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A CONCEPTUAL FOUR STAGE MATURITY MODEL OF INDUSTRY 4.0 TECHNOLOGIES

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Abstract

The emergence of Industry 4.0, the fourth industrial revolution, brings transformative technologies influencing production efficiency and sustainability. Despite its significance, there's a gap in defining the maturity stages of Industry 4.0 initiatives. To show the evolution of technologies in Industry 4.0, this study proposes a four-stage maturity model: Initialization, Integration, Optimization, and Innovation, grounded in the drivers of industrial proactiveness. With a focus on ten key Industry 4.0 technologies, the model aims to advance comprehension of adoption practices. By exploring maturity stages, it aids in strategic decision-making by identifying beneficial technologies and assisting in the formulation of implementation plans. Additionally, this research includes a case study to test the proposed model's efficacy.

Keywords: Industry 4.0; Maturity stages; Technologies; Case study; Coal Mining

1. INTRODUCTION

Industry 4.0 is characterized by digitalization, mechanization, and enhanced communication in production, depends on technologies like Cyber-Physical Systems (CPS), Internet of Things (IoT), Automation, and Large Data (Ben daya et al., 2019); Pereira & Romero, 2017). While providing novelty and effectiveness, Industry 4.0 presents substantial challenges in adoption and assimilation (Wendler, 2012; Jabbour et al., 2014). Current maturation models, such as those in sustainable manufacturing, offer valuable perspectives, however, the developmental phases of Industry 4.0 are still relatively unexplored (Shukla and Adil., 2021). To bridge this knowledge gap, this study suggests a four-step maturation framework for Industry 4.0 implementation in the mining industry, with the objective of comprehending technological utilization, integration obstacles, and potential advantages (Shukla and Adil et al., 2021).

2. INDUSTRY 4.0 TECHNOLOGY

Industry 4.0 technologies, encompassing artificial intelligence and cyber-physical systems, augment industrial procedures, fostering resilience and flexibility (M.Hussain et al., 2019) (R.Sharma et al., 2020). Highlighting worker independence and machine compatibility, Industry 4.0 ensures enhanced security, health surveillance, and work-life equilibrium (R.Sharma et al., 2020). These technologies are essential for contemporary enterprises, providing advantages such as supply chain incorporation, competitiveness, and sustainability (Rajeev et al., 2019). Nonetheless, efficient utilization necessitates specialized policies customized to diverse economies and regions (Rajeev et al., 2019). Industry 4.0 is connected to the following technologies;

(i) Internet of Things (IoT) - The amalgamation of interlinked sensors and devices, referred to as the Internet of Things (IoT), facilitates advanced capabilities such as automated temperature regulation in industrial settings and thermostats (Ben daya et al., 2019).

(ii) Big Data Analytic - Big data technology has attracted a lot of interest from academics and the media (Machado et al., 2020).

(iii) Artificial Intelligence (AI) - A rapidly developing technology, artificial intelligence (AI) imitates human intelligence and automates tasks requiring human-like decision-making. (Ben daya et al., 2019).

(iv) Additive Manufacturing- 3D printing, also referred to as additive manufacturing, is a cutting-edge technique that builds things layer by layer (Johnson, 2018; Smith, 2019; Brown et al., 2020).

(v) Cyber-Physical Systems- Cyber-Physical Systems (CPS) represents a significant development in Industry 4.0 for the fields of computer science and information technology. According to (Monostori et al., 2016), CPS makes it easier to integrate real and virtual worlds, allowing for smooth process and operation control and coordination. Defined by Lee, Bagheri, and Kao 2015, as reported on page 1211 in Pereira and Romero, 2017).

(vi) Cloud computing - With cloud computing, applications and data are managed online rather than simply on your PC. Users and companies utilize it for online collaboration and data access from any location. Verify if it permits effective

teamwork and remote work. 2010; (Ben daya et al., 2019).

(vii) Augmented and virtual Reality - Augmented reality (AR) and virtual reality (VR) are cutting-edge technologies that have become essential in various fields like education, healthcare, and entertainment. AR overlays digital information onto the real world, enhancing user experiences in areas such as healthcare, education, and marketing (Machado et al., 2020).

(viii) Block Chain - Blockchain provides a transparent and safe means of tracking transactions. It tracks product journeys and ensures transaction security in supply chains and finance. Success will be demonstrated if it increases transaction security and transparency. (2018) (Z. Zheng et al.)

