal*. **44**: 14–22.
61. "ARSC Guide to Audio Preservation" (http://www.clir.org/wp-content/uploads/sites/6/pub164.pdf) (PDF). Retrieved 2019-05-04.
62. Institute, Canadian Conservation (2017-09-14). "The Digitization of Audio Tapes – Technical Bulletin 30" (https://www.canada.ca/en/conservation-institute/services/conservation-preservation-publications/technical-bulletins/digitization-audio-tapes.html#a2). *aem*. Retrieved 2019-05-04.
63. Greene, M. A. (2010). MPLP: It's not just for processing anymore. *The American Archivist, 73*(1), 175-203.
64. Lampert, Cory (2018). "Ramping up". *Digital Library Perspectives*. **34**: 45–59. doi:10.1108/DLP-06-2017-0020 (https://doi.org/10.1108%2FDLP-06-2017-0020).
65. UK Parliament. (2016, October 24). *Parliamentary archives: The digitisation process* [Video]. https://www.youtube.com/watch?v=0p3-v0rp1rc
66. Erway, R. (2008, December). Supply and demand: Special collections and digitisation. *LIBER Quarterly, 18*(3/4), 324-336.
67. Chapman, S. (2009, June 2). Chapter 2: Managing digitization. *Library Technology Reports, 40*(5), 13-21.
68. Sutton, Shan C. (2012). "Balancing Boutique-Level Quality and Large-Scale Production: The Impact of "More Product, Less Process" on Digitization in Archives and Special Collections" (https://doi.org/10.5860%2Frbm.13.1.369). *RBM: A Journal of Rare Books, Manuscripts, and Cultural Heritage*. **13**: 50–63. doi:10.5860/rbm.13.1.369 (https://doi.org/10.5860%2Frbm.13.1.369).
69. Duran Casablancas, Cristina; Holtman, Marc; Strlič, Matija; Grau-Bové, Josep (2022-10-12). "The end of the reading room? Simulating the impact of digitisation on the physical access of archival collections" (https://doi.org/10.1080%2F17477778.2022.2128911). *Journal of Simulation*. **18** (2): 191–205. doi:10.1080/17477778.2022.2128911 (https://doi.org/10.1080%2F17477778.2022.2128911). ISSN 1747-7778 (https://www.worldcat.org/issn/1747-7778). S2CID 252883425 (https://api.semanticscholar.org/CorpusID:252883425).
70. "6.6 Preservation and Selection for Digitization" (https://www.nedcc.org/free-resources/preservation-leaflets/6.-reformatting/6.6-preservation-and-selection-for-digitization). *Northeast Document Conservation Center*. Retrieved 2023-04-14.
71. Anderson, Talea (2015). "Streaming the Archives: Repurposing Systems to Advance a Small Media Digitization and Dissemination Program". *Journal of Electronic Resources Librarianship*. **27** (4): 221–231. doi:10.1080/1941126X.2015.1092343 (https://doi.org/10.1080%2F1941126X.2015.1092343). S2CID 61418169 (https://api.semanticscholar.org/CorpusID:61418169).
72. Skulan, Naomi (2018). "Staffing with students". *Digital Library Perspectives*. **34**: 32–44. doi:10.1108/DLP-07-2017-0024 (https://doi.org/10.1108%2FDLP-07-2017-0024).
73. Kelly, E. (2014, May 14). Processing through digitization: University photographs at Loyola University New Orleans. *Archival Practice, 1*(1).
74. Manzuch, Z. (2017). Ethical issues in digitization of cultural heritage. *Journal of Contemporary Archival Studies, 4(*2), article 4. http://elischolar.library.yale.edu/jcas/vol4/iss2/4
75. Shell-Weiss, Melanie; Benefiel, Annie; McKee, Kimberly (2017). "We Are All Teachers: A Collaborative Approach to Digital Collection Development" (https://doi.org/10.1080%2F01462679.2017.1344597). *Collection Management*. **42** (3–4): 317–337. doi:10.1080/01462679.2017.1344597 (https://doi.org/10.1080%2F01462679.2017.1344597). S2CID 196044884 (https://api.semanticscholar.org/CorpusID:196044884).
76. Caswell, Michelle (2014). "Community-centered collecting: Finding out what communities want from community archives" (https://escholarship.org/uc/item/0rz7t71t). *Proceedings of the American Society for Information Science and Technology*. **51**: 1–9. doi:10.1002/meet.2014.14505101027 (https://doi.org/10.1002%2Fmeet.2014.14505101027). S2CID 52004250 (https://api.semanticscholar.org/CorpusID:52004250).
77. Verheusen, A. (2008). Mass digitization by libraries: Issues concerning organisation, quality and Efficiency. *LIBER Quarterly*, 18(1), 28-38.
78. Muktiarni, M; Widiaty, I; Abdullah, A G; Ana, A; Yulia, C (2019-12-01). "Digitalisation trend in education during industry 4.0" (https://doi.org/10.1088%2F1742-6596%2F1402%2F7%2F077070). *Journal of Physics: Conference Series*. **1402** (7): 077070. Bibcode:2019JPhCS1402g7070M (https://ui.adsabs.harvard.edu/abs/2019JPhCS1402g7070M). doi:10.1088/1742-6596/1402/7/077070 (https://doi.org/10.1088%2F1742-6596%2F1402%2F7%2F077070). ISSN 1742-6588 (https://www.worldcat.org/issn/1742-6588).
79. Duggineni, Sasidhar (2023-06-02). "Impact of Controls on Data Integrity and Information Systems" (http://article.sapub.org/10.5923.j.scit.20231302.04.html). *Science and Technology*. **13** (2): 29–35.
80. Chapman, S. (2009, June 2). Chapter 2: managing digitization. *Library Technology Reports, 40*(5), 13-21.
81. Smithsonian Institution Archives. (n.d.). *Digitizing collections.* Retrieved October 10, 2021, from https://siarchives.si.edu/what-we-do/digital-curation/digitizing-collections

82. Society of American Archivists. (n.d.). *External digitization standards*. Retrieved October 23, 2021, from https://www2.archivists.org/standards/external/123
83. The Mind Maidens. Aired Nov. 5 1977 on the ABC Network along with other segments.

Further reading

- Anderson, Cokie G.; Maxwell, David C, *Starting a Digitization Center*, Chandos Publishing, 2004, ISBN 978-1843340737
- Bulow, Anna; Ahmon, Jess, *Preparing Collections for Digitization*, Facet Publishing, 2010, ISBN 978-1856047111
- Perrin, Joy, "Digitization of Flat Media: Principles and Practices", Rowman & Littlefield Publishers, 2015, ISBN 978-1442258099
- Piepenburg, Scott, "Digitizing Audiovisual and Nonprint Materials: the Innovative Librarian's Guide", Libraries Unlimited, 2015, ISBN 978-1440837807
- Robinson, Peter, *Digitization of Primary Textual Sources*, Office for Humanities Communication, 1993, ISBN 978-1897791059
- S Ross; I Anderson; C Duffy; M Economou; A Gow; P McKinney; R Sharp; The NINCH Working Group on Best Practices, Guide to Good Practice in the Digital Representation and Management of Cultural Heritage Materials (https://web.archive.org/web/20160221223614/http://www.ninch.org/guide.pdf), Washington DC: NINCH, 2002.
- Speranski, V. Challenges in AV Digitization and Digital Preservation (http://www.nationalvideo.com.au/challenges-in-audio-visual-digitization-and-digital-preservation)
- 'The Library of Congress National Recording Preservation Plan' (https://www.loc.gov/rr/record/nrpb/PLAN%20pdf.pdf)

Fourth Industrial Revolution



Top-left: an image of robots in a grocery warehouse. **Top-right**: augmented tablet information of a painting in Museu de Mataró, linking to Wikipedia's Catalan article on Jordi Arenas i Clavell. **Bottom-left**: illustrated understanding of the Internet of things in a battlefield setting. **Bottom-right**: customers using Amazon Go, an example of "just walk out shopping" where integrated technology creates a seamless consumer journey through including computer vision, deep-learning algorithms, and sensor fusion.

