

Adoption and diffusion of industry 4.0: critical analytical study

Ibrahiem M. M. El Emary and A. V. Senthil Kumar

King Abdulaziz University, Jeddah, Saudi Arabia
Hindusthan College of Arts and Science, Coimbatore, India
E-mail: Omary57@hotmail.com, avsenthilkumar@yahoo.com

Abstract

Business organisations are presently in an era of transformation. This is a transformational requirement from traditional state to automated state. Industry 4.0 adoption and this adoption guided by diffusion is the soul of this review paper. It is a summarised presentation of various works on Industry 4.0 which synthesis the obligations of corporate in varied spectrums of STEM (Science, Technology, Engineering and Mathematics). Earlier literature levy its focus on varied aspects of system science implementations, sustainable development goals in adoption of Industry 4.0, strategical framework and other allied areas of automation. While diffusion has taken as one among the strategical framework of Industry 4.0 adoption. Overall analysis of this study reveals adoption of Industry 4.0 is need of the hour and all the organisations already started to travel on this pathway with different and varied strategies however proper care has to be given to the circular economy aspect and when the decision of diffusion comes into picture, employees training and skill set improvement has to give importance.

2010 Mathematics Subject Classification. **65D17.** 81P68, 68Q12.

Keywords. industry 4.0, adoption, diffusion, AI, CPS, IoT, circular economy, cloud computing..

1 Introduction

Industry 4.0 will be a huge anatomy change over the past 250 years, although companies undergone wide revolution; the Industry 4.0 adoption will be more of AI driven. Technology integration should connect the dots of achieving value for the company; in simple, work-creating value to the stakeholders would be the ultimate target of Industry 4.0 adoption. Industry 4.0 is the result of rapid changes in technology and innovation in industrial sector, its processes, products etc., which is need of the 21st century. Increasing automation, interconnectivity, smart technology coined the growth and adoption of Industry 4.0. Every firm aiming growth phase in extending the production scales, process reengineering, social innovation for sustainable global development are in a situation to adopt industry 4.0. It is a perfect blend of smart factories, circular economy, developmental business model and much more. Even though all these factors are core components responsible for Industry 4.0, there is serious issue on proper selection of automation based on the industry type and requirement. When all the industrial giants are ready to embrace Industry 4.0 at a very rapid pace, whether it is backed up with appropriate plans, strategies and whether existing workforce are ready to adapt these rapid changing environment. This paper throws light on these factors as well as the evaluation factors on the successful adoption and diffusion of Industry 4.0.

The research problem in the field of adoption and diffusion of Industry 4.0 is to understand the factors that influence the successful adoption and diffusion of Industry 4.0 technologies in organizations and society. Industry 4.0, also known as the fourth industrial revolution, represents

a new era of digitalization and automation in industrial processes. However, the adoption and diffusion of Industry 4.0 is a complex process that is influenced by a range of factors such as technological innovation, organizational change, and government policies. Understanding these factors is crucial for organizations, policymakers, and researchers seeking to successfully adopt and diffuse Industry 4.0 technologies. Furthermore, understanding the long-term impacts of Industry 4.0 on organizations and society is also important. This research problem is significant as it has the potential to provide insights that can help organizations and society to fully leverage the potential benefits of Industry 4.0 while mitigating any negative consequences.

2 Objectives of the study

The pivot role of the review paper is on i) Industry 4.0 Adoption strategies; ii) Automation & Technological requirements iii) Need of circular economy pathway iv) Diffusion of technology, products, process v) Other but primary focus on the adaptability of current organisational scenarios.

3 Research methodology

This study adopted a structured literature review approach to analyse the pattern and trend prevalent around the globe to facilitate diffusion of the model. Industry has undergone 3 phases of revolution in the past several decades. Perhaps industry 4.0 has a huge shift from the earlier revolution which literally focussed on usage of water & steam power, targeting on mass production through computerisation & electronic devices [20]. Industry 4.0 has extremely wider bull's eye on AI, ML, IoT, CPS and much more. This paper in a nutshell throws light on major drivers of industry 4.0 viz cyber physical systems, virtualization & decentralisation, open network building, servitization and diffusion [21]. Other relevant areas of growth and development for Industries has to be analysed, in particular ways of integrating several technological advancement as per the need and requirements of the Industry is the vital decision making phase of all the organisations. Successful implementation and benefits of Industry 4.0 adoption through diffusion may happen only when the business firms frame appropriate strategic business model.

