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Article

Frameworks of the Maturity Model for Industry 4.0 with Assessment of Maturity Levels on the Example of the Segment of Steel Enterprises in Poland

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Abstract: The aim of the article is to present the author's concept of steel market enterprises' maturity for functioning in Industry 4.0. The model is based on the assessment of key technologies or pillars of the new industrial concept. The proposed assessment includes five levels of investment maturity under the conditions of the fourth industrial revolution (a five-point assessment scale was used to measure the degree of maturity of developed enterprises by implemented projects of smart manufacturing (SM). The maturity assessment proposal is based on direct research. The research was carried out in the segment of enterprises from the Polish steel sector. The tool used for the research was a questionnaire survey. The research was carried out with 79 selected steel enterprises in Poland for the pilot study. On the basis of the research, it was established that the segment of enterprises in the Polish steel market are at the third level of maturity in the five-level scale of the model, where level 1 is the "preliminary" level, and 5 represents the optimal maturity level. Within particular pillars of Industry 4.0, according to all respondents, the biggest changes in terms of implementing the industrial concept took place in connection with the use of Internet and mobile technologies in the process of customer service, including EDI, an e-invoicing system. The second position belonged to investments in production automation with the use of individual machines (installation of sensors on devices and sensors for collecting data on the state of the machine). In addition, similar and relatively higher answers were given by respondents to questions about the development and compatibility of IT systems for production support, such as CAx, MRP, MES. The remaining technological pillars, such as data processing from machines, installations of real-time data; network and chain integration (end -to -end engineering); production automation with the use of interoperating machines (production nests); expansion of databases (Big Data) and visualisation of processes together with their optimisation using IoT were found to be initiated as activities in very large and large enterprises. The lowest rated scope of investment changes concerned the block chain in the steel sector. The research of investment of enterprises can be used to assess the maturity of enterprises in this segment of industry in Poland.

Keywords: Industry 4.0 (I 4.0); smart manufacturing (SM); steel industry; maturity model (MM)

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1. Introduction

In the conditions of the fourth industrial revolution and the strongly popularised concept of Industry 4.0 (I 4.0), the majority of large and international companies all over the world focus on process optimisation using key technologies (pillars) of the concept. The term Industry 4.0 comes from the German government's draft of high-tech strategy and was first used at the international Hannover Messe in 2011. Industry 4.0 is a concept that describes the complex process of the technological and organisational transformation of companies, which includes the integration of the value chain, introduction of new business models and digitization of products and services. New industry is revolutionizing the way companies manufacture, improve and distribute their production. Manufacturers are integrating new technologies, including the Internet of Things (IoT), cloud computing and analytics, and AI and machine learning into their production facilities and throughout their operations [1–3]. Synonymous with Industry 4.0 is smart manufacturing (SM), which is realised on the basis of digital transformation and new technologies of the fourth industrial revolution that emphasise productivity, flexibility and agility. Currently, large companies in developed countries are in the transitionary process to Industry 4.0. Many researchers have highlighted the importance of new technologies in smart production systems [4–6]. Companies, since the introduction of the concept of Industry 4.0 (2011) are gradually building smart manufacturing. In general, the maturity model (MM) is defined as the state of being complete, ideal or ready [7]. Maturity can be measured by quantitative and qualitative methods. In maturity research, the idea is to capture the degree of readiness to co-create a new industry. Companies realize smart manufacturing projects, starting with the improvement of individual workstations or machines, up to whole production lines and processes, to finally reach the level of a smart factory. New solutions of the fourth industrial revolution are implemented in companies, businesses and supply chains. In the conditions of the fourth industrial revolution, the key question pertains to the levels of implementation of new technologies (technological pillars of new revolution) and maturity of optimisation of business. In order to achieve the intended competitive advantage, an enterprise must focus on building a new reality. Enterprises implement new investments or projects of modifying existing means of production in order to build an environment of smart manufacturing.

The aim of the article is to present the author's concept of a model of steel market enterprises' maturity for the enterprises projects during their developmental path to new smart manufacturing. The model was established with the example of the steel enterprises segment in Poland. The model is based on the SM projects that were implemented in the studied enterprises.

This paper is organised as follows: the introduction is presented in Section 1, Section 2 explains the existing maturity models (MM) and frameworks in the literature, Section 3 presents the methodology, and the results of direct research with our conclusions are presented in Section 4, new levels of the maturity model presented in our research in the segment of steel enterprises in Poland are proposed in Section 5. Finally, a discussion and summary of the work (Section 6) is presented.

2. Background for Building the Enterprise Maturity Models in Industry 4.0

Although the idea of Industry 4.0 was introduced a decade ago in Germany, where the first Industry 4.0 platform was created, there are still more and more supporters of this development concept both in scientific and practical (business) environments. The new concept of industry development under the conditions of the fourth industrial revolution has not yet been clearly defined (there is no single and universal definition of Industry 4.0). Among researchers, there are authors who assume that it is a general concept of technical changes in the production environment with features typical of the fourth industrial revolution [1,2]. For many authors, the new industrial concept is a collection of technologies that, when introduced, create a digital business and smart factory [3,8–15]. Industry of the fourth industrial revolution is a new trend in manufacturing that centres around smart manufacturing with smart products [16]. The factories of the future need to be more intelligent, autonomous, flexible, sustainable and dynamic. The list of innovations, technologically and otherwise, adopted by enterprises on the road to smart development is endless [17]. According to H. Peters (2016), the idea of Industry 4.0 is not only related to the availability of new technology but it is a strong paradigm and a philosophy that establishes new directions for improving production, and the scope of changes introduced depends on the company's level of development and its resource capabilities [18]. Emphasis is placed on the fact that innovation in level 4.0 is built on sustainability [19–21] and saving resources, especially in highly energy intensity sectors such as the steel industry [22–24].

In the conditions of the fourth industrial revolution, companies focus on the implementation of key technologies, building the base of Industry 4.0 (KETs from Key Enabling

Technologies). Key Enabling Technologies (KETs) are investments and technologies that will allow European industries to retain competitiveness and capitalise on new markets. The Industrial Technologies Programme (NMP) focuses on the following four KETs: nanotechnologies, advanced materials, advanced manufacturing and processing (production technologies) and biotechnology. KETs are used in the European Commission (EC) document on the "Knowledge for Policy" website [25]. The key technologies form the pillars with which smart factories with smart processes and smart products are built. Researchers present new technological solutions in narrower or broader terms. G. Erboz (2017) defines the four technological pillars as the Cyber-Physical Systems (CPS), the Internet of Things (IoT), Cloud computing and cognitive computing [10]. Additionally, S. Greengard (2015) focuses on the four components of Industry 4.0, which are: the Cyber-Physical Systems (connections between the real and virtual worlds), the Internet of Things (IoT) which increases the data available as different products can be connected to the Internet, the Internet of Services (IoS) and the smart factory [26]. C. Senn (2019) and B. Sniderman (2016) instead characterise nine pillars of the new concept, including those mentioned, which are as follows: Big Data, machine learning, computer prediction and simulation, process visualization, cyber security, horizontal and vertical integration [27,28]. Eleven components of Industry 4.0 are studied by the Boston Consulting Group, and they are: Big Data, augmented reality, 3D printing, cloud computing, autonomous robots, cyber security technologies, computer simulation technologies, system software, process visualisation technologies, integrated technologies, building an environment for vertical and horizontal integration and IIoT [29]. The set of technologies forming the new concept of industry is open and constantly expanding. This article assesses the maturity model of the steel enterprises segment in Poland based on nine pillars of Industry 4.0, which are: Big data and data analytics, autonomous robots, visualization, simulation and computer modeling of the process, horizontal and vertical systems integration based on new solutions, Industrial Internet of Things (IIoT), technologies of cybersecurity in cyber-physical production systems, cloud computing, additive manufacturing, 3D printing and solutions of augmented reality. In order to determine the degree of transformation of enterprises to maturity in new reality it is necessary to identify the scope of implemented smart manufacturing investments (projects). Smart manufacturing (SM) projects are based on collaborative innovation technologies and the real-time management of processes in enterprises and in the whole supply chain. Smart manufacturing, which represents the Fourth Revolution in the manufacturing industry and is considered a new paradigm, is a set of state-of-the-art technologies that support efficient and accurate real-time engineering decision-making through the introduction of various ICT technologies and their convergence with existing manufacturing technologies [30]. According to Kulvatunyou, "SM integrates the latest information and communication technologies (ICT) into manufacturing systems to enable real-time response to changing demands and conditions in the factory, in the supply network, and in customer needs. In this new paradigm, the Internet of Things (IoT), the digital factory, and cloud computing technology play major roles in transforming the rigid hierarchical architecture into a flexible style" [31]. Smart manufacturing (SM) projects in enterprises have different scopes, sizes and types of changes and kinds of investments. Each enterprise develops and implements projects (a set of projects, a program of projects) according to its capabilities and strategic objectives. Some companies emphasise real-time machine data collection, while others emphasise process visualisation and others emphasise servitisation and predictive maintenance. SM projects are based on a combination of OT and IT in an agile and flexible way. The projects can drive various innovation and creative activities throughout the entire manufacturing life cycle from design refinement, process optimization to business model innovation [32–34]. In order to optimise operations, it is necessary to apply key performance indicators (KPIs) for manufacturing operations management (ISO 22400: Automation systems and integration—key performance indicators for manufacturing operations) [35]. A mature company applies project portfolio management and consistently implements the smart strategy at the different levels of organisational management. At each maturity level, SM projects should have established and consistent directions for change [36,37]. It is highly unlikely for an enterprise to develop a mature approach to programme delivery without first establishing consistent project management (PM). Exceptionally, at a very low maturity level, it may occur that enterprises manage projects inconsistently. The earlier an enterprise is aware of the shift towards smart development, the better the chance of getting its SM projects in order. The ordering of SM projects starts with workstations and single machines with the support of IT-computer systems, in the next step they continue according to processes and the many installations in the production lines that are included in the smart factory with smart processes and smart products and services [38,39].

