Building a Taxonomomy of Industry 4.0 Needs and Enabling Technologies

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May 26, 2021

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Abstract. A thorough understanding of the concept of Industry 4.0 is needed to assess the overall plethora of I4.0 enabling technologies and define their application domains and uses. The objective of the research paper is to review Industry 4.0's main application fields and examine which enabling technologies are used in use cases in the industrial environment, as well as developing two taxonomies: one for enabling technologies in the Industry 4.0 world and the other for classifying I4.0 problems. This taxonomy can be used for both product innovation and product optimization in industrial companies' strategic planning. This goal was met by analyzing the state-of-the-art in Industry 4.0 based on recent scientific developments and real-world use cases in industrial enterprises.

Keywords: Industry 4.0 applications · Edge Computing · Artificial Intelligence · Machine Learning · Internet of Things.

1 Introduction

The fourth Industrial Revolution, also known as I4.0, is now in full swing. The word "Industry 4.0" was coined in Germany when the government and private sector, led by Bosch, formed a research group to make German manufacturing more competitive in the global market [1]. This term encompasses all manufacturing domains and includes advanced manufacturing technologies that collect, optimize, and deploy data.The idea of German government behind Industry 4.0 is to exploit the potentials of new technologies and concepts such as :

- availability and use of the internet and IoT
- integration of technical processes and business processes in the companies
- digital mapping and virtualization of the real world
- 'Smart' factory including 'smart' means of industrial production and 'smart' products

Smart factories are equipped with sensors, embedded software, and robotics solutions that collect and analyze data for better decision-making. Analysis of large amounts of data can provide tools that perform predictive maintenance, self-optimization of the process, and meet customers needs more cost-effectively which was not possible before.

Industry 4.0 technologies assist businesses in managing production planning and scheduling, capacity usage, maintenance, and energy conservation, as well as allowing for customized solutions, flexibility, and cost savings in manufacturing processes.

A question that many experts ask nowadays is **what are the typical problems that can be addressed by Industry 4.0?** Industry 4.0 allows comprehensive real-time tracking of operations, allowing for real-time data collection, monitoring, and maintenance; it implements a new and significantly enhanced system of development, service provision, mode of supply, storage, distribution and a significant enhancement of business support activities. One of the challenges faced by Industry 4.0 is managing the large amounts of data produced by analyzing output data and integrating the results with customer information systems.

Big data analysis may help managers detect defects, faults, and flaws in the manufacturing process at an early stage, optimize automation processes and conduct trend studies, use resources more effectively, and perform predictive maintenance. Predictive maintenance identifies equipment failure before it happens, allowing you to continually improve the production process and increase manufacturing performance.

Given this wide range of potential enhancements enabled by 4.0 applications another question arises: **What are the 4.0 key enabling technologies?**

In the Industry 4.0 environment, the European Commission identifies nine main enabling technology developments (Figure 1.) and investigates their possible technological and economic benefits for manufacturers and production equipment suppliers [2]. We used the enabling technologies provided from European Commission as guidelines for our research, for categorize the technologies.

These enabling technologies are Advanced Manufacturing Solutions , Additive Manufacturing, Augmented Reality, Simulation, Horizontal/Vertical Integration, Industrial Internet, Cloud, Cyber-security, Big Data, and Analytics; their existence helps in turning manufacturing into a completely digitized and intelligent operation.

Furthermore, according to the Microsoft study [3], crucial technology drivers for IoT success in the coming years are AI, Edge Computing, and 5G. Companies should be aware of these enabling technologies' capabilities and they need a detailed technology roadmap and guide lines for incorporating enabling technologies into their strategies and businesses. There are still many companies that doesn't know the potentiality, benefits and how of use Industry 4.0 and AI technologies for improving the productivity and quality of the company.