"**Fourth Industrial Revolution**", "**4IR**", or "**Industry 4.0**"[1] is a buzzword and neologism describing rapid technological advancement in the 21st century.[2] The term was popularised in 2016 by Klaus Schwab, the World Economic Forum founder and executive chairman,[3][4][5][6][7] who says that the changes show a significant shift in industrial capitalism.[8]

A part of this phase of industrial change is the joining of technologies like artificial intelligence, gene editing, to advanced robotics that blur the lines between the physical, digital, and biological worlds.[8][9]

Throughout this, fundamental shifts are taking place in how the global production and supply network operates through ongoing automation of traditional manufacturing and industrial practices, using modern smart technology, large-scale machine-to-machine communication (M2M), and the Internet of things (IoT). This integration results in increasing automation, improving communication and self-monitoring, and the use of smart machines that can analyse and diagnose issues without the need for human intervention.[10]

It also represents a social, political, and economic shift from the digital age of the late 1990s and early 2000s to an era of embedded connectivity distinguished by the ubiquity of technology in society (i.e. a metaverse) that changes the ways humans experience and know the world around them.[11] It posits that we have created and are entering an augmented social reality compared to just the natural senses and industrial ability of humans alone.[8]

History

The phrase *Fourth Industrial Revolution* was first introduced by a team of scientists developing a high-tech strategy for the German government.[12] Klaus Schwab, executive chairman of the World Economic Forum (WEF), introduced the phrase to a wider audience in a 2015 article published by *Foreign Affairs*.[13] "Mastering the Fourth Industrial Revolution" was the 2016 theme of the World Economic Forum Annual Meeting, in Davos-Klosters, Switzerland.[14]

On 10 October 2016, the Forum announced the opening of its Centre for the Fourth Industrial Revolution in San Francisco.[15] This was also subject and title of Schwab's 2016 book.[16] Schwab includes in this fourth era technologies that combine hardware, software, and biology (cyber-physical systems),[17] and emphasises advances in communication and connectivity. Schwab expects this era to be marked by breakthroughs in emerging technologies in fields such as robotics, artificial intelligence, nanotechnology, quantum computing, biotechnology, the internet of things, the industrial internet of things, decentralised consensus, fifth-generation wireless technologies, 3D printing, and fully autonomous vehicles.[18]

In *The Great Reset* proposal by the WEF, *The Fourth Industrial Revolution* is included as a strategic intelligence in the solution to rebuild the economy sustainably following the COVID-19 pandemic.[19]

First Industrial Revolution

The First Industrial Revolution was marked by a transition from hand production methods to machines through the use of steam power and water power. The implementation of new technologies took a long time, so the period which this refers to was between 1760 and 1820, or 1840 in Europe and the United States. Its effects had consequences on textile manufacturing, which was first to adopt such changes, as well as iron industry, agriculture, and mining although it also had societal effects with an ever stronger middle class.[20]

Second Industrial Revolution

The Second Industrial Revolution, also known as the Technological Revolution, is the period between 1871 and 1914 that resulted from installations of extensive railroad and telegraph networks, which allowed for faster transfer of people and ideas, as well as electricity. Increasing electrification allowed for factories to develop the modern production line. It was a period of great economic growth, with an increase in productivity, which also caused a surge in unemployment since many factory workers were replaced by machines.[21]

Third Industrial Revolution

The Third Industrial Revolution, also known as the Digital Electronics Revolution, occurred in the late 20th century, after the end of the two world wars, resulting from a slowdown of industrialisation and technological advancement compared to previous periods. The production of the Z1 computer, which used binary floating-point numbers and Boolean logic, a decade later, was the beginning of more advanced digital developments.

A book titled The Third Industrial Revolution, by Jeremy Rifkin, was published in 2011, which focused on the intersection of digital communications technology and renewable energy. It was made into a 2017 documentary by Vice Media.

Characteristics

In essence, the Fourth Industrial Revolution is the trend towards automation and data exchange in manufacturing technologies and processes which include cyber-physical systems (CPS), IoT, industrial internet of things,[22] cloud computing,[23][24][25][26] cognitive computing, and artificial intelligence.[26][27]

The machines cannot replace the deep expertise but they tend to be more efficient than humans in performing repetitive functions, and the combination of machine learning and computational power allows machines to carry out highly complicated tasks.[28]

The Fourth Industrial Revolution has been defined as technological developments in cyber-physical systems such as high capacity connectivity; new human-machine interaction modes such as touch interfaces and virtual reality systems; and improvements in transferring digital instructions to the physical world including robotics and 3D printing (additive manufacturing); the Internet of Things (IoT); "big data" and cloud computing; artificial intelligence-based systems; improvements to and uptake of Off-Grid / Stand-Alone Renewable Energy Systems: solar, wind, wave, hydroelectric and the electric batteries (lithium-ion renewable energy storage systems (ESS) and EV).

The Fourth Industrial Revolution marks the beginning of the imagination age.[29]

Key themes

Industry 4.0 increases operational efficiency. Four themes are presented that summarise an Industry 4.0:[23]

- Decentralized decisions – the ability of cyber physical systems to make decisions on their own and to perform their tasks as autonomously as possible. Only in the case of exceptions, interference, or conflicting goals, are tasks delegated to a higher level[30]

Distinctiveness

Proponents of the Fourth Industrial Revolution suggest it is a distinct revolution rather than simply a prolongation of the Third Industrial Revolution.[13] This is due to the following characteristics:

- Velocity — exponential speed at which incumbent industries are affected and displaced[13]
- Scope and systems impact – the large amount of sectors and firms that are affected[13]
- Paradigm shift in technology policy – new policies designed for this new way of doing are present. An example is Singapore's formal recognition of Industry 4.0 in its innovation policies.

Critics of the concept dismiss Industry 4.0 as a marketing strategy. They suggest that although revolutionary changes are identifiable in distinct sectors, there is no systemic change so far. In addition, the pace of recognition of Industry 4.0 and policy transition varies across countries; the definition of Industry 4.0 is not harmonised. One of the most known figures is Jeremy Rifkin who "agree[s] that digitalization is the hallmark and defining technology in what has become known as the Third Industrial Revolution".[31] However, he argues that "that the evolution of digitalization has barely begun to run its course and that its new configuration in the form of the Internet of Things represents the next stage of its development".[31]

Components

The application of the Fourth Industrial Revolution operates through:[32]

Self-driving car

- Mobile devices
- Internet of things (IoT) platforms
- Location detection technologies (electronic identification)
- Advanced human-machine interfaces
- Authentication and fraud detection
- Smart sensors
- Big analytics and advanced processes
- Multilevel customer interaction and customer profiling
- Augmented reality/wearables
- On-demand availability of computer system resources
- Data visualisation and triggered "live" training[32]

Mainly these technologies can be summarised into four major components, defining the term "Industry 4.0" or "smart factory":[32]

- Cyber-physical systems
- Internet of things (IoT)
- On-demand availability of computer system resources (e.g. cloud computing)
- Cognitive computing[32]

Industry 4.0 networks a wide range of new technologies to create value. Using cyber-physical systems that monitor physical processes, a virtual copy of the physical world can be designed. Characteristics of cyber-physical systems include the ability to make decentralised decisions independently, reaching a high degree of autonomy.[32]

The value created in Industry 4.0, can be relied upon electronic identification, in which the smart manufacturing require set technologies to be incorporated in the manufacturing process to thus be classified as in the development path of Industry 4.0 and no longer digitisation.[33]

Trends

Smart factory

Smart Factory is the vision of a production environment in which production facilities and logistics systems are organised without human intervention.