The maturity models still develop in dynamic environments of business. The history of the development of maturity models (MM) which are adopted to new concept of industrial development (I 4.0) is made up of R. Nolan's Theory of Development Stages (1973) [40], Ph. Crosby's 1979 model [41], the H. Harrington model of 1991 [42], the CMM (Capability Maturity Model) developed by the Software Engineering Institute (SEI) and a version with Innovation—CMMI [43], the Prince 2 Maturity Model, Kerzner Project Management Maturity Model (KMP3) [44], OGC Project Management Maturity Model and the PM Solutions Project Management Maturity Model [45–47]. Examples of modern models are The Singapore Smart Industry Readiness Index [48], RAMI 4.0 [49], the Five Levels of Changes proposed by M. Fisher (2015) [50], SMKL—the Smart Manufacturing Kaizen Level method developed by Mitsubishi Electric [51], and a number of models introduced by consulting organizations, e.g., PwC, 2016 [52] and IMPULS, 2016 [53]. The list is not complete. There are many models available on the scientific and research market by which to measure the progress made by companies in the improvement process. These include universal models as well as models strictly dedicated to a particular business and a particular scope of improvement [54–62]. For each business area in companies, a way (or ways) of maturity assessment can be developed, e.g., for Business Intelligence (BI) [63], for IT management [64], for optimization of processes [65,66], and for the agility of organization [58,67–69]. There is no single and universal roadmap to smart manufacturing [48,70]. Companies that build new industry determine their own areas of change towards smart manufacturing [71]. Chen et al. (2021) [62] analysed models in categories such as AI-related technologies [72,73], managing data [74,75] and realizing SM (e.g., [74,76]) that are related to I-AI.

Maturity models have been proposed for guiding enterprises on the journey to business perfection. It can be assumed that each organisation and each researcher can determine the degree of maturity with their own assessment methods based on the principles of business in the conditions of the fourth industrial revolution. The essence of project maturity of companies towards a new development strategy can be determined by measuring the degree of implementation of internal smart manufacturing projects. The OMG organisation (Object Management Group, 2008) defines MMs evolutionary processed of implementing key practices in one or more areas of a company's operation [77]. Studying the topic of 4.0 maturity on the basis of the literature, reference was made to several model proposals developed by researchers and business practitioners (consulting organizations) [52,53]. The origins of the assumptions for the development of business process maturity models for new conditions can be found in the classical models of reengineering and business process improvement. The process of maturity in the new industrial reality is a measure of an enterprise's ability to effectively manage business processes using high technology, which enables companies to create smart processes with smart products and services.

Several stages are distinguished in process improvement. From the basic stage, which defines the process, through to its measurement and quantitative management and its continuous improvement [78]. The Kerzner Project Management Maturity Model (KMP3) consists of five basic levels to enable a better understanding of its functionality and proficiency for project management [44]. These levels are commonly known as the levels of common language, common process, singular methodology, benchmarking, and continuous improvement [44]. H. Harrington, in 1991, postulated an approach that is based on the following six successive maturity levels: (1) process unknown—the status of the process has not been determined, (2) process understandable and complies with established procedure and documentation, (3) process effective, i.e., systematically measured and improved to meet customer expectations, (4) process effective—significantly efficient, (5) process flawless—optimised, characterised by high efficiency, free of errors, (6) world-class process—benchmark for other companies [42]. Among many processes in the enterprise, some are at a higher level of improvement and others at a lower level, but the approach of the whole organisation to the improvement of business processes is important. Five levels of process maturity were presented by Object Management Group Inc. (OMG) in Business Process Maturity (BPM) and are as follows: (1) Initial work is performed in inconsistent and ad hoc ways, (2) Managed—Management ensures that work within work-units can be performed in a repeatable manner, (3) Standardised—standardised processes are established throughout the organization, (4) Predictable—processes are managed quantitatively to establish predictable results, (5) Innovating—processes are continuously improved [77]. In this model process improvement is strongly linked to innovation by the methods, tools and techniques used to identify, analyse, execute, monitor and change these business processes [78,79]. In CMMI (Capability Maturity Model Integration), processes are classified from the so-called initial stage (Level 1: Initial), in which processes are chaotic, activities are conducted ad hoc, budgets and deadlines are regularly exceeded, through the second stage (Level 2: Managed), which focuses on managed processes—processes are planned, managed, measured and controlled on the basis of a plan, project management is implemented and applied, the third stage (Level 3: Defined), in which processes are defined and well characterised and understood, described in standards and procedures, the fourth stage (Level 4: Quantitatively managed) where processes are quantitatively managed and are controlled using statistical and other quantitative measurement methods, up to the fifth stage (Level 5: Optimizing) optimizing processes—processes are further developed and improved (optimised) to achieve business objectives [43]. The specificity of the model is the analysis of two categories (representations) of processes, namely staged and continuous [43]. The CMM and other maturity models operate as a tool that helps organizations to rank specific processes according to their structures. Processes that have a higher rank—also referred to as a higher level of maturity—are claimed to be associated with better performance of those processes and in particular with better quality output [80].

The importance of new technologies in achieving process maturity by companies was emphasised by DM Fisher, who described Five Levers of Change (Fisher, 2004), which are measured using the following aspects: strategy (strategic understanding of the role, positioning and focus for enterprise-wide decision-making in support of overall company objectives), controls (the governance model for the management, administration, and evaluation of initiatives, with a strong focus on the appropriate metrics applied for measurement), people (the human resource environment, including skills, organizational culture, and organizational structure), technology (enabling information systems, applications, tools, and infrastructure), processes (operating methods and practices, including policies and procedures, which determine the way activities are performed) [50]. In the model, he proposes the following five levels of maturity: "(1) Siloed, (2) Tactically Integrated, (3) Process Driven (4) Optimized Enterprise and the last and highest (5) Intelligent Operating Network" [50]. This model introduces companies to the new industry of the fourth industrial revolution. Nowadays, process execution is so strongly connected with the use of appropriate IT technologies that it is difficult to imagine achieving higher levels of process maturity without implementing IT tools that facilitate efficient management, automation, monitoring and optimisation of processes. At the same time, IT tools and the degree to which they are used in an organisation can themselves be subject to evaluation. Therefore, there is a close relationship between process maturity models and the implemented IT technologies [51]. Between 2000 and 2006, M. Hammer presented the PEMM (Process and Enterprise Maturity Model). M. Hammer analysed the following two areas: process enablers and enterprise capabilities [81]. The categories of process enablers include the process infrastructure, including the information and management systems that support the process and the metrics that are used to monitor process performance.