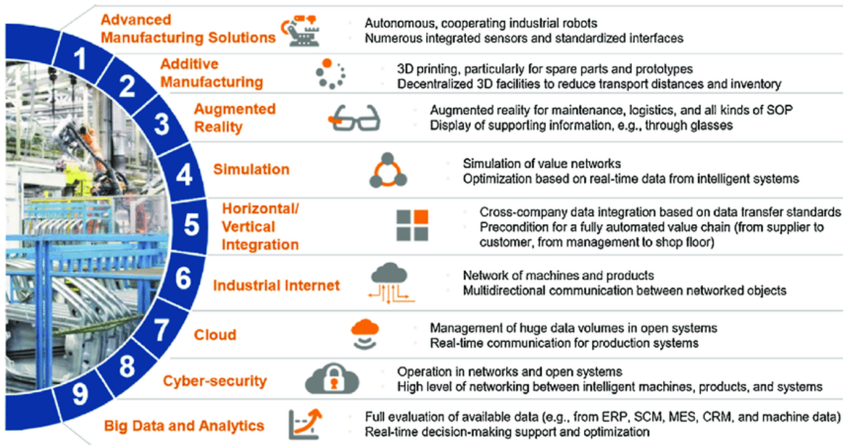

Fig. 1. Key nine enabling technology trends.

AI technologies are methods and procedures that allow technical systems to interpret their environments, solve problems independently, find new ways to solve challenges, make decisions, and, most importantly, learn from experience to become more proficient at completing tasks and actions, according to the industry.

The AIoT paradigm [4] , the combination of AI with IoT has become popular during recent years. It's a groundbreaking computing approach that can contribute to the creation of more scalable, effective, and secure I4.0 solutions.

For help the companies to use enabling technologies and improve the productivity and quality , we tried to answer the following questions : **1) Which of these Industry 4.0 addressable issues and which of these Industry 4.0 key enabling technologies have been implemented and used in industrial use cases? 2) Is it possible to create a taxonomy that categorizes I4.0 problems and supporting technologies? 3) What is the relationship between I4.0 issues and enabling technologies?**

2 4.0 Taxonomies Building

There is a need to look beyond scientific articles to find answers to these questions. As a result, we conducted desk research using academic papers as well as white papers, business use cases, and consulting company reports as sources. Two taxonomies were developed, one based on enabling technologies in the Industry 4.0 environment, and the other for classify I4.0 problems. The two taxonomies are connected by the use cases founded on white and academic paper. Each use case was regarded as representative of one or more Industry 4.0 issues, from which we extracted the I4.0 enabling technologies that were used to solve the issues.

2.1 4.0 innovation problems

First of all, we can divide the I4.0 innovation problems into 2 main categories: Product innovation, Process optimization .

- **Product Innovation -** aims at building a new generation of products that are typically IoT connected thus migrating the business toward a service-based solution. Product Innovation in the 4.0 era also aims at improving the usability of products by making them easier to use and understand.
- **Process Optimization -** aims at improving the efficiency of production processes to reduce the product and goods production costs. Industrial processes can be optimized by improving the efficiency of equipment, workforce and supply-chain. It consists of changes of production processes of the product/service, and may not necessarily have explicit impact on the final output, while increasing the productivity and reducing producing costs .

From Product Innovation we can derive other sub-problems of I4.0 as:

- **Product Servitization** the innovation of organization's capabilities and processes to better create mutual value through a shift from selling product to selling Product-Service Systems
- **Usability Improvement** product usability improvement by designing user interface, with usability testing, targeting customer.
- **After-Sales support** any service provided after a customer has purchased a product
- **Automatic consumables reorder** measuring consumable usage to reliably determine when to increase or decrease the production
- **Inventory Management** is a systematic approach to sourcing, storing, and selling inventory, both raw materials (components) and finished goods (products).
- **Cost and Number of parts Reduction** is the achievement of real and permanent reduction in unit cost of products manufactured
- **Smart products (self-diagnosing products)**

From Process Optimization we can derive more sub-problems of innovation on I4.0 as :

- **Equipment efficiency improvement**
  - **Real-time Production monitoring and Supervision** : Constant stream of data about the overall health and performance of assets and production lines. Real-time alerts can help operators quickly address any issues before they become major failures that can cost plant valuable time and money. With the right information at their fingertips,operators can make faster, more data-driven decisions to ensure your optimal performance
  - **Predictive maintenance** : Detects the early signs of equipment malfunctions, allowing store managers to prepare spare machinery and avoid downtime. The IoT enables reducing downtimes and machine repair expenses, facilitating warehouse management considerably