The Smart Factory is no longer a vision. While different model factories represent the feasible, many enterprises already clarify with examples practically, how the Smart Factory functions.

The technical foundations on which the Smart Factory – the intelligent factory – is based are cyber-physical systems that communicate with each other using the Internet of Things and Services. An important part of this process is the exchange of data between the product and the production line. This enables a much more efficient connection of the Supply Chain and better organisation within any production environment.

The Fourth Industrial Revolution fosters what has been called a "smart factory". Within modular structured smart factories, cyber-physical systems monitor physical processes, create a virtual copy of the physical world and make decentralised decisions.[34] Over the internet of things, cyber-physical systems communicate and cooperate with each other and with humans in synchronic time both internally and across organizational services offered and used by participants of the value chain.[23][35]

Predictive maintenance

Industry 4.0 can also provide predictive maintenance, due to the use of technology and the IoT sensors. Predictive maintenance – which can identify maintenance issues in real time – allows machine owners to perform cost-effective maintenance and determine it ahead of time before the machinery fails or gets damaged. For example, a company in Los Angeles could understand if a piece of equipment in Singapore is running at an abnormal speed or temperature. They could then decide whether or not it needs to be repaired.[36]

3D printing

The Fourth Industrial Revolution is said to have extensive dependency on 3D printing technology. Some advantages of 3D printing for industry are that 3D printing can print many geometric structures, as well as simplify the product design process. It is also relatively environmentally friendly. In low-volume production, it can also decrease lead times and total production costs. Moreover, it can increase flexibility, reduce warehousing costs and help the company towards the adoption of a mass customisation business strategy. In addition, 3D printing can be very useful for printing spare parts and installing it locally, therefore reducing supplier dependence and reducing the supply lead time.[37]

The determining factor is the pace of change. The correlation of the speed of technological development and, as a result, socio-economic and infrastructural transformations with human life allows one to state a qualitative leap in the speed of development, which marks a transition to a new time era.[38]

Smart sensors

Sensors and instrumentation drive the central forces of innovation, not only for Industry 4.0 but also for other "smart" megatrends, such as smart production, smart mobility, smart homes, smart cities, and smart factories.[39]

Smart sensors are devices, which generate the data and allow further functionality from self-monitoring and self-configuration to condition monitoring of complex processes. With the capability of wireless communication, they reduce installation effort to a great extent and help realise a dense array of sensors.[40]

The importance of sensors, measurement science, and smart evaluation for Industry 4.0 has been recognised and acknowledged by various experts and has already led to the statement "Industry 4.0: nothing goes without sensor systems."[41]

However, there are a few issues, such as time synchronisation error, data loss, and dealing with large amounts of harvested data, which all limit the implementation of full-fledged systems. Moreover, additional limits on these functionalities represents the battery power. One example of the integration of smart sensors in the electronic devices, is the case of smart watches, where sensors receive the data from the movement of the user, process the data and as a result, provide the user with the information about how many steps they have walked in a day and also converts the data into calories burned.

Agriculture and food industries

Smart sensors in these two fields are still in the testing stage.[42] These innovative connected sensors collect, interpret and communicate the information available in the plots (leaf area, vegetation index, chlorophyll, hygrometry, temperature, water potential, radiation). Based on this scientific data, the objective is to enable real-time monitoring via a smartphone with a range of advice that optimises plot management in terms of results, time and costs. On the farm, these sensors can be used to detect crop stages and recommend inputs and treatments at the right time. As well as controlling the level of irrigation.[43]


Hydroponic vertical farming

The food industry requires more and more security and transparency and full documentation is required. This new technology is used as a tracking system as well as the collection of human data and product data.[44]

Accelerated transition to the knowledge economy

Knowledge economy is an economic system in which production and services are largely based on knowledge-intensive activities that contribute to an accelerated pace of technical and scientific advance, as well as rapid obsolescence.[45][46] Industry 4.0 aids transitions into knowledge economy by increasing reliance on intellectual capabilities than on physical inputs or natural resources.

Challenges

Challenges in implementation of Industry 4.0:[47][48]

Economic

- High economic cost
- Business model adaptation
- Unclear economic benefits/excessive investment[47][48]

Social

- Privacy concerns
- Surveillance and distrust
- General reluctance to change by stakeholders

- Threat of redundancy of the corporate IT department
- Loss of many jobs to automatic processes and IT-controlled processes, especially for blue collar workers[47][48][49]
- Increased risk of gender inequalities in professions with job roles most susceptible to replacement with AI[50][51]

Political

- Lack of regulation, standards and forms of certifications
- Unclear legal issues and data security[47][48]

Organizational

- IT security issues, which are greatly aggravated by the inherent need to open up previously closed production shops
- Reliability and stability needed for critical machine-to-machine communication (M2M), including very short and stable latency times
- Need to maintain the integrity of production processes
- Need to avoid any IT snags, as those would cause expensive production outages
- Need to protect industrial know-how (contained also in the control files for the industrial automation gear)
- Lack of adequate skill-sets to expedite the transition towards a fourth industrial revolution[52][53]
- Low top management commitment
- Insufficient qualification of employees[47][48]

Country applications

Many countries have set up institutional mechanisms to foster the adoption of Industry 4.0 technologies. For example,

Australia

Australia has a Digital Transformation Agency (est. 2015) and the Prime Minister's Industry 4.0 Taskforce (est. 2016), which promotes collaboration with industry groups in Germany and the USA.[54]

Germany

The term "Industrie 4.0", shortened to I4.0 or simply I4, originated in 2011 from a project in the high-tech strategy of the German government and specifically relates to that project policy, rather than a wider notion of a Fourth Industrial Revolution of 4IR,[8] which promotes the computerisation of manufacturing.[55] The term "Industrie 4.0" was publicly introduced in the same year at the Hannover Fair.[56] Renowned German professor Wolfgang Wahlster is sometimes called the inventor of the "Industry 4.0" term.[57] In October 2012, the Working Group on Industry 4.0 presented a set of Industry 4.0 implementation recommendations to the German federal government. The workgroup members and partners are recognised as the founding fathers and driving force behind Industry 4.0. On 8 April 2013 at the Hannover Fair, the final report of the Working Group Industry 4.0 was presented. This working group was headed by Siegfried Dais, of Robert Bosch GmbH, and Henning Kagermann, of the German Academy of Science and Engineering.[58]

As Industry 4.0 principles have been applied by companies, they have sometimes been rebranded. For example, the aerospace parts manufacturer Meggitt PLC has branded its own Industry 4.0 research project M4.[59]

The discussion of how the shift to Industry 4.0, especially digitisation, will affect the labour market is being discussed in Germany under the topic of Work 4.0.[60]

The federal government in Germany through its ministries of the BMBF and BMWi, is a leader in the development of the I4.0 policy. Through the publishing of set objectives and goals for enterprises to achieve, the German federal government attempts to set the direction of the digital transformation. However, there is a gap between German enterprise's collaboration and knowledge of these set policies.[61] The biggest challenge which SMEs in Germany are currently facing regarding digital transformation of their manufacturing processes is ensuring that there is a concrete IT and application landscape to support further digital transformation efforts.[61]

The characteristics of the German government's Industry 4.0 strategy involve the strong customisation of products under the conditions of highly flexible (mass-) production.[62] The required automation technology is improved by the introduction of methods of self-optimization, self-configuration,[63] self-diagnosis, cognition and intelligent support of workers in their increasingly complex work.[64] The largest project in Industry 4.0 as of July 2013 is the German Federal Ministry of Education and Research (BMBF) leading-edge cluster "Intelligent Technical Systems Ostwestfalen-Lippe (its OWL)". Another major project is the BMBF project RES-COM,[65] as well as the Cluster of Excellence "Integrative Production Technology for High-Wage Countries".[66] In 2015, the European Commission started the international Horizon 2020 research project CREMA (cloud-based rapid elastic manufacturing) as a major initiative to foster the Industry 4.0 topic.[67]

Estonia

In Estonia, the digital transformation dubbed as the 4th Industrial Revolution by Klaus Schwab and the World Economic Forum in 2015 started with the restoration of independence in 1991. Although a latecomer to the information revolution due to 50 years of Soviet occupation, Estonia leapfrogged to the digital era, while skipping the analogue connections almost completely. The early decisions made by Prime Minister Mart Laar on the course of the country's economic development led to the establishment of what is today known as e-Estonia, one of the worlds most digitally advanced nations.