In the ongoing industrial revolution, process improvement is assessed according to the degree of digitalization of the business and the degree of implementation of technologies (pillars) of Industry 4.0. According to H. Kagermann (2015), digitalization is the basis for building new industry [8]. The digital maturity of a company is determined by its ability to effectively apply digital technology in the process of business process improvement. A company's digital maturity is determined by its ownership of digital technologies and how the company designs and offers its products, how it works with customers and business partners, how it manages data, the extent to which it uses autonomous solutions and systems or how it implements collaboration with partners. Production on the 4.0 level requires intelligent manufacturing systems, that reveal the knowledge, make decisions and perform the actions intelligently and independently. It is comprised of predictive maintenance, autonomous decision making, intelligence capabilities and agility, self-awareness, the self-optimization of processes and self-configuration of technologies [1,9]. In this revolution, the development of maturity models focuses on technologies and solutions used in production and based on the new technological pillars. The industry relies on technological concepts such as the Cloud, Internet of Things (IoT), Cyber Physical Systems (CPS), Big Data, Additive Manufacturing (AM), Artificial Intelligence (AI), and Autonomous Robots [76,82]. The purpose of assessing the maturity of companies is to determine the degree of efficient management of processes and resources, and to identify the levels of change to achieve the expected outcome in smart manufacturing. For the method of assessing the level of maturity by SM projects, range scales or nominal scales describing characteristic scenarios for a given level of a given characteristic defining the digital maturity variable are used. Most often, the assessment of the level of digital maturity is made using a five-point scale. In the category of models used to assess companies' 4.0 maturity, the Singapore Smart Industry Readiness Index is popular [48] and the Acatech Study Index [83]. The basis of this Index was developed from the 'Reference Architectural Model for Industry 4.0' (RAMI 4.0) [49]. The RAMI 4.0 model depicts the hierarchy levels of Internet-connected manufacturing equipment, the life cycle of equipment and products, and the IT presentation of Industry 4.0 components on three axes. RAMI 4.0 combines all the key assumptions relating to how to achieve a smart factory ecosystem. The model is described in scientific publications by, among others, Hankel, and Rexroth (2015), Resman et al. (2019), Flatt et al. (2016), Wang et al. (2017) [84–87]. A key reference for building models is the Industry 4.0 Maturity Index developed by the German Academy of Science and Engineering (acatech) [83]. Among the researchers who have proposed their own models for assessing the maturity in new situation are Lichtblau et al. (2015) [88], Schumacher et al., (2016) [76], Schuh et al. (2017) [83], Bibby, and Dehe (2018) [89], Santos, and Martinho (2019) [90], Akdil et al. [91], Gökalp et al. [92], Menon et al. [93] and Temur et al. [94]. Many models for assessing digital maturity have been created by consulting companies, using them as a tool to further deepen the assessment within their services (IMPULS, 2016, PWC, 2016) [52,53] or by companies that are recognised as benchmarks in process improvement, e.g., the Smart Manufacturing Kaizen Level (SMKL) method developed by Mitsubishi Electric (IAF, 2020) [51].

The model from Lichtblau et al., (2015) is based on four components, which are: "(1) smart factory, (2) smart operations, (3) smart products (4) data-driven services" [88]. The level of maturity of smart factory is assessed by the use of solutions in companies such as digital modelling, data usage, IT systems and by the degree of innovation of equipment and infrastructure. The level of smart operations is assessed by the ways of and technologies providing information sharing, cloud usage, IT security, autonomous process. The level of smart products is assessed by ICT additional product functionalities and the extent to which data from the use phase are analysed. The level of data-driven services consists of the availability of data-driven services, share of revenue coming from data-driven services and the share of data used.

The model from Schumacher et al. (2016) is based on the following four components: "(1) technology, (2) operations, (3) products, (4) governance, and (5) customers". The key components of the new model are: "strategy, organization culture and leadership in organization" [76]. The assessment component of technology includes ICTs, mobile devices and machine communication systems used in the company. Operations include the decentralization of processes, modeling and simulation and interdisciplinary and interdepartmental collaboration. The category of products includes the individualization of products, digitalization of products, product integration into other systems, the autonomy of products and the flexibility of product characteristics. The level of governance reaches beyond the enterprise and includes activities and forms of support provided to companies on their way to Industry 4.0. At this level, the following aspects are assessed: labour regulations for new industry, suitability of technological standards and the protection of intellectual property. The customers level includes activities convenient for the customer, including the digitisation of sales and services, as well as activities related to its security in systems, e.g., utilisation of customer data. All solutions related to the costumer's digital media competence are also assessed at this level. In the model of Schuh et al. (2017), special emphasis is placed on information technology. In this model, the following two areas of development are analysed: "(1) resources and (2) information systems" [83]. In the category of resources are materials, technology, human, information, etc. In the category information systems are solutions used for data analysis, contextualised data delivery, application-specific user interface, resilient IT infrastructure, horizontal and vertical integration, data governance, standard data interface, IT security. Bibby, and Dehe (2018) proposed the following three areas in their model: "(1) factory of the future, (2) people and culture, and (3) strategy" [89]. To evaluate the factory of the future, the authors propose technologies such as 3DP (3D printing), Cloud, MES (Manufacturing Execution Systems), IoT and CPS, Big Data, sensors, e-value and Autonomous Robots. The category People and Culture is examined by openness to innovation and CI culture. The strategy category includes technology investment planning, agile vision and manufacturing strategy [89]. Santos and Martinho (2019) proposed a model based on the development process of the maturity model of De Bruin et al. (2005). The authors detailed the following levels: "(1) strategy, structure and organisational culture, (2) workforce (3) smart factories, (4) smart processes (5) smart products and services" [90]. Akdil et al. introduced a new maturity model of business focusing on the following three dimensions: (1) services, (2) strategy and (3) organization [91]. Menon et al. focused on building maturity models around the use of industrial internet solutions [92]. Gökalp et al. analysed seven MM (Maturity Model) in terms of scope, purpose, completeness and clarity, and transparency [93]. Temur et al. reviewed the I4.0 readiness level assessment methodology and applied the IMPULS MM to three different Turkish manufacturers in terms of operational and socio-economic perspectives from different industry sectors [94]. Particular researchers focus on technological components of the maturity of modern or social and economic components.

The model published by a consulting organization—IMPULS—is characterised by the following six foundations: "(1) strategy and organisation, (2) smart factory, (3) smart operations, (4) smart products, (5) Data-driven services and (6) employees". Within these six categories the model scores an organisation's progress on a scale of 0–5. After completion of the model, the organisation is ranked according to its progress according to the following six levels: "Outsider (0), Beginner (1), Intermediate (2), Experienced (3), Expert (4) and Top Performer (5)" [53]. PwC uses these six different categories to analyse the organisation: "(1) business models, (2) product and service portfolio, (3) market and customer access, (4) value chain and processes, (5) IT architecture, compliance, legal, risk, security and tax and (6) organisation & culture". The model requires users to self-assess the organisation by interpreting the state of maturity on a scale of 1–5, followed by indicating a target maturity level on a scale of 1–5. Subsequent to the completion of the model, the organisation is categorised depending on maturity, into these four sections: Digital Novice, Vertical Integrator, Horizontal Collaborator and Digital Champion [52].

Becker et al. (2009), Backlund et al. (2014), Langstone, and Ghanbaripour (2016) present the Management Maturity Model (MMM) [64,92–95]. The maturity assessment model is described as a framework for systematic and continuous performance improvement. New models are benchmarks for enterprises on the way to the perfection in business [90]. The problem of assessing the degree of maturity of companies for IT management was the subject of a publication by Becker et al. (2009) [64]. The transformation of companies to the 4.0 level is the agenda of various technological projects. Here, a list of sample projects is presented: (1) transformation, adaptation, building of production/production lines in I 4.0 technology standards, (2) adaptation of IT area (e.g., SCADA, MES, ERP), (3) cyber security, (4) modelling and data analytics—Big Data, Smart Data, (5) technical infrastructure ensuring the connectivity of machines, processes, (6) area of work safety, (7) product life cycle management (in accordance with IEC 62890), (8) implementation of the assumptions of an ecological factory (e.g., circular economy), (9) programmes introducing employees to I 4.0, (10) building an I 4.0 culture. The scale in which I 4.0 will be implemented in the company varies in companies, from piloting at the level of one production line, through to projects implemented in the entire production plant and production system building projects. At the initial stage of companies' maturity for Industry 4.0, many of the implemented projects focus on IT and IC systems [96,97]. A literature review about the MM was realised by Tarhan et al. (2016) [98]. According to Felch et al. (2019), [99] the MM are adopted to Industry 4.0. The key constructs of the project model in Industry 4.0 are based on principles of PM and change management process [100,101]. Implementing Industry 4.0 in companies can take the form of radical change or small steps. Mitsubishi Electric proposes a method focused on Kaizen, which is a Japanese approach based on the continuous improvement of the organisation in small steps. The method is presented in the form of a 4 × 4 matrix, and there are levels of maturity organised into successive rows (1) data collection, (2) visualization, (3) analysis, (4) optimisation, while there are four levels of management formatted in columns, which are as follows: (1) installation and worker, (2) workshop, (3) factory, and (4) supply chain (https://www.mitsubishielectric.com/fa/sols/digital-manufacturing/en/smkl/ (accessed on 13 March 2022)) [102]. The SMKL method was used, among others, by She et al. (2019) in building a model to assess changes referred to as sustainable smart manufacturing [55,56].

Maturity levels often describe technology design and other changes from Level 0 to Level 5, where Level 0 describes a company with low or no implementation. Level 1 described a company that implements pilot activities that are planned or under development. Level 2 involves the implementation of actions that have been initiated, with some benefits observed. Level 3 includes the partial implementation of actions that increase the competitiveness of the company. Level 4 describes the advanced implementation of actions with clear economic benefits. Level 5 is a reference for the application of concepts and implementation of smart technologies. This scale of estimation—comprising five levels—is used in SEMMI 4.0 [103], a Maturity Model for Assessing I4.0 Readiness [76], digital MM [104] and MM in the Information System [105].