(ix) Wireless communication - In order to achieve effective data transmission, wireless communication systems employ a variety of technologies. One method is the employment of beamforming antennas, which produce concentrated beams for signal transmission and reception (L.Bagheri et al., 2014).

(x) Robotics and automation -Automation and robotics are quickly developing technologies that have a big impact on many different industries. Robotic systems are becoming more intelligentand efficient thanks to developments in artificial intelligence, machine learning, and the Internet of Things (M.Hussain et al., 2019).

3. MATURITY MODEL

The purpose of the Industry 4.0 technological maturity models (MMs) is to evaluate how prepared and advanced businesses are incorporating Industry 4.0 technologies into their daily operations. Numerous scholarly investigations have underscored the significance of these models in steering organizations towards the Industry 4.0 transformation process. (Shukla and Adil., 2020).

3.1 The various levels of maturity of Industry 4.0 technology

Stage 1- Initialization

Early on in the deployment of Industry 4.0, organizations are just starting to look into the potential of new technologies. There's curiosity, of course, but no clear route. The implementation of digital transformation is haphazard and often spearheaded by isolated teams or departments without a clear strategy. When making decisions reactively, immediate issues take precedence over long-term goals. The concepts of Industry 4.0 are not well understood, and data usage is straightforward. the necessity for businesses to adopt Internet of Things (IoT) and Industry 4.0 in order to manage supply chains sustainably (Ben daya et al., 2019).

Technology	Level 1 Initialization	Level 2 Integration	Level 3 Optimization	Level 4 Innovation
Drivers	Basic Automation **(J. Gerhard et al 2016)**	Efficiency gain **(J.Gerhard et al 2016)**	Skill Development **(J.Gerhard et al 2016)**	Using smart computers **(J.Gerhard et al 2016)**
Internet of Things (IoT)	Just starting to use some sensors and devices to collect basic data. **(Ben daya et al., 2019)**	Using more devices and sensors for better data collection and control. **(Ben Daya et al., 2019)**	Using many devices and sensors, connecting everything for smart decision-making. **(BenDaya et al., 2019)**	Using devices and sensors everywhere, making decisions quickly and flexibly. **(Ben Daya et al., 2019)**
Big Data and Analytics	Collecting some data but not sure how to use it effectively. **(Machado et al., 2020)**	Learning to analyze data and make better decisions based on it. **(Machado et al., 2020)**	Analyzing a lot of data to make smart decisions, predict issues, and save money. **(Machado et al., 2020)**	Using advanced analytics, making smart decisions that lead to innovative solutions. **(Machado et al., 2020)**

Artificial Intelligence (AI)	Not really using AI,most decisions are made by people. **(M.Hussain et al., 2019)**	Starting to use AI for specific tasks like chatbots and self-driving cars. **(M.Hussain et al., 2019)**	Using AI in many areas for better decision-making and making things more efficient. **(M.Hussain et al., 2019)**	Mastering AI, using it to create new products, make autonomous decisions, and push boundaries. **(M.Hussain et al., 2019)**
Augmented Reality (AR) and Virtual Reality (VR)	Not using AR or VR in your company. **(Machado et al., 2020)**	Beginning to use AR and VR for training and improving designs. **(Machado et al., 2020)**	Widely using AR and VR for training and real-time support in operations. **(Machado et al., 2020)**	Creating immersive experiences that push the boundaries of AR and VR. **(Machado et al., 2020)**
Block chain	Not using blockchain for security or transparent records. **(Zheng et al 2018)**	Starting to experiment with blockchain for more secure transactions. **(Zheng et al 2018)**	Using blockchain for secure supply chain management and transparent transactions. **(Zheng et al 2018)**	Integrating blockchain into every part of operations for ultimate security. **(Zheng et al 2018)**
Robotics and Automation	Not many machines or robots doing work in your company. **(M.Hussain et al., 2019)**	Getting more machines and robots to help with tasks and save time**.** **(M.Hussain et al., 2019)**	Most tasks are done by machines and robots, making work more efficient. **(Hussain et al., 2019)**	Nearly everything is automated, and your company can quickly adapt to changes. **(M.Hussain et al., 2019)**
Cyber-Physical Systems	Not really connecting computers and machines to monitor and control work. **(L.Bagheri et al., 2014)**	Connecting more machines and computers to work together better. **(L. Bagheri et al., 2014)**	Everything is connected, allowing you to monitor and control work in real-time. **(L.Bagheri et al., 2014)**	Mastering connections, making fast decisions, and quickly adapting to changes. **(L.Bagheri et al., 2014)**
Cloud Computing	Not using cloud much, just for basic data storage. **(Rajeev et al., 2019)**	Starting to use cloud for data storage and sharing information more easily. **(Rajeev et al., 2019)**	Using the cloud for data processing and real time collaboration. **(Rajeev et al., 2019)**	Fully relying on the cloud for all data and making decisions collaboratively. **(Rajeev et al., 2019)**
Additive Manufacturing	Not using 3D printing much, only for a few experiments. **(Machado et al., 2020)**	Starting to use 3D printing to make prototypes and special parts. **(Machado et al., 2020)**	Using many devices and sensors, connecting everything for smart decision-making. **(Machado et al., 2020)**	Using 3D printing for almost everything, creating innovative and complex products. **(Machado et al., 2020)**

