Index of Industry 4.0

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Industry 4.0 is currently identified as a major factor in the future competitiveness of enterprises. However, the implementation and readiness of different technologies varies from one enterprise to another. Based on the performed factor analysis, an Industry 4.0 index (VPi4) was created, which allows the enterprises to determine their current level of Industry 4.0.

Keywords: Industry 4.0 ; index ; smart ; intensity of technology ; manufacturing ; implementation

1. Introduction

The VPi4 index and its methodology allow enterprises to easily identify their own level of technology readiness within Industry 4.0. The index is a tool for managers to set strategic objectives and formulate strategies in line with the challenges of the Fourth Industrial Revolution. It can also be a criterion in deciding on investment plans in terms of selecting priorities for the further development of an enterprise. The proposed solution allows better assessment of strategic initiatives in terms of their future return. The managers can also help to decide which projects should be implemented in order to ensure greater synergies. The index includes technologies that need to be implemented in the enterprises, as well as the processes that need to be set up, changed, and reintroduced. In this sense, it can also, in addition to project management, help with the management and identification of key processes in the organization [1].

The initial level of index includes the basic requirements of Industry 4.0 such as well-qualified (the right) people [2], and processes of data collecting [3], storage in the cloud [4], and analysis of data [5]. These processes and variables are necessary for higher levels of Industry 4.0 and can be limits for the future development and introduction of Industry 4.0 implementation. The second level of the index consists of necessary infrastructure which is needed to operate with technologies. This level has more parts, such as using sensors for collecting data [4], IT infrastructure including MES [6], ERP information systems [6], linked data via M2M (or IoT), robots [7], and user-end technologies such as mobile terminals [4]. The last level is more advanced in terms of using learning software [5], virtual reality, and simulations including digital twins [8] or sharing data with other parties [9].

The cornerstone of Industry 4.0 is based on machines, equipment, logistics, and humans who are connected to each other to exchange data, process data, and make decisions, appropriately coordinating the ever-present machines [10]. Industry 4.0 is characterized primarily by digitization, robotics, and artificial intelligence.

Use o sensors. Sensors are sources of information for the control system (computer, brain) and technical devices, which measure certain physical and technical quantities and convert them into a signal that is remotely transmitted and further processed. These are various global positioning system (GPS) sensors, cameras, and microphones, forming the digital nervous system. These devices acquire information on position, distance, motion, speed, displacement, temperature, drought, humidity, sound, vibration, gases, chemicals, flow, strength, load, pressure, level, electricity, acceleration, tilt, light, etc. The use of sensors in smart factories has many facets, as discussed by many authors [11].

Data collection and analysis. The process of data collection process includes retrieving, searching, selecting, and generating. As more and more business activities are digitized, new data sources arise, and the equipment to process these data becomes increasingly cheaper; we are entering a new era [12]. The volume of stored data is growing four times faster than the world economy, and computing power is increasing nine times faster.

Information Technology (IT) Infrastructure and Mobile Terminals. In particular, Industry 4.0 includes a radical shift in how IT infrastructure works, defined as the overall transformation of the manufacturing industry through the introduction of digitization and the internet. These transformations mean a revolutionary improvement in the design and manufacturing processes, operations, and services of manufacturing products and systems. Tjahjono [13] defines Industry 4.0 requirements for IT infrastructure in terms of device automation, auto-driving, increased need for reality, an extremely large number of monitored and managed devices, and process automation. The enterprises using the Internet of things (IoT) cannot rely solely on wireless networks such as WiFi, ZigBee, and low-power wide-area network (LPWAN) for their future critical related systems [14].

Cloud storage and Big Data. Data storage includes recording, transportation, replication, compression, cleaning, indexing, stream processing, integration, and transformation of data. Given the increase in data volume (big data), the main question is how to store all data and where. Data warehouses and centers are the most often used. A data warehouse (DW) is an integrated collection of subject-oriented decision support data [15]. Clouds are hardware services offering computing, networking, and storage capacity [16].