The number of building maturity models differs in particular countries. Çınar et al. conducted a broad review of enterprise maturity models in I 4.0 [106]. Based on their publication [106], the authors conclude that the scope of maturity research is adapted to the level of development of a country's economy. Among the countries where research on the degree of maturity of enterprises to Industry 4.0 is carried out, the models implemented in Germany are dominant and include IMPULS [53], RAMI [49,85,107], I4.0 Reifegradmodel [108], Empowerment and Implementation Strategies for I4.0 [109], I4.0/Digital Operations Self-Assessment [110], SIMMI4.0 [111], A Maturity Model for Assessing I4.0 Readiness [76] and the ACATECH I4.0 Maturity Index [83].

Work on the development of universal maturity measurement models is also conducted at the government level. In Poland, the Model of Digital Maturity in Industry 4.0 consists of three basic modules. These modules are as follows: "(1) Technology, (2) Processes, (3) Organisation" [112]. Companies should consider all three areas in order to fully exploit the potential of 4.0 technology. The pillars are based on 12 key modules representing critical aspects on which companies should focus in order to become an organisation prepared for the future within the Industry 4.0 reference model. The "Processes" category includes an analysis of production life cycle integration, integration with the environment, internal integration and standardisation. The following are included in the category "Technology": connectivity, automation, autonomisation and intelligent production. The "Organisation" category analyses leadership, employees, strategy, cooperation and projects (DELab UW, 2020/11) [112]. The model was developed on behalf of the Ministry of Entrepreneurship and Technology in Poland and is provided as a tool for companies in Poland to test maturity (it is available on government websites: https://przemyslprzyszlosci.gov.pl/formularze/samoocena-dojrzalosci-cyfrowej/ (accessed on 13 March 2022) [113].

The maturity assessment models available in publications and on consultancies' websites intend to help companies determine their position on the road to smart implementations. The models presented on the basis of the literature review are either narrow or broad. In broad models, measures of maturity include technology, process optimisation and transformation of the organisation to the conditions of the fourth revolution. In narrow models, the authors focus on IT systems or It infrastructure (e.g., Schuh et al., 2017) [83]. In broad models, the analysis consists of IC technology, changes in workplaces, the degree of building a smart factory, and the degree of achieving smart processes and smart products (e.g., Santos et al., 2019) [90]. With projects implemented within the company, over time one goes beyond the company, and the idea of a smart factory includes business networks and supply chains. Support for transforming companies is provided in the form of government instruments and a critical aspect that should be considered by enterprises on their way to I 4.0 is enshrined in the category, of Governance, as in the model of Schumacher et al. (2016) [76].

The 4.0 maturity model must correspond with the business models that exist in particular economies [99]. The key components of business process maturity models are based on business models [98]. The key components of maturity models are presented in Figure 1. To develop manufacturing to become faster, more efficient, and customer-centric while pushing beyond automation and optimization to discover new business opportunities and models is key. Models present a simplified view of reality. Models can help to capture and understand the phenomena involved in processes, but they certainly cannot describe all possible situations. Each model sets a direction for change, but does not dictate specific solutions, so the scope of research on maturity models is constantly expanding and models change as businesses develop.

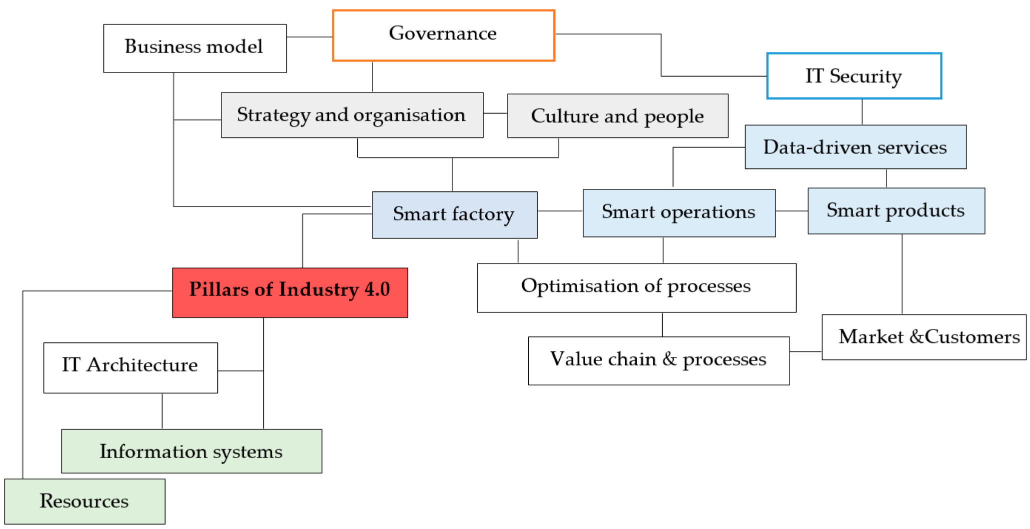

Figure 1. Key components of maturity models for Industry 4.0. Own elaboration.

In the steel sector, which was used for the pilot study, there are also studies on the degree of maturity of companies in terms of new business requirements. Martins et al. analysed the key technologies of the steel sector that frame business models. The transformation of the steel sector has been implemented gradually [114]. According to Peters et al. (2016) and Peters (2017), the greatest impacts of I4.0 for the steel maturity model include the computer decision system of quality control, the smart control of automated processes; smart evaluation of large amounts of data; re-scheduling of materials; smart assistance technologies (drones); predictive maintenance [18,115,116]. Naujok and Stamm [117] propose that the development of business models in the steel sector is influenced by market product requirements (e.g., shorter product-life-cycles, heterogeneous product portfolio, stronger and more durable steel), production costs (cost pressure), process complexity, service requirements (focus on service and flexibility, development of digital supply chain, process automation) and regulatory requirements (desire of steel companies to reduce CO2 emissions, rational management of resources—saving energy used in production processes, ensuring sustainability). The EU strives for increasing overcapacity in European steel plants, especially in the situation of strong competition from China. The policy of increasing productivity is implemented through technological and organisational measures. A report by Steelinstitute VDEh (BFI 2017) provides a more general overview of the implications of Industry 4.0 [118]. Neef et al. [119] presented the results of the survey in their paper titled The role of Industry 4.0 in 2030 based on steel industry. In new business models, production and/or process parameters will become part of the product. In addition to product parameters, it is expected that customers will gain access to information about the production process that is currently only available to steel producers. From the 2030 perspective, batch size production and defect-free production are also considered viable options. Information and computer technology, automation and an emphasis on flexibility will improve supply chain control. In the proposed directions of change, in addition to the application of high technology in metallurgy, including DRI steel-melting technology, an emphasis is placed on the development of new workforce skills. The document ESSA (European Steel Skills Agenda) [120] contains lots of information about the reorganisation of the human factor in smart manufacturing. The metallurgist 4.0 is expected to have a strong link between technological knowledge and digital skills [121]. The requirements proposed by Romero et al. [122] for 4.0 operators are also useful in the steel sector. Considering these factors, it can be assumed that the steel sector maturity models should continue to prioritise sustainability and that new technologies provide support for steel mills on their path to continuous business improvement.

3. Design, Methodology, and Approach

One way to determine the maturity of companies for Industry 4.0 is through research carried out by companies belonging to a particular sectors of industry. The author assumes in her own research that the maturity model of manufacturing enterprises under the conditions of the fourth industrial revolution is the degree and level of implementation of key technologies of the fourth industrial revolution in the processes of enterprises. The maturity assessment conducted by the author aims to determine the degree of adaptation of enterprises to the requirements (principles) of smart production. In order to identify changes in the business environment, the author conducted direct research in the steel sector in Poland.

The research on the degree of maturity of steel enterprises within the conditions of Industry 4.0 was implemented within the general topic of my own research entitled: Transformation of steel enterprises in Poland to Industry 4.0. The research was implemented in the period from October 2019 to June 2020. The research was carried out with the CAWI technique—Computer-Assisted Web Interview—and selected enterprises within the steel sector filled in the questionnaire in electronic form. Companies were selected from the databases of industry organisations in the Silesia and Lesser Poland regions. These are the two regions in which the largest steel plants are located in Poland. The author did not restrict enterprises' access to participate in the research. She assumed that making the questionnaire available on the steel industry website was an automatic criterion of verification of companies in terms of their membership in the Polish steel market. The whole survey was supervised and representatives of the enterprises (managerial staff and operational engineers) were able to contact the author of the research to avoid mistakes while filling in the questionnaire. The research involved 79 steel market enterprises in Poland. The surveyed companies constitute a small segment of the steel sector, which according to the Polish Classification of Activities includes enterprises registered as producers of metals and metal products. Apart from the producers of steel and steel products, the research included companies intermediating in the sale of steel products, as well as companies from industries classified as steel consumers. The segment was called the steel segment because it was dominated by steel companies, which are key links in the steel chain.