According to the goals set in the Estonia's Digital Agenda 2030,[68] next leaps in the country's digital transformation will be switching to event based and proactive services, both in private and business environment, as well as developing a green, AI-powered and human-centric digital government.

Indonesia

Another example is Making Indonesia 4.0, with a focus on improving industrial performance.[54]

India

India, with its expanding economy and extensive manufacturing sector, has fully embraced the digital revolution, leading to a new era of manufacturing excellence. The Indian program for Industry 4.0 centers around leveraging technology to produce globally competitive products at cost-effective rates while adopting the latest technological advancements of Industry 4.0.[69]

Japan

Society 5.0 envisions a society that prioritizes the well-being of its citizens, striking a harmonious balance between economic progress and the effective addressing of societal challenges through a closely interconnected system of both the digital realm and the physical world. This concept was introduced in 2019 in the 5th Science and Technology Basic Plan for Japanese Government as a blueprint for a forthcoming societal framework.[70]

South Africa

South Africa appointed a Presidential Commission on the Fourth Industrial Revolution in 2019, consisting of about 30 stakeholders with a background in academia, industry and government.[71][72] South Africa has also established an Inter ministerial Committee on Industry 4.0.

South Korea

The Republic of Korea has had a Presidential Committee on the Fourth Industrial Revolution since 2017. The Republic of Korea's I-Korea strategy (2017) is focusing on new growth engines that include AI, drones and autonomous cars, in line with the government's innovation-driven economic policy.[71]

Spain

See Science and technology in Spain

Uganda

Uganda adopted its own National 4IR Strategy in October 2020 with emphasis on e-governance, urban management (smart cities), health care, education, agriculture and the digital economy; to support local businesses, the government was contemplating introducing a local start-ups bill in 2020 which would require all accounting officers to exhaust the local market prior to procuring digital solutions from abroad.[71]

United Kingdom

In a policy paper published in 2019, the UK's Department for Business, Energy & Industrial Strategy, titled "Regulation for the Fourth Industrial Revolution", outlined the need to evolve current regulatory models to remain competitive in evolving technological and social settings.[9]

United States

The Department of Homeland Security in 2019 published a paper called 'The Industrial Internet of things (IIOT): Opportunities, Risks, Mitigation'. The base pieces of critical infrastructure are increasingly digitised for greater connectivity and optimisation. Hence, its implementation, growth and maintenance must be carefully planned and safeguarded. The paper discusses not only applications of IIOT but also the associated risks. It has suggested some key areas where risk mitigation is possible. To increase coordination between the public, private, law enforcement, academia and other stakeholders the DHS formed the National Cybersecurity and Communications Integration Center (NCCIC).[73]

Industry applications

The aerospace industry has sometimes been characterised as "too low volume for extensive automation"; however, Industry 4.0 principles have been investigated by several aerospace companies, and technologies have been developed to improve productivity where the upfront cost of automation cannot be justified. One example of this is the aerospace parts manufacturer Meggitt PLC's M4 project.[59]

The increasing use of the industrial internet of things is referred to as Industry 4.0 at Bosch, and generally in Germany. Applications include machines that can predict failures and trigger maintenance processes autonomously or self-organised coordination that react to unexpected changes in production.[74] in 2017, Bosch launched the Connectory, a Chicago, Illinois based innovation incubator that specializes in IoT, including Industry 4.0.

Industry 4.0 inspired Innovation 4.0, a move toward digitisation for academia and research and development.[75] In 2017, the £81M Materials Innovation Factory (MIF) at the University of Liverpool opened as a center for computer aided materials science,[76] where robotic formulation,[77] data capture and modelling are being integrated into development practices.[75]

Criticism

With the consistent development of automation of everyday tasks, some saw the benefit in the exact opposite of automation where self-made products are valued more than those that involved automation.[78] This valuation is named the IKEA effect, a term coined by Michael I. Norton of Harvard Business School, Daniel Mochon of Yale, and Dan Ariely of Duke. Another problem that is expected to accelerate with the growth of IR4 is the prevalence of mental disorders.[79] The world has already experienced such problems in high-tech industries.[80]

Future

Industry 5.0

Industry 5.0 has been proposed as a strategy to create a paradigm shift for an industrial landscape in which the primary focus should no longer be on increasing efficiency but on promoting the well-being of society and sustainability of the economy and industrial production.[81][82]

See also

- Computer-integrated manufacturing
- Cyber manufacturing
- Digital modelling and fabrication
- Industrial control system
- Intelligent maintenance systems
- Lights-out manufacturing
- List of emerging technologies
- Machine to machine
- Nondestructive Evaluation 4.0
- Simulation software
- Technological singularity
- Technological unemployment
- The War on Normal People
- Work 4.0
- World Economic Forum 2016
- Digitization
- Transhumanism
- AI boom

References

1. Bai, Chunguang; Dallasega, Patrick; Orzes, Guido; Sarkis, Joseph (1 November 2020). "Industry 4.0 technologies assessment: A sustainability perspective" (https://doi.org/10.1016%2Fj.ijpe.2020.107776). *International Journal of Production Economics*. **229**: 107776. doi:10.1016/j.ijpe.2020.107776 (https://doi.org/10.1016%2Fj.ijpe.2020.107776). ISSN 0925-5273 (https://www.worldcat.org/issn/0925-5273). S2CID 218941878 (https://api.semanticscholar.org/CorpusID:218941878).