Information Systems and Learning Software. The implementation of Industry 4.0 uses the concept of an automation pyramid in connection with information technology. The pyramid is closely related to the vertical integration of information systems in an enterprise. Typical solutions and technologies in this vertical integration include data acquisition sensors: programmable logic controllers (PLC) that control production processes and take control levels, supervisory control and data acquisition (SCADA), which allows managing different levels of support processes and supervision, manufacturing execution systems (MES) controlling production processes, and intelligent enterprise resource planning (ERP) management for the enterprise level, the highest level in this hierarchical image [17]. Learning software includes pattern and machine learning (ML), which embodies some of the aspects of the human mind that allow us to deal with an extremely complex solution to the problem with the speed overcoming even the fastest computers [18].

Robots. Production process automation began in the 1960s with the introduction of industrial robots into the automotive manufacturing process. The automation of production systems by the introduction of industrial robots is an ongoing process and is now in line with the evolution of information technology [19]. The area of collaborative robots was extensively explored, but it is necessary to define precisely what type of robot can be specified as cooperative.

M2M Communication. Digital production includes a wide range of applied sciences. Studies in these fields attract a lot of effort both in academia and in industry, especially in connection with machine connectivity and communication (M2M), vitally important for machine collaboration and process optimization [20]. M2M communication will be provided both between physical objects and between their cloud-based digital counterparts [21].

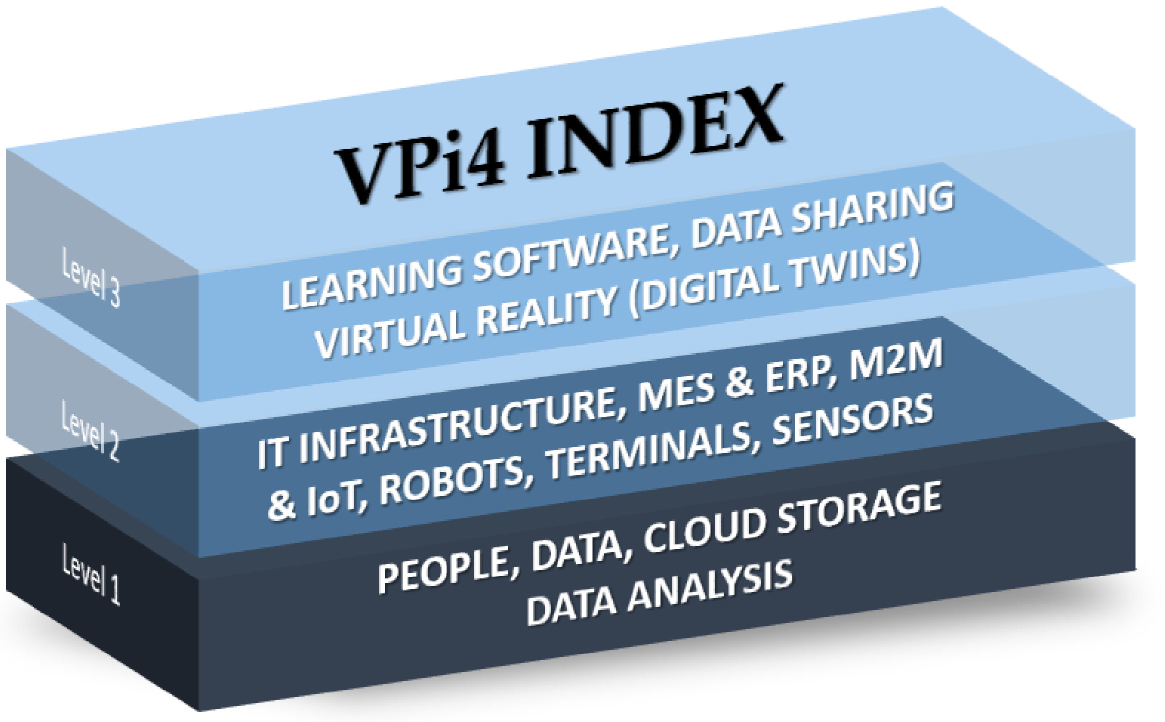
Sharing and using data with suppliers and customers. Enterprises face a precarious environment and strive to achieve greater cooperation in the supply chain to leverage the resources and knowledge of their suppliers and customers [22]. In such a chain, this cooperation takes place through electronic data interchange (EDI) [23].