The companies participating in the research were segmented according to company size and business markets. The classification of the surveyed enterprises by size was based on employment (enterprises with more than 500 people were categorised as very large, those that employed 250–500 people were considered large, enterprises with 50–250 employees were considered medium-sized and enterprises employing up to 50 people were considered small). In turn, classification by markets of activity was based on the location of the company's centre (headquarters) and the structure of the capital group. Figure 2 shows the structure of the enterprises under study. Individual enterprises were represented by managers, production line managers, process managers and operating engineers. In order for individuals representing companies to participate in the research, they were required to pass a knowledge test about the concept of Industry 4.0 and its key technologies. Only those individuals who passed the test participated in the research.

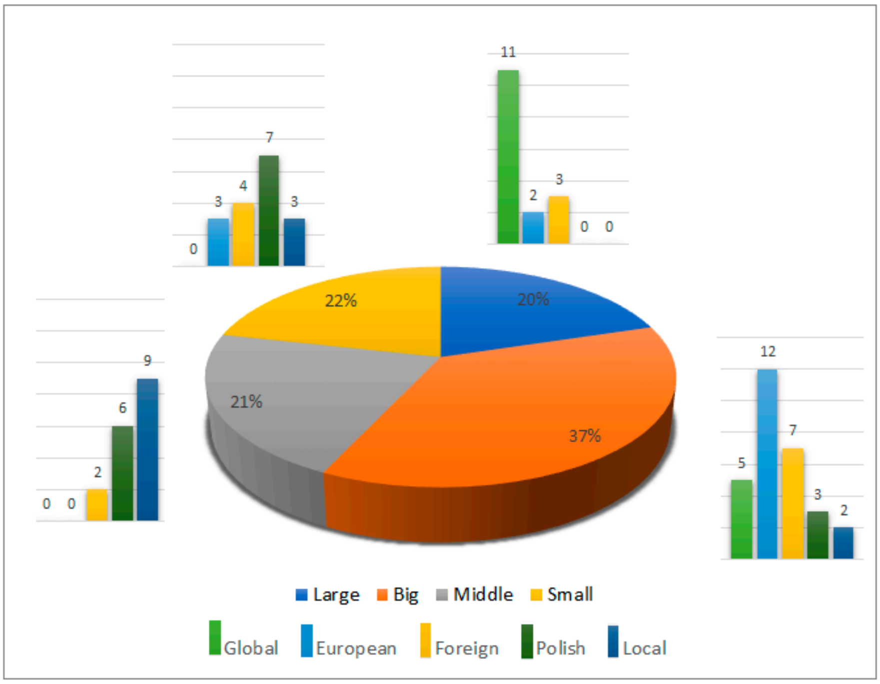

Figure 2. The structure of studied enterprises in pilot direct research. Source: own research [123].

The following hypothesis was adopted during the research:

Hypothesis H1. *The level of maturity of steel market enterprises in Poland to operate in the conditions of Industry 4.0 is determined by the size of enterprises and the size of the market, the larger the enterprise the greater the possibilities of implementing key industrial technologies into business processes.*

The author used a maturity measurement model based on pillars (key technologies) of the next industrial concept which were described using specific technological projects and assessed on a five-point scale—a Likert scale scoring system from 1 to 5, where 1 describes a very low level of maturity, 2—low, 3—medium, 4—high, 5—very high. The applied (used) maturity scale described the phases of smart technology development in enterprises from initial and small projects implemented at the level of individual workstations or machines (pilot projects) to large projects with a wide range of enterprise management towards smart steel production (changes at the level of entire technological installations, production cells, production lines, individual processes and facilities). With time, projects implemented in enterprises reach beyond them and are implemented in the entire supply chain.

At this stage of the research, another (second) hypothesis was accepted:

Hypothesis H2. *Achieving the maturity of steel market enterprises in Poland to function in the conditions of maturity 4.0 is realised gradually (in stages) from individual workstations or machines through production sockets and production lines, as well as full processes and facilities (e.g., production halls, warehouses), up to the broadly understood business together with structures of business relations (in capital group) and forms of cooperation and integration in supply chains*.

The conducted research and its results should be treated as a pilot study. On the basis of the respondents' knowledge of the changes introduced in their companies, the author attempted to determine whether the changes introduced fit into the maturity model of the analysed segment of companies. In further studies, the structure of the research tool will be clarified and which technological changes are at which levels of maturity will be unambiguously determined. The conducted research only provides preliminary recognition of the situation in companies which carry out smaller or larger projects and which, in their opinion, are classified as SM projects. The knowledge gathered on the basis of the research will be used by the author to refine the research by defining the scope of SM projects carried out in the steel sector and by sorting them according to maturity levels.

4. Research Results and Conclusions

The studied enterprises assessed their maturity levels on the basis of implemented technological projects, which were components of particular pillars of Industry 4.0. The enterprises indicated the following project areas (P—project): automation of production using single machines (P_1), automation of production using interacting machines in production nests (P_2), automation and robotization of full production lines (P_3), automation of warehouse processes—the stage of partially or fully automated warehouses (P_4), multi-tasking production lines controlled automatically with machine learning (ML) (P_5), Internet and mobile technologies (ICTs) in customer services, including EDI, e-invoicing system (P_6), TPM—equipment with sensors generating data about efficiency of machines in real time (P_7), development and compatibility of production support information systems: CAx, MRP, MES (P_8), business network and chain integration with the system end-to-end engineering (P_9), extension of databases (Big Data) and process visualization (P_10), access to cloud services and the Industrial Internet of Things IIoT (P_11), development of block chain in the steel sector and distribution of steel products (product protection, cybersecurity in chain, etc. (P_12)—Figure 3. The individual projects formed a set of technological solutions of the Smart Manufacturing type at the current stage of implementation of the breakthrough technological pillars in the examined sector. Particular areas of change were evaluated according to a five-grade scale, with 5 as a very high rating. It can be assumed that companies are entering the third—medium—level of maturity of the implementation of changes towards maturity 4.0. Each company (N = 79) selected one employee from the management team to assess the maturity of the company based on their knowledge of the undertaken projects. The questions used in the questionnaires were single-choice. Each question was rated by the respondents on a scale from 1 to 5.

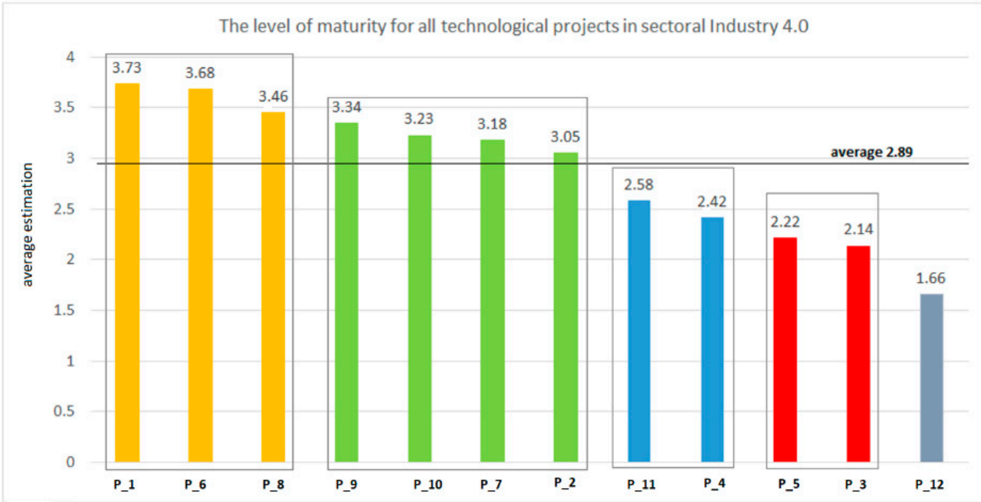

Figure 3. The levels of maturity based on realised projects in the studied steel sector. Source: own research for N = 79 [123].