2. Ross, Philip; Maynard, Kasia (2021). "Towards a 4th industrial revolution" (https://doi.org/10.1080%2F17508975.2021.1873625). *Intelligent Buildings International*. **13** (3): 159–161. doi:10.1080/17508975.2021.1873625 (https://doi.org/10.1080%2F17508975.2021.1873625).
3. McGinnis, Devon (27 October 2020). "What Is the Fourth Industrial Revolution?" (https://www.salesforce.com/blog/what-is-the-fourth-industrial-revolution-4ir/). *The 360 Blog from Salesforce*. Retrieved 22 January 2023.
4. "The Fourth Industrial Revolution will be people powered | McKinsey" (https://www.mckinsey.com/capabilities/operations/our-insights/the-fourth-industrial-revolution-will-be-people-powered). *www.mckinsey.com*. Retrieved 22 January 2023.
5. Signé, Njuguna Ndung'u and Landry (8 January 2020). "The Fourth Industrial Revolution and digitization will transform Africa into a global powerhouse" (https://www.brookings.edu/research/the-fourth-industrial-revolution-and-digitization-will-transform-africa-into-a-global-powerhouse/). *Brookings*. Retrieved 22 January 2023.
6. Marr, Bernard. "Why Everyone Must Get Ready For The 4th Industrial Revolution" (https://www.forbes.com/sites/bernardmarr/2016/04/05/why-everyone-must-get-ready-for-4th-industrial-revolution/). *Forbes*. Retrieved 22 January 2023.
7. Park, Hyeoun-Ae (10 November 2016). "Are We Ready for the Fourth Industrial Revolution?" (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5171547). *Yearbook of Medical Informatics* (1): 1–3. PMC 5171547 (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5171547). PMID 27830223 (https://pubmed.ncbi.nlm.nih.gov/27830223).
8. Philbeck, Thomas; Davis, Nicholas (2018). "The Fourth Industrial Revolution" (https://www.jstor.org/stable/26588339). *Journal of International Affairs*. **72** (1): 17–22. ISSN 0022-197X (https://www.worldcat.org/issn/0022-197X). JSTOR 26588339 (https://www.jstor.org/stable/26588339).
9. "Regulation for the Fourth Industrial Revolution" (https://www.gov.uk/government/publications/regulation-for-the-fourth-industrial-revolution/regulation-for-the-fourth-industrial-revolution). UK Gov Department for Business, Energy & Industrial Strategy. 11 June 2019. Retrieved 18 November 2021.
10. November 2019, Mike Moore 05 (5 November 2019). "What is Industry 4.0? Everything you need to know" (https://www.techradar.com/news/what-is-industry-40-everything-you-need-to-know). *TechRadar*. Retrieved 27 May 2020.
11. Lee, MinHwa; Yun, JinHyo; Pyka, Andreas; Won, DongKyu; Kodama, Fumio; Schiuma, Giovanni; Park, HangSik; Jeon, Jeonghwan; Park, KyungBae; Jung, KwangHo; Yan, Min-Ren (21 June 2018). "How to Respond to the Fourth Industrial Revolution, or the Second Information Technology Revolution? Dynamic New Combinations between Technology, Market, and Society through Open Innovation" (https://doi.org/10.3390%2Fjoitmc4030021). *Journal of Open Innovation: Technology, Market, and Complexity*. **4** (3): 21. doi:10.3390/joitmc4030021 (https://doi.org/10.3390%2Fjoitmc4030021). hdl:11563/139044 (https://hdl.handle.net/11563%2F139044). ISSN 2199-8531 (https://www.worldcat.org/issn/2199-8531).
12. "Industrie 4.0: Mit dem Internet der Dinge auf dem Weg zur 4. industrial Revolution - vdi-nachrichten.com" (https://web.archive.org/web/20130304101009/http://www.vdi-nachrichten.com/artikel/Industrie-4-0-Mit-dem-Internet-der-Dinge-auf-dem-Weg-zur-4-industriellen-Revolution/52570/1). 4 March 2013. Archived from the original (http://www.vdi-nachrichten.com/artikel/Industrie-4-0-Mit-dem-Internet-der-Dinge-auf-dem-Weg-zur-4-industriellen-Revolution/52570/1) on 4 March 2013. Retrieved 25 January 2021.
13. Schwab, Klaus (12 December 2015). "The Fourth Industrial Revolution" (https://www.foreignaffairs.com/articles/2015-12-12/fourth-industrial-revolution/). *Foreign Affairs*. Retrieved 15 January 2019.

14. Marr, Bernard. "Why Everyone Must Get Ready For The 4th Industrial Revolution" (https://www.forbes.com/sites/bernardmarr/2016/04/05/why-everyone-must-get-ready-for-4th-industrial-revolution/). *Forbes*. Retrieved 14 February 2018.
15. Monck, Adrian (10 October 2016). "New Forum Center to Advance Global Cooperation on Fourth Industrial Revolution" (https://www.weforum.org/press/2016/10/new-forum-center-to-advance-global-cooperation-on-fourth-industrial-revolution/). *World Economic Forum*. Archived (https://web.archive.org/web/20161120152702/https://www.weforum.org/press/2016/10/new-forum-center-to-advance-global-cooperation-on-fourth-industrial-revolution/) from the original on 20 November 2016. Retrieved 15 October 2018.
16. Schwab, Klaus (2016). *The Fourth Industrial Revolution* (https://books.google.com/books?id=ST_FDAAAQBAJ). New York: Crown Publishing Group (published 2017). ISBN 9781524758875. Retrieved 29 June 2017. "Digital technologies ... are not new, but in a break with the third industrial revolution, they are becoming more sophisticated and integrated and are, as a result, transforming societies and the global economy."
17. "The Fourth Industrial Revolution: what it means and how to respond" (https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/). *World Economic Forum*. 14 January 2016. Retrieved 20 March 2018.
18. Schwab, Klaus (14 January 2016). "The Fourth Industrial Revolution: what it means, how to respond" (https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/). *World Economic Forum*. Retrieved 29 June 2017. "The possibilities of billions of people connected by mobile devices, with unprecedented processing power, storage capacity, and access to knowledge, are unlimited. And these possibilities will be multiplied by emerging technology breakthroughs in fields such as artificial intelligence, robotics, the Internet of Things, autonomous vehicles, 3-D printing, nanotechnology, biotechnology, materials science, energy storage, and quantum computing."
19. "Strategic Intelligence – World Economic Forum" (https://archive.today/20201222034658/https://intelligence.weforum.org/topics/a1Gb0000001RIhBEAW?tab=publications). Archived from the original (https://intelligence.weforum.org/topics/a1Gb0000001RIhBEAW?tab=publications) on 22 December 2020.
20. "The Industrial Revolution and Work in Nineteenth-Century Europe – 1992, Page xiv by David Cannadine, Raphael Samuel, Charles Tilly, Theresa McBride, Christopher H. Johnson, James S. Roberts, Peter N. Stearns, William H. Sewell Jr, Joan Wallach Scott" (https://web.archive.org/web/20200129200235/https://www.questia.com/read/107622079/the-industrial-revolution-and-work-in-nineteenth-century). Archived from the original (https://www.questia.com/read/107622079/the-industrial-revolution-and-work-in-nineteenth-century) on 29 January 2020. Retrieved 9 June 2019.
21. "History of Electricity" (https://www.instituteforenergyresearch.org/history-electricity/).
22. "IIOT AND AUTOMATION" (https://www.punetechtrol.com/blogs/iiot-and-automation).
23. Hermann, Pentek, Otto, 2016: Design Principles for Industrie 4.0 Scenarios (http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=7427673&newsearch=true&queryText=industrie%204.0%20design%20principles). Retrieved 4 May 2016
24. Jürgen Jasperneite:*Was hinter Begriffen wie Industrie 4.0 steckt (http://www.computer-automation.de/steuerungsebene/steuernregeln/fachwissen/article/93559/0/Was_hinter_Begriffen_wie_Industrie_40_steckt/) Archived (https://web.archive.org/web/20130401204034/http://www.computer-automation.de/steuerungsebene/steuernregeln/fachwissen/article/93559/0/Was_hinter_Begriffen_wie_Industrie_40_steckt/) 1 April 2013 at the* Wayback Machine in *Computer & Automation*, 19 December 2012 accessed on 23 December 2012
25. Kagermann, H., W. Wahlster and J. Helbig, eds., 2013: Recommendations for implementing the strategic initiative Industrie 4.0: Final report of the Industrie 4.0 Working Group