Use of virtual reality, simulation, and digital twins. Simulation is defined as an imitation of a real thing, a state, or a process. Generally, it implies displaying or modeling some key features and behavior of some physical or abstract systems for testing, optimization, and education. Product and process simulations are used extensively in production, especially processes of visualization, representation, simulation, modeling, and interpretation. Enriching digital simulations with sensor data brings reality closer and improves the accuracy of simulation results [24]. Virtual reality (VR) is broadly defined as a computer-generated three-dimensional (3D) world [25], and an environment that simulates complex situations and contexts in real life and allows people to immerse, navigate, and communicate [26]. Digital twins are a mirror image of a real-time physical process [27]. The concept of using "twins" comes from the Apollo NASA (National Aeronautics and Space Administration) program; later, it was used also in aviation, such as the "Iron Bird" [8].

2. Model Description

The results of the factor analysis were used to create an index for the implementation level of Industry 4.0 (VPi4) in the enterprise. In terms of interpretation and for model purposes, the factors were identified as levels 1–3 of Industry 4.0 in the enterprises. Level 1 was primarily saturated with the human capital variable, collecting data, storing data in the cloud, and analyzing data. These variables have in common that they focus on working with data and the availability of human capital, i.e., the need to operate equipment and technology. Level 2, on the other hand, included all the variables related to the core infrastructure of industry 4.0. This means IT infrastructure, the presence of MES and ERP information systems, M2M-based data interconnection, the use of robots and their arms in production, mobile devices, and sensors. Level 3 included a higher level of Industry 4.0 that can be expressed through the use of learning software, data sharing with suppliers, and virtual reality. Based on these data, it was possible to divide 13 areas into three levels of Industry 4.0 implementation into the enterprise, using factor analysis, where the numbers after each area represent their factor load.

Figure 1. VPi4 INDEX



Source: authors

The first level of introducing Industry 4.0 into an enterprise consists of the following areas (with factor biases):

- We have the right people (mechatronics, mounter, technologist)—0.61;
- We collect data—0.82;
- Data storage in the cloud—0.63;
- We analyze data—0.86.

The second level of introducing Industry 4.0 into an enterprise consists of the following areas:

- IT infrastructure (speed, stability)—0.53;
- MES, ERP—0.75;
- We use linked data (M2M)—0.58;
- Use of robots, robotic arms (in production and elsewhere)—0.54;
- Mobile terminals—0.54;
- Use of sensors—0.58.

The third level of introducing Industry 4.0 into an enterprise consists of the following areas:

- Use of learning software—0.44;
- Suppliers can use our data (response options, predictions)—0.67;
- Use of virtual reality (digital twins, simulation)—0.68.

VPi4 index aims to categorize Industry 4.0 components into a clear framework. The proposed index brings a new three-level structure of the Industry 4.0 phenomenon. The main theoretical contribution is, in particular, the determination of the content of the term and the determination of the importance of different factors in the context of the readiness of companies to implement Industry 4.0 concepts. The differences between more technologically and less technologically demanding industries confirm the specifics of different fields in the use of new technologies. This confirms the conclusions of many other researches and the fact that new technologies are largely being introduced, especially in the field of mechanical engineering. The results also indicate that the subjective perception of enterprises of their own level of Industry 4.0 corresponds more or less to the actual situation. The problem, however, is probably the lack of visibility in terms of the current challenges, priorities, and complexity of technology [28].

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