The average scores for the projects (P_1, P_2, . . . , P_12, letter P from the word: Project) as assessed by the respondents were grouped according to maturity levels based on the degree of project implementation and the scope of implemented changes. Three areas of change were classified by enterprises as projects implemented at the first, lowest, but basic level of maturity, i.e., the automation of production with the use of individual machines (P_1), the use of the Internet and IC technology for customer service, including EDI, e-invoice system (P_6) and the extension of production support IT systems, such as CAx, MRP, MES and actions towards compatibility of IT and computer systems used in enterprises (P_8). The second maturity level (higher than the first) was represented by the following projects: network and chain integration with end-to-end engineering) (P_9), expansion of databases and data analysis (Big Data and Data Analytics) and visualisation of processes towards automatic process control (P_10), installation of sensors on machines to collect real-time data on the state of machines and processes as part of the improvement of the TPM (P_7) and production automation using interoperating machines in production centres (P_2). The remaining projects (P_11, P_4, P_5, P_3, P_12) were rated very low (the average grade for the degree of their implementation in the companies was below grade 3). In the opinion of the companies, projects P_11, P_4, P_5, P_3, P_12 can be implemented after reaching the first and second or even third level of maturity on a scale from 1 to 5. The third level (medium) starts with the following projects: technologies for access to cloud services and Industrial Internet of Things IIoT (P_11) and full automation of work in metallurgical processes, e.g., at steel product mills, in steel product warehouses (P_4). Projects aiming at full automation and the robotization of entire production lines with integrated smart technologies (P_3) and projects of multi-task production lines controlled by IC systems and application of machine learning technologies in metallurgical processes and other smart solutions (P_5) are classified into the fourth level of maturity of the steel sector. The fifth—the highest—level of maturity is formed by projects that improve smart production within companies as well as projects implemented in companies belonging to a joint capital group or in business networks and supply chains. In the steel sector, companies are interested in the development of blockchain technologies (P_12).

In order to illustrate the current stage of change in steel enterprises in Poland, charts in the form of heat maps were used, where each percentage of a given number of answers to a given question is assigned a colour (from grey to black). The higher the percentage of a given answer in relation to all answers for a given question, the more intense the colour—black (Figure 4).

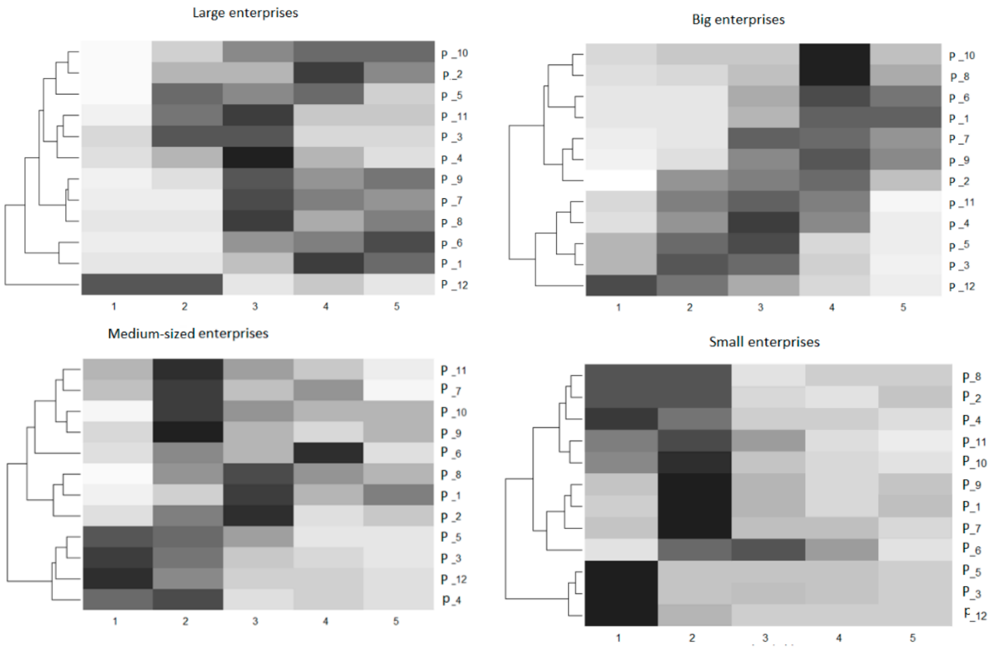

Figure 4. Degrees of SM project implementation in the steel enterprises in Poland. Source: own research for N = 79 [123].

On the left side of each heat map a dendrogram is presented, which defines the similarity between individual variables. According to all respondents, the biggest changes in the implementation of the Industry 4.0 concept have occurred due to the use of Internet and mobile technologies in customer service, including EDI, an e-invoicing system (P_6). The automation of production with single machines is also significant among very large, large and medium-sized enterprises. Respondents in very large and large enterprises rated the changes already implemented in enterprises in the following areas as high: development and compatibility of IT systems used to support the control of production processes, e.g., CAx, MRP, MES; equipping equipment with sensors generating data in real time; network and chain integration through ICTs, including systems of end-to-end engineering; automation of production with the use of cooperating machines and IC systems and the expansion of process visualisation systems and databases (Big Data) for ongoing process control. The evaluations of medium-sized enterprises were similar in terms of project ranking, but the average maturity was lower than in very large and large enterprises. The lowest level of maturity in relation to Industry 4.0 was noted in the sector of small enterprises. In these enterprises, apart from the application of Internet technologies in communication with customers and partners (P_6), the other projects were not implemented or were implemented with a very narrow range of technological capabilities. Of course, there are even enterprises in this group that have achieved a high level of change in this respect, but these are rather singular situations.

In the next step of research, the development of the changes discussed above is presented using a principal component analysis in relation to market coverage. The validity of its application (Bartlett's test and KMO coefficient are appropriate for the studied variables) is presented in Figure 5.

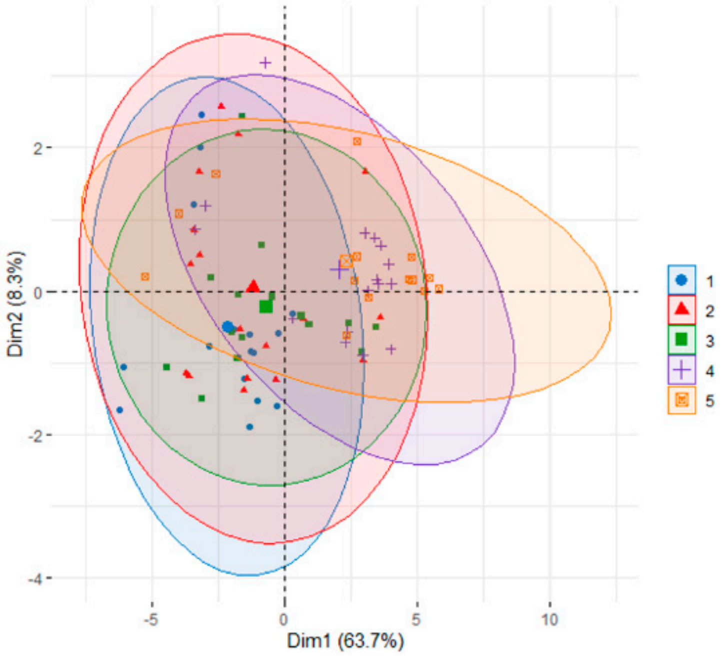

Figure 5. Degree of implementation of projects in enterprises by markets. Source: own research for N = 79 [123]. Where 1 is global market, 2 is European market, 3 is foreign markets, 4 is national market, 5 is local, regional market.

The studied enterprises operating in international markets are characterised by the highest degree of implementation of Industry 4.0 concepts in relation to projects such as the automation of production with the use of interacting machines (production nests); equipping devices with sensors generating data in real time; network and chain integration; expansion of databases (Big Data) and visualisation of processes; automation of production with the use of machine learning and expansion of IT systems supporting production including CAx, MRP, MES and obtaining an increasing compatibility of ICTs. For the maturity of SM projects, slightly lower scores were achieved by enterprises operating in the European market or in selected foreign markets. The worst performers are national and local enterprises, where, looking at the average, the results are similar, but the spread of responses is greater for local markets.

Based on the pilot study, it was found that steel segment companies in Poland have embarked on a process of manufacturing transformation towards smart manufacturing. According to the research hypothesis (H1), companies implement projects gradually. In their pursuit of smart manufacturing, simple (low-budget) projects are first implemented on single workstations or machines and then to additional workstations and machines up to the scale of full production lines and processes. On the adopted scale of grades from 1 to 5 of the maturity model, it was established that the steel sector enterprises in Poland are currently entering the third level of maturity of technological solutions towards smartness (the fifth level is the highest). Lower-level projects mainly consist of online communication technologies, data collection and data processing during business processes, while at higher maturity levels companies expand the scope of changes and processes are visualised and monitored to achieve level 5 in the form of the self-optimisation of processes using high technology. The current technological direction of change in very large and large steel enterprises is defined as smarter production and not smart. In the opinion of respondents, the greatest changes in the implementation of the Industry 4.0 concept have taken place in connection with the use of the Internet and IC technologies in business processes, including in particular in customer service (EDI, e-invoice system, etc.) and the automation of production and other processes, including the storage of steel products. According to the adopted hypothesis (H2), changes occurring in enterprises in the context of implementation of the Industry 4.0 concept are more intensive in very large and large enterprises than in medium and small ones; in very large and large enterprises, the intensity of changes is realised at the third maturity level, and in small and medium enterprises change is realised at the first and second maturity level. Referring to H_2, it was found that enterprises operating on the international market are characterised by the highest degree of implementation of the Industry 4.0 concept in relation to the following projects: automation of production with the use of interacting machines (production cells); equipping devices with sensors generating data in real time; network and chain integration; expansion of databases (Big Data) and visualisation of processes; automation of production with the use of single machines and the development and compatibility of IT systems supporting production including CAx, MRP, MES. The conducted research included identifying the status of technological changes made in enterprises of the surveyed sector. The research did not assess the degree of usefulness of the introduced changes, but only obtained confirmation about the implementation of technological projects, e.g., implementation of an ERP system, such as the installation of smart sensors on key production equipment.