The major research gap is all the studies focused on a particular aspect of technology diffusion, SDG in Industry 4.0, business model implementation and so on which is narrow in its objectives. Further study can be developed on the areas of Strategic Business Model development for the perfect choice of integration in technology, sustainability, diffusion.

4 Literature review

System automation is the key indicator for the adoption of industry 4.0. Bringing in intelligent manufacturing profound to the extreme utility of physical technologies, cyber technologies, this in turn leads to the improvement in performance, quality of product, controllability, efficient management and transparency [1]. System automation perspectives collectively represent intelligent manufacturing as well as innovative services. Standardization, information system integration, training and development of employees, AI applications & its infrastructural requirements are some sample of things covered in innovation services which are prerequisites of system automation [2].

System science integrated with business strategies emanates the adoption strategies much simpler. [4] High level of automation, industrial information integration is enabled by Internet of things (IOT), Cyber Physical Systems (CPS), cloud computing, block chain and other technologies. Integration process of system science and business strategies [5] is the value addition of the

firm's stakeholders. Predominately adoption of industry 4.0 requires new terminology platform, which in singularity can connect IOT, big data design thinking and human machine for the sake of transformational production system& enhancement of human productivity.

There always exists an interrelationship between business strategy and leadership styles. [6] when we talk about leadership styles, there exist numerous styles among those transformational leadership mixed with emotional intelligence can do wonders on industry 4.0 adoption. Employee's contribution towards high –tech infrastructural and technology implementation is countless. Without the efforts and commitment of employees, none of the business organisations can get into industry 4.0. Such contributions is highly recognised by transformational leadership styles, this motivates and encourages the employees.

Role and prospectus of smart factory, system perspectives, and business strategy formulation has a connecting link with decision-making. Industry 4.0 has its focus towards automated decision making through cyber- physical production system and digital twins of the product [7]. Data integration coupled with autonomous decision-making facilitates perfect mix and contribution. A paradigm emphasis is given to safety management [3] in industry 4.0, which connects safety principles, technologies, innovations and automations.

As an innovative framework, many companies went for diffusion of digitalisation through cyber – physical systems and manufacturing unit human intelligence system [15]. Theories of diffusion of Innovation and Organisational Diffusion of Innovation aids in knowledge improvement and to gain understanding on the adoption of industry 4.0 Business model Innovations as the heart of Industry 4.0 fosters policy driven institutionalised and system innovation [18]; along with serious concern on workload demands of the employees [19]. When it comes to institutionalised systematic innovation Triple Helix mode of innovation, which terms to the proliferation of digital technologies in manufacturing industries. Triple Helix mode is widely accepted innovation policy approach among business people, academia and politics. On the other hand, workload demands needs to be focussed. As Industry 4.0 adoption along with various diffusions demands high level of workload from employees, it may be on physical as well skill-oriented workload. Skill enhancement on the areas on IoT, cloud computing, big data, ML /AI etc., involves various dimensions of mental demand, physical demand, temporal demand besides frustration level. Even though Industry 4.0 travels in the direction of automation and smart digitalization, nothing can replace the contribution from the employees. Therefore, curating the planning process coupled with managerial efforts to mitigate potential issues clears the workload demand throwing light on the era of adoption of Industry 4.0.

5 Summary of results

How the adoption of industry 4.0 requires system science, automation, safety management, technology frameworks like IOT, cyber science, information technology etc., like wise diffusion is an effort to track the ideas of innovation, technology, strategies among the community to implement or infuse into the potential adopters. [8] business model innovation (BMI) play a role of significant agent to bring in changes in the current industrial systems. Business model innovation leverages the collective intelligence of bringing the inevitable diffusion principle as a key determinant for the adoption of industry 4.0.