26. Heiner Lasi, Hans-Georg Kemper, Peter Fettke, Thomas Feld, Michael Hoffmann: Industry 4.0. In: Business & Information Systems Engineering 4 (6), pp. 239–242
27. Gazzaneo, Lucia; Padovano, Antonio; Umbrello, Steven (1 January 2020). "Designing Smart Operator 4.0 for Human Values: A Value Sensitive Design Approach" (https://doi.org/10.1016%2Fj.promfg.2020.02.073). *Procedia Manufacturing*. International Conference on Industry 4.0 and Smart Manufacturing (ISM 2019). **42**: 219–226. doi:10.1016/j.promfg.2020.02.073 (https://doi.org/10.1016%2Fj.promfg.2020.02.073). hdl:2318/1735962 (https://hdl.handle.net/2318%2F1735962). ISSN 2351-9789 (https://www.worldcat.org/issn/2351-9789).
28. Pedota, Mattia; Piscitello, Lucia (3 November 2021). "A new perspective on technology-driven creativity enhancement in the Fourth Industrial Revolution" (https://dx.doi.org/10.1111/caim.12468). *Creativity and Innovation Management*. **31** (1): 109–122. doi:10.1111/caim.12468 (https://doi.org/10.1111%2Fcaim.12468). hdl:11311/1208221 (https://hdl.handle.net/11311%2F1208221). ISSN 0963-1690 (https://www.worldcat.org/issn/0963-1690). S2CID 243788231 (https://api.semanticscholar.org/CorpusID:243788231).
29. Recke, Martin (June 2019). "Why imagination and creativity are primary value creators" (https://nextconf.eu/2019/06/why-imagination-and-creativity-are-primary-value-creators/). SinnerSchrader Aktiengesellschaft.
30. Gronau, Norbert, Marcus Grum, and Benedict Bender. "Determining the optimal level of autonomy in cyber-physical production systems." 2016 IEEE 14th International Conference on Industrial Informatics (INDIN). IEEE, 2016. DOI:10.1109/INDIN.2016.7819367
31. "StackPath" (https://www.industryweek.com/technology-and-iiot/information-technology/article/21967057/the-2016-world-economic-forum-misfires-with-its-fourth-industrial-revolution-theme). 15 January 2016.
32. "How To Define Industry 4.0: Main Pillars Of Industry 4.0" (https://www.researchgate.net/publication/326557388). *ResearchGate*. Retrieved 9 June 2019.
33. "Industrie 4.0 Maturity Index – Managing the Digital Transformation of Companies" (https://en.acatech.de/publication/industrie-4-0-maturity-index-managing-the-digital-transformation-of-companies/). *acatech – National Academy of Science and Engineering*. Retrieved 21 December 2020.
34. Chen, Baotong; Wan, Jiafu; Shu, Lei; Li, Peng; Mukherjee, Mithun; Yin, Boxing (2018). "Smart Factory of Industry 4.0: Key Technologies, Application Case, and Challenges" (https://doi.org/10.1109%2FACCESS.2017.2783682). *IEEE Access*. **6**: 6505–6519. Bibcode:2018IEEEA...6.6505C (https://ui.adsabs.harvard.edu/abs/2018IEEEA...6.6505C). doi:10.1109/ACCESS.2017.2783682 (https://doi.org/10.1109%2FACCESS.2017.2783682). ISSN 2169-3536 (https://www.worldcat.org/issn/2169-3536). S2CID 3809961 (https://api.semanticscholar.org/CorpusID:3809961).
35. Padovano, Antonio; Longo, Francesco; Nicoletti, Letizia; Mirabelli, Giovanni (1 January 2018). "A Digital Twin based Service Oriented Application for a 4.0 Knowledge Navigation in the Smart Factory" (https://doi.org/10.1016%2Fj.ifacol.2018.08.389). *IFAC-PapersOnLine*. 16th IFAC Symposium on Information Control Problems in Manufacturing INCOM 2018. **51** (11): 631–636. doi:10.1016/j.ifacol.2018.08.389 (https://doi.org/10.1016%2Fj.ifacol.2018.08.389). ISSN 2405-8963 (https://www.worldcat.org/issn/2405-8963).
36. "Are You Ready For The Fourth Industrial Revolution?" (https://theonebrief.com/are-you-ready-for-the-fourth-industrial-revolution/). *The One Brief*. 4 May 2017. Retrieved 27 May 2020.
37. Yin, Yong; Stecke, Kathryn E.; Li, Dongni (17 January 2018). "The evolution of production systems from Industry 2.0 through Industry 4.0" (https://doi.org/10.1080%2F00207543.2017.1403664). *International Journal of Production Research*. **56** (1–2): 848–861. doi:10.1080/00207543.2017.1403664 (https://doi.org/10.1080%2F00207543.2017.1403664). ISSN 0020-7543 (https://www.worldcat.org/issn/0020-7543).

38. Shestakova I. G. New temporality of digital civilization: the future has already come // // Scientific and Technical Journal of St. Petersburg State Polytechnical University. Humanities and social sciences. 2019. # 2. P.20-29 (https://elibrary.ru/item.asp?id=39147614)
39. Imkamp, D., Berthold, J., Heizmann, M., Kniel, K., Manske, E., Peterek, M., Schmitt, R., Seidler, J., and Sommer, K.-D.: Challenges and trends in manufacturing measurement technology – the "Industrie 4.0" concept, J. Sens. Sens. Syst., 5, 325–335, https://doi.org/10.5194/jsss-5-325-2016, 2016
40. A.A. Kolomenskii, P.D. Gershon, H.A. Schuessler, Sensitivity and detection limit of concentration and adsorption measurements by laser-induced surface-plasmon resonance, Appl. Opt. 36 (1997) 6539–6547
41. Arnold, H.: Kommentar Industrie 4.0: Ohne Sensorsysteme geht nichts, available at: http://www.elektroniknet.de/messen-testen/ sonstiges/artikel/110776/ (last access: 10 March 2018), 2014
42. Ray, Partha Pratim (1 January 2017). "Internet of things for smart agriculture: Technologies, practices and future direction" (https://content.iospress.com/articles/journal-of-ambient-intelligence-and-smart-environments/ais440). *Journal of Ambient Intelligence and Smart Environments*. **9** (4): 395–420. doi:10.3233/AIS-170440 (https://doi.org/10.3233%2FAIS-170440). ISSN 1876-1364 (https://www.worldcat.org/issn/1876-1364).
43. Ferreira, Diogo; Corista, Pedro; Gião, João; Ghimire, Sudeep; Sarraipa, João; Jardim-Gonçalves, Ricardo (June 2017). "Towards smart agriculture using FIWARE enablers" (https://ieeexplore.ieee.org/document/8280066). *2017 International Conference on Engineering, Technology and Innovation (ICE/ITMC)* (https://zenodo.org/record/1261839). pp. 1544–1551. doi:10.1109/ICE.2017.8280066 (https://doi.org/10.1109%2FICE.2017.8280066). ISBN 978-1-5386-0774-9. S2CID 3433104 (https://api.semanticscholar.org/CorpusID:3433104).
44. Otles, Semih; Sakalli, Aysegul (1 January 2019), Grumezescu, Alexandru Mihai; Holban, Alina Maria (eds.), "15 – Industry 4.0: The Smart Factory of the Future in Beverage Industry" (http://www.sciencedirect.com/science/article/pii/B9780128152607000158), *Production and Management of Beverages*, Woodhead Publishing, pp. 439–469, ISBN 978-0-12-815260-7, retrieved 26 September 2020
45. Schwok, Karen (2 December 2020). "A "new" tech revolution is coming and the winds of change will hit the U.S. first" (https://www.calcalistech.com/ctech/articles/0,7340,L-3878571,00.html). *CTECH - www.calcalistech.com*. Retrieved 11 March 2022.
46. Powell, W. W.; Snellman, K. (2004). "The knowledge economy". *Annu. Rev. Sociol*. 199–220 (30): 199–220. doi:10.1146/annurev.soc.29.010202.100037 (https://doi.org/10.1146%2Fannurev.soc.29.010202.100037). S2CID 56043796 (https://api.semanticscholar.org/CorpusID:56043796).
47. "BIBB : Industrie 4.0 und die Folgen für Arbeitsmarkt und Wirtschaft" (http://doku.iab.de/forschungsbericht/2015/fb0815.pdf) (PDF). *Doku.iab.de* (in German). August 2015. Retrieved 30 November 2016.
48. Birkel, Hendrik Sebastian; Hartmann, Evi (2019). "Impact of IoT challenges and risks for SCM". *Supply Chain Management*. **24**: 39–61. doi:10.1108/SCM-03-2018-0142 (https://doi.org/10.1108%2FSCM-03-2018-0142). S2CID 169819946 (https://api.semanticscholar.org/CorpusID:169819946).
49. Longo, Francesco; Padovano, Antonio; Umbrello, Steven (January 2020). "Value-Oriented and Ethical Technology Engineering in Industry 5.0: A Human-Centric Perspective for the Design of the Factory of the Future" (https://doi.org/10.3390%2Fapp10124182). *Applied Sciences*. **10** (12): 4182. doi:10.3390/app10124182 (https://doi.org/10.3390%2Fapp10124182). hdl:2318/1741791 (https://hdl.handle.net/2318%2F1741791).