5. The Proposition of Maturity Model for the Studied Segment of Steel Enterprises

In order to assess the degree of maturity of steel enterprises in Poland in terms of smart production or smart factories, the author introduced five levels of implementation of changes in enterprises on the basis of smart manufacturing projects (degree of complexity of projects, scope of introduced changes and results of changes). The maturity levels introduced in this study are presented in Figure 6. The author proposes to call the first level of maturity (Level 1), which represents a very low maturity, “the initial maturity on the way of enterprises to Industry 4.0” or simply “Initiating Smart Maturity” or “Smart Maturity on Start”. The first level is characterised by the introduction of single innovation solutions inside enterprises on single workstations or machines, e.g., the installation of sensors to collect data on the state of the machine. Changes are introduced to improve the quality of work through the use of technological solutions, which over time will create a smart environment. The changes introduced are most often inconsistent and fragmented, or even random, and do not cover entire processes. The organisation does not provide a stable IT-computer environment to support processes (IT systems used in the enterprise do not cooperate with each other or cooperate to a limited extent, the level of compatibility of IT-computer systems within the enterprise is low). The first projects are reactive (the company’s response to the situation which necessitates the introduction of changes—the need to introduce changes precede the improvement introduced) and pilot projects (a narrow range of introduced changes). Effectiveness (results of the changes) are assessed only on the basis of individual (single) projects. The first successes of the projects are difficult to repeat (the company did not have full knowledge or experience in building smart manufacturing). Very often at this stage of maturity, companies have not yet specified objectives (directions) in their development strategies about following the idea of Industry 4.0 and the adaptation of breakthrough technologies. The author proposes to call the second level (Level 2), which describes low maturity, “Smart Maturity in Building” (maturity under construction or maturity building). At this stage, companies implement subsequent smart manufacturing projects and benefit from the experience and knowledge of the project team from previous projects (subsequent projects are planned and managed based on the experience gained in previous activities). Projects are managed based on previously mastered tasks that can be repeated. At this stage of maturity, companies focus on the repeatability of activities (operations), compatibility of information and computer systems, integration of technologies and flexibility between cooperating devices. Projects are implemented on successive workstations and machines, which provide the basis (components) of key processes. Projects are implemented on several related workstations and machines in production cells. The extent of changes (progress) is visible at the individual management levels. Data from equipment and processes are collected electronically and sent to a decision-making centre. Processes are monitored and optimised in real time. Companies are taking steps to integrate internal information and computer systems at individual management levels. The author proposes to call the third level (Level 3) of medium maturity call "Smart Maturity in Growth" (growth or increasing maturity of companies on their way to Industry 4.0). At this stage of change, companies have already implemented many smart manufacturing projects. The results of the implemented projects are characterised by repeatability at the level of optimising activities using smart solutions. The developed and implemented smart manufacturing projects are already quite familiar to project teams. Companies, at this point, have included key technologies (pillars) in their development strategies towards smart manufacturing. Projects (investments) are based on understanding individual processes and assigning roles and responsibilities to people (teams) responsible for building a smart environment within the company. Companies are aware of the changes and consistently pursue smart manufacturing (smart factory) strategies. The results of new technologies are improvements in key processes and individual business areas. Smart solutions appear across entire production lines or cover entire facilities (e.g., warehouses). The author proposes to call the fourth level (Level 4)—of high maturity—"Results of Smart Maturity—More and More Smarter", or more simply "Smart Maturity in Results" (smarter process and smarter production today than it was yesterday). At this stage, companies are very aware of smart manufacturing project management. The enterprise is comprehensively implementing changes on its path to new industry. Data from equipment are collected in real time and performance metrics are collected and used to control processes that are visualised and optimised in real time. Quality, efficiency and optimisation are embedded in smart technology algorithms and process control systems. The company's strategy with the goals of building smart production and smart factory is written into many (many) projects of modification of existing solutions and many (many) new investments even across the entire production line. Investments cover many processes and business areas, and over time are even implemented across entire supply chains and business networks. Smart technology is implemented in many companies with capital and business links. Enterprises (R&D offices) strongly cooperate (with each other) at the stage of designing and implementing investments such as lubricants—the investments of producers are connected with investments of product recipient markets, etc. Enterprises focus on developing solutions, which are already smarter than those used by the company not so long ago, a process during which individual solutions are improved. Level five (Level 5)—very high and full maturity is referred to as "to Full Smart Maturity"—this level is the stage of developing smart production and building a smart factory. The organisation is fully aware of existing innovation technologies and recognises the need for the continuous improvement of manufacturing process. The enterprise achieves high productivity through process optimisation using intelligent solutions provided by new technologies. The enterprise applies many technologies and the principles of the fourth industrial revolution (modularity, integration, flexibility, agility, speed, adaptation, etc.). Best practices and innovations are identified over an ongoing basis and communicated throughout the company.

The strategical direction of companies is to reach and surpass the third level of technological maturity towards smart manufacturing. After level three, subsequent levels have a greater predictability of results. At levels four and five, the entire enterprise and business are managed so as to achieve higher levels of manufacturing maturity, which is ultimately defined as smart. Level five is smart production and smart factory, i.e., the full components of the new concept of development in the fourth industrial revolution.

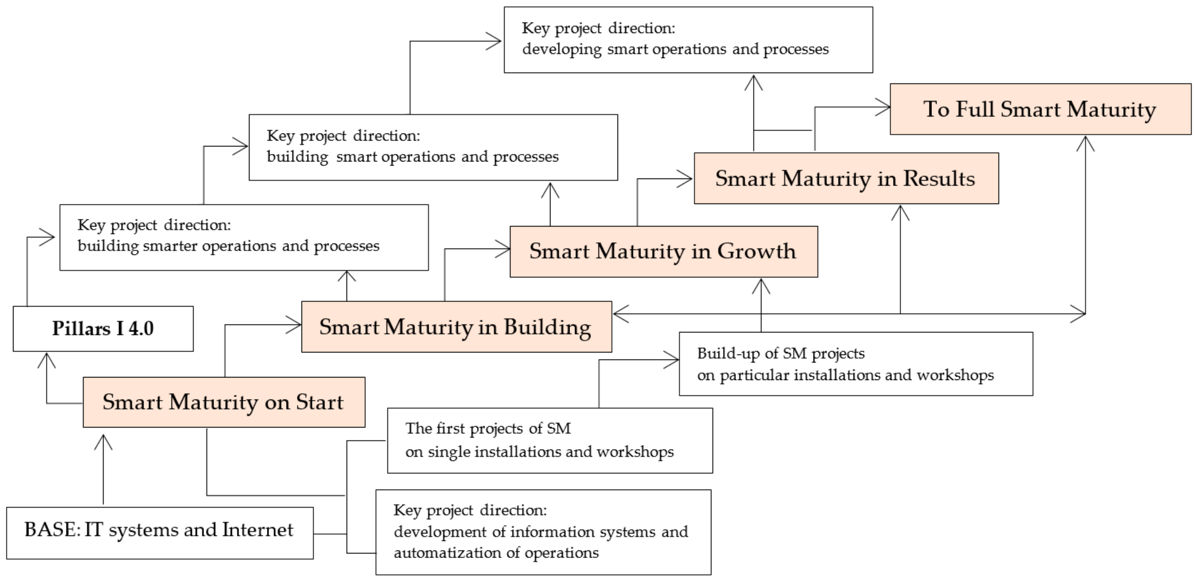

Figure 6. Levels of maturity model based on own pilot research for the segment of Polish steel industry. Own elaboration.

6. Discussion and Conclusions

The steel sector is an important area of research because steel is a basic industrial material. The steel industry is an important economic sector in many countries. The steel market is also an important downstream sector for many other sectors, such as the automotive industry, construction or electronics. The production of crude steel is increasing year on year. According to the world report, from 1950 to date steel production has increased from 189 Mt to 1950.5 Mt in 2021 [124]. Since the world needs steel, companies have to innovate to exist in the market. Maturity models are one form of testing the degree of innovation of companies in a highly dynamic environment. Technology 4.0 creates new opportunities for steel producers to compete, which in short is called smart manufacturing. According to the World Steel Association, smart manufacturing is not just about having a smart factory that produces steel. It requires a significant transformation of the way we source raw materials, produce and bring products to the market through horizontal and vertical supply chain integration—and it is deeply customer-centric [125]. This change is not a one-step process as there are obvious sustainability challenges.