Stage 2 - Integration

As Industry 4.0 adoption grows, organizations are beginning to see the potential benefits of digital transformation. Though still in its early stages, use of technologies like cloud computing, data analytics, and the Internet of Things is becoming more concentrated (Ben daya et al., 2019). According to the Maturity Model for Industry 4.0 Technology, firms progress from early experimentation to a more thorough integration of critical technologies into their daily operations throughout the Integration Stage. This is how these technologies act at this point.

Stage 3 - Optimization

Several important elements are the main drivers of Industry 4.0 technology's Optimization stage. Among these is the implementation of Industry 4.0 technology to strengthen City Logistics procedures, with the goal of improving communication between the different stakeholders (R.Sharma et al., 2020).

Stage 4- Innovation

Technological developments are driven by variables such as cost reduction, performance enhancement, innovation, and competitiveness during the Industry 4.0 innovation stage (Shukla and Adil., 2020). In order to open up new possibilities for development and innovation, this stage is concentrated on pushing the limits of technology.

4. A CASE STUDY

A case study can be utilized in many ways, including cumulative, illustrative, exploratory, critical instance, implementation, and program effects (Havens, 1990; Yin, 1994). Using a case company, this case study tries to illustrate a theoretical four-stage maturity model of Industry 4.0 technology, using an illustrative manner to explain what is happening and why (Shukla and Adil., 2020).

4.1 Selection of case

Yin (1994) asserts that the example chosen should fulfill the researcher's research goals. The global mining corporation Company A was selected due to its industry-leading technology implementation, easily accessible location, and sustainability reports. The implementation of Industry 4.0 technology in mining at Company A is examined in this Case study.

4.2 Development of Case protocol

An organized method of gathering data is made easier with the use of a case procedure (McCutcheon and Meredith, 1993). For case studies, it's a crucial tool since it facilitates data collecting and enhances the validity and dependability of the data (Yin, 1994). An industry 4.0 technology implementation report, company details, and research background were all included in the case study protocol that was created prior to the visitation of the case company. In addition, the protocol lists sources to obtain the required information as well as questions to ask during the visit:

a) What are the industry 4.0 initiatives being implemented in South Eastern Coalfields Limited (SECL)?

b) What factors serve as the main motivations behind the adoption of Industry 4.0 initiatives in SECL?

c) What are the characteristics demonstrated by these technologies?

4.3 Data collection and Analysis

Top-level managers were surveyed over a three-month period to verify validity and reliability. Semi-structured interviews, direct observation, and secondary data analysis were also used in the study. Based on semi-structured interviews with top-level managers at Company A, the analysis reveals that the company is primarily at level 1 of Industry 4.0 adoption, characterized as laggards in the decision-making process regarding technological innovation.

5. RESULT AND CONCLUSION

- This study proposes a four stage maturity model for Industry 4.0 technologies that will assist the manufacturing firms to evolve towards the adoption of industry 4.0 practices.
- The manufacturers will be able to know the next stage they will have to move from their existing capabilities.
- They will be able to know which what changes they have to incorporate in order to move to the next maturity stage.
- This model can be validated by performing the case study to test and conceptualize the framework.
- As the number of practices under Industry 4.0 is likely to increase in upcoming years, this model can incorporate more number of technologies for their evolution.

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