  - **Smart Scheduling** : The adoption of Smart Scheduling will allow industries to profit from the cumulative experience in their fields (for instance, facilitating the selection of appropriate rescheduling strategies). In turn, the adoption of tolerance scheduling allows making intuitive and natural decisions, seen from the point of view of the requirements of manufacturing industries, overcoming the resistance to the implementation of Smart Manufacturing and Industry 4.0 environments, usual among personnel in traditional firms
  - **Vertical interconnection and integration (between departments in a factory)** The integration of IT systems at various hierarchical production and manufacturing levels, rather than horizontal levels, into one comprehensive solution
- **Worker security improvement and accident prevention**
  - **Smart PPE (personal protection equipment)** PPE, such as safety shoes, ear plugs and protective eyewear, has always been important in protecting the wearer from one or many occupational safety and health (OSH) risks. If an activity carried out by a person — the wearer of the PPE — involves a certain risk that cannot be further reduced by other (collective technical or organizational) means, the use of PPE is essential to enable that person to do their job without or with less risk of injury. PPE must function reliably and provide a high level of protection. This principle of the hierarchy of prevention has been successfully used for a long time.
  - **Worker attention and mental state monitoring** Improving working conditions based on real-time temperature, humidity and other data in the plant or warehouse, quick detection and enhanced protection in case of incidents, detection of presence of gasses, radiation and so forth, better communication and collaboration possibilities, a focus on ergonomics,clean air and clean factory initiatives (certainly in Industry 4.0 as the EU wants to be leading in clean air and clean anything technologies)
- **Worker routine and operation optimization**
  - **Time and Method smart measurement** Scheduling is the process of arranging and controlling workloads via shift work scheduling and data analytic.
- **Supply Chain**
  - **Horizontal interconnection and integration (between different actors of the supply chain)** Horizontal integration in Industry 4.0: from supplier to consumer, end-to-end integration of IT systems and information flows with IoT, analytics and data
  - **Production on demand enabling technology**
  - **Smart warehouse** IoT solutions for warehouse management provide real-time data on product locations, transportation conditions, the integrity of packaging, and so on. Thanks to instant updates, store managers can ensure no inventory is lost during transportation and ensure that supply chain vendors are managing deliveries responsibly

- **Supply chain transparency and reliability improvement** Achieving supply chain transparency is the fundamental process of increasing visibility, traceability and transparency by collecting and sharing information throughout the supply chain and communicating it to authorised internal and external stakeholders. The purpose of improving the reliability of supply chains is to meet the needs of consumers as quickly and qualitatively as possible

2.2 4.0 needs and enabling technology identification

Table 1 shows a list of sources that can be used to build a taxonomy of both problems and enabling technologies. The white paper, research paper, and business use cases were all considered sources for the development of two taxonomies, as shown in the table.

Table 1: List of articles for development of a Taxonomy.

Article Name	Article Type	Publication Date
AI in production [5]	white paper	7 Mar. 2019
Optimization of machining process [6]	academic paper	2 Mar. 2019
AI for defect detection [7]	business use case	30 Mar. 2020
Predicting Defects in Manufacturing [8]	academic paper	Oct. 1999
IoT Impacts the Supply Chain [9]	white paper	22 Oct. 2019
Smart Scheduling [10]	academic paper	Aug. 2018
Process Discovery: Capturing the Invisible [11]	academic paper	Mar. 2010
Designing a novel shuttle with picking system [12]	academic paper	2019
Condition monitoring in I4.0 [13]	academic paper	2019
Industry 4.0 in the tobacco industry [14]	academic paper	Feb. 2020
Logistic Industry Innovations with IoT [15]	white paper	17 Sept. 2019
ML in Demand Forecasting [16]	business use case	20 June 2020
Edge - Computing [17]	business use case	25 Aug. 2020
Predictive Maintenance using ML [18]	business use case	
5G Heart of Industry 4.0 [19]	white paper	
Real-Time Production Performance Monitoring [20]	business use case	
Smart Warehouse System [21]	business use case	
Blockchain-enabled IoT shipment tracking system [22]	business use case	