The fourth industrial revolution is creating new business models. The maturity models are made up of a combination of organisational, process, technological, product and marketing innovations (according to the 2010 Eurostat update of the methodology used in the EU Business Innovation Activity Survey) [126]. New industry focuses on building synergies between the innovation features of the technologies of the fourth industrial revolution and the technological capabilities of companies to provide highly optimised business processes. A company's level of development is the result of changes in all these areas. Changes towards I 4.0 have been introduced by large companies, as well as medium-sized and small companies [34,127]. The essence of the models is based on the digital integration of production systems and the creation of digitally controlled networks of autonomous machines and sensors, which make extensive use of the Internet and various other information technologies to communicate with each other and with the people supervising their work [128,129]. There are many examples of early adopters in the steel industry, especially in vertical integration within business segments, where the building blocks for smart factories are emerging. Changes are being made in logistics (with new solution used by GPS, RFID), product quality systems (e.g., Computer Aided Quality Control -CAQC), predictive maintenance and process control (sensor of noise, temperature, real-time process management systems, etc.) [130–134].

In line with the policies of developed countries, including those of the European Union, models in the steel sector should be analysed not only in terms of technological levers (digital data, automation, connectivity and digital customer access), but also in combination with the development of green technologies that need to be implemented in steel mills in order to meet climate targets. The steel sector maturity models are a set of CSPs and roadmaps for R + D + I (research + development + innovation) actions for sustainable production [135]. Sustainability is the basis for today's industrial changes [136].

It is assumed that the new development concept will be introduced in industry over the next few years [137]. It is assumed that new manufacturing technologies will increase the speed and efficiency of production and thus minimise production "delays" resulting from the unreliability (weakness) of the human factor and traditional (non-intelligent) machinery. Autonomous robots and collaborative technologies bridge the gap between traditional technologies operated by workers and will open up new areas for the full automation and robotisation of production. Autonomous robots perform work in a human-like manner, but they can monitor and transmit real-time data about the state of the machine and the process flow to decision center, and, through learning algorithms, adapt to changes [138,139]. The new business models have been transformed from traditional manufacturing to industrial digital-physical systems (CPS), which represents the highest level of implementation of industrial technologies gathered around Cyber-Physical Production Systems (CPPS). CPPS are responsible for creating the final product, highly charged with knowledge and are personalised. According to Verganti's (2009) model, the framework for innovation is technology and meaning [140]. In addition to discovering new technologies, it is also important to identify customer needs and use user knowledge in the innovation design process [141]. Industry 4.0 encompasses entire value chains, from placing orders to supplying components for production, to shipping goods to customers, and then to after-sales services. In new business models, cooperation is extended by integrating the technologies of individual companies in supply chains [142,143].

For strong mature models of modern business to emerge, companies must first invest in digitalisation. Digitisation in the fourth revolution is much broader than the third industrial revolution. Digitalisation of the production process and artificial intelligence determines the directions of contemporary industrial developments and places them in the architecture of a new business model [144,145]. The digitalisation of industrial processes involves replacing all analogue manufacturing processes, including traditional machining, with digital–physical manufacturing systems that are automated and digitally controlled to the maximum extent possible [146,147]. The process of the digital transformation of products, in turn, includes extending their functionality with digital elements, e.g., intelligent sensors or communication devices. In this way, data can be obtained on product usage and the product can be improved to better meet growing customer requirements [148–150]. In each revolution, the manufacturing sector invests in new technologies. Rapid advances in emerging technologies of the fourth industrial revolution such as the Industrial Internet of Things (IIoT), advanced mobile robots, industrial connectivity and artificial intelligence solutions are assisting companies to create a smart environment. Companies select the most appropriate technology to invest in at a given stage of the company's transformation to become smart. Combining innovations with new artificial intelligence capabilities has led to a revolutionary change in manufacturing management where systems operate in a highly autonomous manner, dynamically changing their structure and functions within an organisation.

The 4.0 maturity models presented in the literature differ in the areas of research, which concern the technology and organisation of production towards building a smart factory environment. The steel sector maturity model cited above—the result of our own pilot research—is built on the basis of the opinions of respondents from 79 companies in the steel sector in Poland, or rather on their knowledge of the changes taking place in production, which decision makers consider to be the beginning of changes for steel mills and companies towards Industry 4.0. The proposed levels of the maturity model are a result of the combination of the research results with the author's concept of describing five key levels of development, which were also most often adopted in the literature to assess the degree of maturity, where level five was the highest—representing complete maturity, and level one was the lowest—representing the initial stage of changes towards the new industry.

On the basis of the research, it was established that steel companies are entering the third level of maturity. The third level is the start of medium maturity. Companies have included key changes in their development strategies towards smart manufacturing. Projects of smart manufacturing (SM) are based on understanding individual processes and assigning roles and responsibilities to people (teams) responsible for building a smart environment within the company. Companies in the steel industry are aware of the changes and consistently realize projects of smart manufacturing and digital projects in their business processes and activities [151]. The realisation of capital consolidation in the world steel market helps companies in their transformation to a new reality [152]. Strong capital groups in the world steel market are benchmarks of changes towards I 4.0. Very large steel companies have pioneered smart manufacturing in their realisation of new strategies, e.g., ArcelorMittal, Thyssen Krupp, Tata Steel. The results of new technologies have led to improvements in key processes and individual business areas [153,154]. The steel enterprises in Poland have achieved the basic level of digitalization of business and they can now work towards new industry [155,156]. The author points out that the research conducted in this study pertaining to the sector of industry is presented as a pilot study and is experimental. In further (future) research, the author seeks to analyse the implemented projects in companies more extensively and aims to develop a universal tool to measure the maturity level of steel sector enterprises on their way to smart production.

The changes in enterprises that have accompanied the creation of the new industry will be implemented over the next decades and will be more and more radical. At the current stage of transformation, companies of the analysed segment tend to focus on market criteria, including quality and personalisation, and the operational criteria of implemented changes, including the speed of performing operations by new technologies, the agility and flexibility of operations through access to data provided by equipment in real time and their use to optimise processes, and the accuracy of performed operations by machines with a high degree of independence from humans and their activities [157].The creation of new solutions of flexible cyber-production will require many changes at various levels of enterprises' functioning [158]. The purpose of this publication was to present the empirical results of project impact assessments in enterprises that are already on the way to Industry 4.0. As technology advances, it is important for factories and production facilities to be proactive in their open innovation strategy [159,160]. On the road to full maturity, companies are evolving from a digitisation strategy to an open innovation strategy based on smart solutions [161]. New business models arise from the digitization and utilization of big data and lead to smart factories based on interoperability, decentralization, work in real-time, service, modularity and the reconfigurability of new innovative solutions [162,163]. In order to build new maturity models, it is necessary to overcome routine thinking and to innovate by adopting an orientation towards the possibilities of new technologies as well as open innovation and user-driven innovation (UDI- is one of the open innovation methods indicating the way to communicate with customers and use their ideas to find a solution or create new profitable products or services) [141,164,165].

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Institutional Review Board Statement: According to our University Ethical Statement following the following shall be regarded as research requiring a favourable opinion from the Ethic Commission in the case of human research (based on document in polish: https://prawo.polsl.pl/Lists/Monitor/Attachments/7291/M.2021.501.Z.107.pdf (accessed on 4 February 2022)): research in which persons with limited capacity to give informed or research on persons whose capacity to give informed or free consent to participate in research and who have a limited ability to refuse research before or during their implementation, in particular: children and adolescents under 12 years of age, persons with intellectual disabilities persons whose consent to participate in the research may not be fully voluntary prisoners, soldiers, police officers, employees of companies (when the survey is conducted at their workplace), persons who agree to participate in the research on the basis of false information about the purpose and course of the research (masking instruction, i.e., deception) or do not know at all that they are subjects (in so-called natural experiments); research in which persons particularly susceptible to psychological trauma and mental health disorders are to participate mental health, in particular: mentally ill persons, victims of disasters, war trauma, etc., patients receiving treatment for psychotic disorders, family members of terminally or chronically ill patients; research involving active interference with human behaviour aimed at changing it research involving active intervention in human behaviour aimed at changing that behaviour without direct intervention in the functioning of the brain, e.g., cognitive training, psychotherapy psychocorrection, etc. (this also applies if the intended intervention is intended to benefit (this also applies when the intended intervention is to benefit the subject, e.g., to improve his/her memory); research concerning controversial issues (e.g., abortion, in vitro fertilization, death penalty) or requiring particular delicacy and caution (e.g., concerning religious beliefs or attitudes towards minority groups) minority groups); research that is prolonged, tiring, physically or mentally exhausting. Our research is not done on people meeting the mentioned condition. Any of the researched people: any of them had limited capacity to be informed, any of them had been susceptible to psychological trauma and mental health disorders, the research had not concerned mentioned above controversial issues, the research had not been prolonged, tiring, physically or mentally exhausting.

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