50. Alderman, J (1 June 2021). "Women in the smart machine age: Addressing emerging risks of an increased gender gap in the accounting profession" (https://www.sciencedirect.com/science/article/abs/pii/S0748575121000026). *Journal of Accounting Education*. **55**: 100715. doi:10.1016/j.jaccedu.2021.100715 (https://doi.org/10.1016%2Fj.jaccedu.2021.100715). ISSN 0748-5751 (https://www.worldcat.org/issn/0748-5751). S2CID 233583489 (https://api.semanticscholar.org/CorpusID:233583489).
51. UNESCO (25 February 2021). "Women a minority in Industry 4.0 fields" (https://en.unesco.org/news/women-minority-industry-40-fields). UNESCO. Retrieved 25 June 2021.
52. Spöttl, Georg; Windelband, Lars (2021). "The 4 th industrial revolution – its impact on vocational skills" (https://doi.org/10.1080%2F13639080.2020.1858230). *Journal of Education and Work*. **34** (1): 29–52. doi:10.1080/13639080.2020.1858230 (https://doi.org/10.1080%2F13639080.2020.1858230).
53. Gumbo, Sibukele; Twinomurinzi, Hossana; Bwalya, Kelvin; Wamba, Samuel Fosso (2023). "Skills provisioning for the Fourth Industrial Revolution: A Bibliometric Analysis" (https://doi.org/10.1016%2Fj.procs.2023.01.368). *Procedia Computer Science*. **219**: 924–932. doi:10.1016/j.procs.2023.01.368 (https://doi.org/10.1016%2Fj.procs.2023.01.368).
54. Scott-Kemmis (11 June 2021). Schneegans; Straza; Lewis (eds.). *Southeast Asia and Oceania. In UNESCO Science Report: the Race Against Time for Smarter Development* (https://unesdoc.unesco.org/ark:/48223/pf0000377481.locale=en). Paris: UNESCO. pp. 674–715. ISBN 978-92-3-100450-6.
55. BMBF-Internetredaktion (21 January 2016). "Zukunftsprojekt Industrie 4.0 – BMBF" (https://www.bmbf.de/de/zukunftsprojekt-industrie-4-0-848.html). *Bmbf.de*. Retrieved 30 November 2016.
56. "Industrie 4.0: Mit dem Internet der Dinge auf dem Weg zur 4. industriellen Revolution" (https://web.archive.org/web/20130304101009/http://www.vdi-nachrichten.com/artikel/Industrie-4-0-Mit-dem-Internet-der-Dinge-auf-dem-Weg-zur-4-industriellen-Revolution/52570/1). *Vdi-nachrichten.com* (in German). 1 April 2011. Archived from the original (http://www.vdi-nachrichten.com/artikel/Industrie-4-0-Mit-dem-Internet-der-Dinge-auf-dem-Weg-zur-4-industriellen-Revolution/52570/1) on 4 March 2013. Retrieved 30 November 2016.
57. Szajna, Andrzej; Stryjski, Roman; Wozniak, Waldemar; Chamier-Gliszczynski, Norbert; Kostrzewski, Mariusz (22 August 2020). "Assessment of Augmented Reality in Manual Wiring Production Process with Use of Mobile AR Glasses" (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7506974). *Sensors*. **20** (17). MDPI: 4755. Bibcode:2020Senso..20.4755S (https://ui.adsabs.harvard.edu/abs/2020Senso..20.4755S). doi:10.3390/s20174755 (https://doi.org/10.3390%2Fs20174755). PMC 7506974 (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7506974). PMID 32842693 (https://pubmed.ncbi.nlm.nih.gov/32842693).
58. Industrie 4.0 Plattform (http://www.plattform-i40.de) Last download on 15. Juli 2013
59. "Time to join the digital dots" (https://www.aero-mag.com/meggitt-applied-research-technology-group-data-capture/). 22 June 2018. Retrieved 25 July 2018.
60. Federal Ministry of Labour and Social Affairs of Germany (2015). *Re-Imagining Work: White Paper Work 4.0*.
61. Keller, Matthias (2021). "I4.0 Strategy and Policy Integration in The German Machining Industry" (https://www.researchgate.net/publication/359005363). *KU Leuven*.
62. "This Is Not the Fourth Industrial Revolution" (http://www.slate.com/articles/technology/future_tense/2016/01/the_world_economic_forum_is_wrong_this_isn_t_the_fourth_industrial_revolution.html). *Slate*. 29 January 2016.
63. Selbstkonfiguierende Automation für Intelligente Technische Systeme (https://www.youtube.com/watch?v=JtC3DAfLTxw), Video, last download on 27. Dezember 2012

64. Jürgen Jasperneite; Oliver, Niggemann: Intelligente Assistenzsysteme zur Beherrschung der Systemkomplexität in der Automation. In: ATP edition – Automatisierungstechnische Praxis, 9/2012, Oldenbourg Verlag, München, September 2012
65. "Herzlich willkommen auf den Internetseiten des Projekts RES-COM – RES-COM Webseite" (http://www.res-com-projekt.de/). *Res-com-projekt.de*. Retrieved 30 November 2016.
66. "RWTH AACHEN UNIVERSITY Cluster of Excellence "Integrative Production Technology for High-Wage Countries" – English" (http://www.production-research.de/). *Production-research.de*. 19 October 2016. Retrieved 30 November 2016.
67. "H2020 CREMA – Cloud-based Rapid Elastic Manufacturing" (https://web.archive.org/web/20161123200543/http://www.crema-project.eu/). *Crema-project.eu*. 21 November 2016. Archived from the original (http://www.crema-project.eu/) on 23 November 2016. Retrieved 30 November 2016.
68. "Digiühiskonna arengukava 2030 | Majandus- ja Kommunikatsiooniministeerium" (https://www.mkm.ee/digiriik-ja-uhenduvus/digiuhiskonna-arengukava-2030). *www.mkm.ee*. Retrieved 16 October 2022.
69. "SAMARTH Udyog Bharat 4.0" (https://www.samarthudyog-i40.in/about-i40).
70. "Society 5.0" (https://www8.cao.go.jp/cstp/english/society5_0/index.html). Japanese Government, 2016. Retrieved 10 October 2023.
71. Schneegans, S.; Straza, T.; Lewis, J., eds. (11 June 2021). *UNESCO Science Report: the Race Against Time for Smarter Development* (https://unesdoc.unesco.org/ark:/48223/pf0000377433/PDF/377433eng.pdf.multi). Paris: UNESCO. ISBN 978-92-3-100450-6.
72. Kraemer-Mbula; Sheikheldin; Karimanzira (11 June 2021). *Southern Africa. In UNESCO Science Report: the Race Against Time for Smarter Development* (https://unesdoc.unesco.org/ark:/48223/pf0000377475/PDF/377475eng.pdf.multi). Paris: UNESCO. pp. 534–573. ISBN 978-92-3-100450-6.
73. Ayala, Mario; Cantu, Rob (2019). "THE INDUSTRIAL INTERNET OF THINGS (IIOT): OPPORTUNITIES, RISKS, MITIGATIO" (https://www.dhs.gov/sites/default/files/publications/ia/ia_iiot-intercommections.pdf) (PDF). *Department of Homeland Security-Publications*: 34 – via DHS.
74. Markus Liffler; Andreas Tschiesner (6 January 2013). "The Internet of Things and the future of manufacturing | McKinsey & Company" (https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/the-internet-of-things-and-the-future-of-manufacturing). *Mckinsey.com*. Retrieved 30 November 2016.
75. McDonagh, James; et al. (31 May 2020). "What Can Digitization Do For Formulated Product Innovation and Development" (https://web.archive.org/web/20201019171427/https://figshare.com/articles/What_Can_Digitization_Do_For_Formulated_Product_Innovation_and_Development/11763864). *Polymer International*. **70** (3): 248–255. doi:10.1002/pi.6056 (https://doi.org/10.1002%2Fpi.6056). S2CID 219766018 (https://api.semanticscholar.org/CorpusID:219766018). Archived from the original (https://figshare.com/articles/What_Can_Digitization_Do_For_Formulated_Product_Innovation_and_Development/11763864) on 19 October 2020. Retrieved 28 August 2020.
76. "Formulus" (https://www.cas.org/products/formulus). *Develop Safe and Effective Products with Formulus*. Retrieved 17 August 2020.
77. "Innovation 4.0: A Digital Revolution for R&D" (https://www.newstatesman.com/spotlight/manufacturing/2019/09/innovation-40-digital-revolution-rd). *New Statesman*. Retrieved 17 August 2020.
78. Norton, Michael; Mochon, Daniel; Ariely, Dan (9 September 2011). "The IKEA effect: When labor leads to love" (http://nrs.harvard.edu/urn-3:HUL.InstRepos:12136084). *Journal of Consumer Psychology*. **22** (3): 453–460. doi:10.1016/j.jcps.2011.08.002 (https://doi.org/10.1016%2Fj.jcps.2011.08.002).