Continued on next page

Table 1 – continued from previous page

Article Name	Article Type	Publication Date
Vehicle Tracking and Fleet Management [23]	business use case	
Smart Tracking Solution [24]	white paper	
Reducing Complexity with Simplicity [25]	academic paper	August 2015
IoT Order Fulfillment [26]	white paper	
Asset Tracking [27]	business use case	
Predictive Maintenance [28]	business use case	
Predictive Analytics Using Rattle and Qlik Sense [29]	business use case	
Supply Chain Management [30]	white paper	
IoT in Retail [31]	business use case	
Remote Measurements Control[32]	busines use case	
IT plus OT convergency for your automation solution [33]	white paper	
Data driven technology for efficiency in energy intensive industries [34]	white paper	
Improving stores efficieny using clients shopping times [35]	white paper	
Smart PPE and IoT to improve workplace safety [36]	white paper	
Cost Management For After-Sales Supply Chain [37]	white paper	
IoT Retail with Consumer Smartphone detection [38]	business use case	
IoT Industry Solution [39]	white paper	
Tracking System [40]	white paper	
Product Service System for aerospace maintenance [41]	academic paper	May 2012
Artificial intelligence at the edge [42]	white paper	
Energy sources optimization [43]	white paper	
Predictive maintenance and production optimization[44]	white paper	
Leveraging IoT Framework [45]	academic paper	Sep. 2020

2.3 4.0 enabling technologies

The focus of the research was done on Advanced Manufacturing Solutions, Horizontal/Vertical Integration, Industrial Internet, Cloud, Big data and Analytics out of key nine enabling technology trends from the European Commission, that was mentioned in the Introduction section since based on the found sources these five enabling technologies are said to play a crucial role in the solution of Industry 4.0 problems. Table 2 lists all the technologies investigated in the literature which are considered as enabling technologies of Industry 4.0. The taxonomy was derived using as main categories the same categories identified by the European Commission. Many of the key nine enabling technologies that form the basis for Industry 4.0 are already in use in manufacturing, but when combined with Industry 4.0, they will transform production: isolated, optimized cells will come together as a fully integrated, automated, and optimized production flow, leading to a shift in traditional production relationships among suppliers, manufacturers, and customers—as well as between human and machine. The following is a list of enabling technologies that were considered when creating a taxonomy of enabling technologies [46]:

- **Big Data and Analytics** - the collection and comprehensive evaluation of data from various sources production equipment and systems will become standard to support real-time decision making.
- **Industrial Internet** - devices will be enriched with embedded computing and connected using standard technologies.
- **Cloud** - machine data and functionality will increasingly be deployed to the cloud, enabling more data-driven services for production systems.
- **Horizontal/Vertical Integration** - functions from the enterprise to the shop floor level are not fully integrated. With Industry 4.0, companies and departments will become more cohesive, universal data-integration networks will evolve.
- **Advanced Manufacturing Solutions** - the greater connectivity and interaction of Industry 4.0–capable machines and systems in their factories, manufacturing-system suppliers will have to expand the role of IT in their products.

3 Discussion

We have created the taxonomy to investigate the most important issues and most used technologies in the field of Industry 4.0 . The taxonomy can be used also as guidelines for resolve Industry 4.0 problems

The generated taxonomy can be used as a search engine at the following link: `https://docs.google.com/spreadsheets/d/1JyHiKv_kBnENtA8yGMV3Sn9x05hKOLJwf49LwdYiEU0/edit?usp=sharing`.

Unfortunately, we were unable to identify a use case for every problem that exists in the industry 4.0 world; however, it is worth pointing out that, among the papers reviewed, Real-time Production Monitoring Analysis, Predictive Maintenance, Smart Scheduling, Smart Warehouse, Cost, and several parts/component reduction are said to be the most frequently addressed problems in the Industry 4.0 world. According to the considered business use cases, white papers, and research articles, the most commonly used enabling technologies are Time-series

Table 2. List of I4.0 enabling technologies.

Horizontal/Vertical Integration	**Industrial Internet**
1. DataBases (a) SQL DB (b) Non SQL DB (c) Time series DB i. InfluxDB ii. Prometheus iii. Graphite 2. Blockchain 3. Connectivity (a) GSM/4G/5G (b) MQTT, Node-Red (c) REST API and Webhook (d) RFID/NFC (e) Bluetooth (f) LPWAN	1. Industrial IOT (a) Industrial communication protocols i. Ethernet Protocols ii. Fieldbus Protocols iii. Wireless Protocols (b) Industrial Gateway and data acquisition device
Big Data and Analytics	**Cloud**
1. Data science (a) Data Visualization and Dashboarding i. Grafana ii. Kibana iii. Metabase (b) Data Analytics i. Data lake and Data Warehouse design ii. Data Mining A. Python B. R C. Julia iii. All-inclusive tools A. Tableau B. PowerBI C. Elastic Stack D. SAP Business Intelligence E. QlikView/Qlik Sense iv. Data Engines A. Apache Hadoop B. Apache Kafka C. Apache Spark 2. IoT (a) Signal Processing 3. AI (a) Machine Learning (b) Deep Learning (c) Reinforcement Learning (d) Continuous Learning (e) Computer Vision (f) Natural Language Processing	1. Container Technology (a) Docker (b) Kubernates (c) Terraform 2. Serverless programming (a) AWS Lambda functions (b) Azure functions 3. Device Management (a) Zerynth Device Manager (b) AWS IoT Device Management (c) Azure IoT Hub (d) WinCC OA IOT OPA 4. Cloud Data Storage (a) AWS S3 (b) Google Cloud Storage (c) Microsoft Azure Storage 5. Edge Computing (a) AWS green grass (b) Azure Edge IoT (c) Custom solutions based on docker swarm (d) Multi-access edge computing (MEC) (e) AWS Wavelength
Advanced Manufacturing Solutions	
1. Embedded Computing (a) Arduino (b) STM32 (c) ESP32 (d) FRGA 2. Sensors (hardware) 3. Signal Processing 4. Blockchain	5. Connectivity 1. GSM/4G/5G 2. MQTT, Node-Red 3. REST API and Webhook 4. RFID/NFC 5. Bluetooth 6. LPWAN

Databases, Industrial communication protocols, Cloud Data Storage, Data Analytics, Data Visualization, and Dashboarding, Machine Learning, and Sensors.

Table 3shows a ranking of the most commonly used enabling technologies and issues in the industrial sector.

Table 3. The rank of the most used enabling technologies and problems found in articles.

Enabling Technologies	**Number of articles**	**Problems**	**Number of articles**
Time series Database	20	Smart warehouse	7
Data Visualization and Dashboarding	18	Real-time Production monitoring and analysis	6
Cloud Data Storage	18	Cost and number of parts/component reduction	6
Data Analytics	17	Smart Scheduling	5
Sensors	16	Supply chain transparency and reliability improvement	5
Machine Learning	14	Predictive maintenance	4
Connectivity	12		
Signal Processing	11		
Industrial communication protocols	9		

The rank was created by ordering problems and enabling technologies based on the number of articles associated.

4 Conclusions

Industry 4.0 is forming smart factories based on information on demand as a result of the digital transformation, which is transforming the manufacturer journey.

The challenge is to develop new business models and services, and new products to use efficiently the potential that exists from humans and machines collaborate and to optimize the benefits of this collaboration.

Industry 4.0 enables companies to integrate their customers' needs and expectations into their development and production processes in novel ways, such as by direct data sharing with their machinery; it also makes machine data analysis simpler, which improves productivity and prevents production process failures.

To fuel the 4.0 transformation, it's important to provide both the academic and industrial worlds with a clear picture of what's feasible and what's needed to make it happen. This taxonomy is a first step in the right direction. Despite the fact that this is a preliminary exploratory work, it will help in the explanation of the 4.0 environment and open the door to more investigation aimed at better understanding of how the 4.0 world is developing.

One of the possible future works to continue this research it's to create a dashboard with a search engine to query the taxonomy and analyze statistics about it. Another approach to continue the research it's also to make a survey with companies that are adopting Industry 4.0 solutions to analyze the current situation of smart factories.

Acknowledgements

This work has been partially funded by Programme Erasmus+, Knowledge Alliances, Application No 621639-EPP-1-2020-1-IT-EPPKA2-KA, PLANET4: Practical Learning of Artificial iNtelligence on the Edge for indusTry 4.0.

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