79. Chalaris, M (2022). "Occupational Health and Safety, and Environmental Management on the Age of Fourth Industrial Revolution" (https://doi.org/10.47577%2Fbusiness.v2i3.6941). *Technium Business and Management*. **2** (3): 1–5. doi:10.47577/business.v2i3.6941 (https://doi.org/10.47577%2Fbusiness.v2i3.6941). S2CID 250252625 (https://api.semanticscholar.org/CorpusID:250252625).
80. Arghami, Sh.; Nasl Seraji, J.; Mohammad, K.; Farhangi, A.; van Vuuren, W. (2005). "Mental health in high-tech system". *Iranian Journal of Public Health*. **34** (1): 31–37.
81. Alves, Joel; Lima, Tânia M.; Gaspar, Pedro D. (January 2023). "Is Industry 5.0 a Human-Centred Approach? A Systematic Review" (https://doi.org/10.3390%2Fpr11010193). *Processes*. **11** (1): 193. doi:10.3390/pr11010193 (https://doi.org/10.3390%2Fpr11010193). ISSN 2227-9717 (https://www.worldcat.org/issn/2227-9717).
82. Kraaijenbrink, Jeroen. "What Is Industry 5.0 And How It Will Radically Change Your Business Strategy?" (https://www.forbes.com/sites/jeroenkraaijenbrink/2022/05/24/what-is-industry-50-and-how-it-will-radically-change-your-business-strategy/). *Forbes*. Retrieved 21 February 2024.

Sources

- This article incorporates text from a free content work. . Text taken from *UNESCO Science Report: the Race Against Time for Smarter Development.* (https://unesdoc.unesco.org/ark:/48223/pf0000377433/PDF/377433eng.pdf.multi), Schneegans, S., T. Straza and J. Lewis (eds), UNESCO.

-

Intelligent maintenance system

An **intelligent maintenance system** (**IMS**) is a system that uses collected data from machinery in order to predict and prevent potential failures in them. The occurrence of failures in machinery can be costly and even catastrophic. In order to avoid failures, there needs to be a system which analyzes the behavior of the machine and provides alarms and instructions for preventive maintenance. Analyzing the behavior of the machines has become possible by means of advanced sensors, data collection systems, data storage/transfer capabilities and data analysis tools. These are the same set of tools developed for prognostics. The aggregation of data collection, storage, transformation, analysis and decision making for smart maintenance is called an intelligent maintenance system (IMS).

Definition

An intelligent maintenance system is a system that uses data analysis and decision support tools to predict and prevent the potential failure of machines. The recent advancement in information technology, computers, and electronics have facilitated the design and implementation of such systems.

The key research elements of intelligent maintenance systems consist of:

1. Transformation of data to information to knowledge and synchronization of the decisions with remote systems
2. Intelligent, embedded prognostic algorithms for assessing degradation and predicting the performance in future
3. Software and hardware platforms to run online models
4. Embedded product services and life cycle information for closed-loop product designs

E-manufacturing and e-maintenance

With evolving applications of tether-free communication technologies (e.g. Internet) e-intelligence is having a larger impact on industries. Such impact has become a driving force for companies to shift the manufacturing operations from traditional factory integration practices towards an e-factory and e-supply chain philosophy. Such change is transforming the companies from local factory automation to global business automation. The goal of e-manufacturing is, from the plant floor assets, to predict the deviation of the quality of the products and possible loss of any equipment. This brings about the predictive maintenance capability of the machines.

The major functions and objectives of e-manufacturing are: “(a) provide a transparent, seamless and automated information exchange process to enable an only handle information once (OHIO) environment; (b) improve the use of plant floor assets using a holistic approach combining the tools of predictive maintenance techniques; (c) links entire supply chain management (SCM) operation and asset optimization; and (d) deliver customer services using the latest predictive intelligence methods and tether-free technologies”.

The e-Maintenance infrastructure consists of several information sectors:[1][2]

- Control systems and production schedulers
- Engineering product data management systems
- Enterprise resource planning (ERP) systems
- Condition monitoring systems
- Maintenance scheduling (CMMS/EAM) systems
- Plant asset management (PAM) systems

See also

- Big Data
- Cyber manufacturing
- Cyber-physical system
- Decision support systems
- Industrial artificial intelligence
- Industrial Big Data
- Industry 4.0
- Internet of Things
- Intelligent transformation
- Machine to machine
- Maintenance, repair, and operations
- Predictive maintenance
- Preventive maintenance
- Prognostics
- Smart, connected products

References

1. Moore, W. J.; A. G. Starr (August 2006). "An intelligent maintenance system for continuous cost-based prioritisation of maintenance activities" (http://uhra.herts.ac.uk/bitstream/2299/2247/1/902342.pdf) (PDF). *Computers in Industry*. **57** (6): 596. doi:10.1016/j.compind.2006.02.008 (https://doi.org/10.1016%2Fj.compind.2006.02.008). hdl:2299/2247 (https://hdl.handle.net/2299%2F2247).
2. Baldwin, Robert C (2001). "Enabling an e-Maintenance infrastructure" (http://www.mt-online.com/december2001/enabling-an-e-maintenance-infrastructure). *Maintenance Technology*. **12**.

Further reading

- M. J. Ashby et al., “Intelligent maintenance advisor for turbine engines”, The Journal of the Operational Research Society, vol. 46, No. 7 (July 1995), 831–853.
- A. K. S. Jardine et al., “A review on machinery diagnostics and prognostics implementing condition-based maintenance”, Mechanical Systems and Signal Processing 20 (2006) 1483–1510.
- R. C. M. Yam et al., “Intelligent Predictive Decision Support System forCondition-Based Maintenance”, Int J Adv Manuf Technol (2001) 17:383–391

- A. Muller et al., “On the concept of e-maintenance: Review and current research”, Reliability Engineering and System Safety 93 (2008) 1165–1187
- A. Bos et al., “SCOPE: An Intelligent Maintenance System for Supporting Crew Operations”, AUTOTESTCON 2004. Proceedings. IEEE, 2004.