Technology innovation system (TIS) framework is the widespread ecosystem in the diffusion of new technological innovations. [10] Dynamism in TIS implementation is much needed to unfold the innovation diffusement successfully. When we talk about diffusion of innovation and technologies,

block chain is one that is state of art technology and inseparably vital in all the parts of business activities. [9] It is definitely slow diffusion but has high potential in the future. Block chain as a breakthrough emerging technology, it is still sceptical in adopting in many firms.

5.1 SDG and industry 4.0

Apart from innovation diffusion and technological diffusion towards the pathway of industry 4.0, yet another angle to its vision is circular economy oriented diffusion leading to sustainable development goals. SDGS are the buzzword in the industrial sectors, which levies a major contribution towards external CSR activities. [11] Towards this objectivity of circular contribution diffusion of green products plays a role of dynamic diffusion strategy for economic and environmental performances, this further relates to inventory and production planning system (I&PP).

Indubitably, circular economy practices are a strategic move towards adoption of industry 4.0 [13]. Leading to industry 4.0; circular economy practices & supply chain capabilities helps in firm performance improvement. Carbon management [12] is yet another circular economy contribution of industry 4.0 adoption. Carbon pricing is termed to the promoting element on diffusion of low carbon technologies companies can go for waste heat recovery (WHR) power generation system and energy management and optimisation system (EMOS) to have a check on carbon emission.

5.2 Challenges in industry 4.0

Although industry 4.0 is an inevitable phase of Industrial revolutions, it has some serious issues and challenges .Smart manufacturing, automation in major functioning of industry, diffusion of technology which is new to the employees is truly not a easy task. [22] Implementation of automated & smart services surely require high speed protocols, followed by cyber security threats in a phase of big data, Analytics and system modelling. Another perspective of challenge is on intelligent decision- making capability adoption, which synchronise with huge investments.

Cyber risk, cyber attack and viruses were a biggest threat to IT sector previously but with the adoption of industry 4.0, this will be common factor for all the industrial segments. Risk of cyber attack clubbed with difficulty in sourcing the perfect talent to manage all these smart driven technologies is the challenge need to be sorted out [23].

5.3 Recommendations and solutions

Industry 4.0 is not a new strategic pathway; each and every business has already started their steps on this route. Many has identified the requirement of revolution in the supply chain to foster the demand of Industry 4.0 [16]. Discussions on the evaluation of application of technologies in Industry 4.0 [17] relied on fundamental technology research and technology application research. Evaluation model can constitute 3 steps viz problem and requirement elucidation, options elimination and solution validation. Recommendation to arrive to a successful innovation / technology model targets well – balanced combination of scientific methodology and agile & problem related concept validation.

Recommendation for the widespread issues and challenges on adoption and diffusion of industry 4.0. Transformation is inevitable, along with that budding of unwanted/threat mushrooms is also unavoidable. Each study focuses on the micro level issues and solutions for the same. As a combined analysis pitching of apt business strategy informs of business model innovation (BMI) Together with

vertical and horizontal integration can do wonders on the industry 4.0 adoption. Need not forget SDG policy framework and potential building of workforce for the successful implementation of industry 4.0.

As a agent based model [24] for innovation diffusion, there are many sources to speed up the pace of innovation diffusion like government interventions, promotion, educational support, technology standardisation, financial aid etc.

6 Scope for further research

Based on the findings of this study, there are several recommendations for further research in the field of adoption and diffusion of Industry 4.0.

Firstly, future research could focus on the adoption and diffusion of Industry 4.0 in specific industries such as manufacturing, healthcare, and transportation. This would provide a more detailed understanding of the unique challenges and benefits of Industry 4.0 in these industries.

Secondly, research could also examine the role of government policies in facilitating the adoption and diffusion of Industry 4.0. This could include studying the effectiveness of government-led initiatives such as training programs and funding for Industry 4.0 projects.

Thirdly, future research could also explore the long-term impacts of Industry 4.0 on organizations and society. This could include studying the effects of Industry 4.0 on employment, income inequality, and environmental sustainability.

Additionally, research could also focus on the diffusion of Industry 4.0 in developing countries, which would provide a better understanding of the specific challenges and opportunities of Industry 4.0 in these countries.

Finally, research could also examine the role of other actors such as suppliers, customers and other stakeholders in the adoption and diffusion of Industry 4.0. This would provide a more holistic understanding of the process of Industry 4.0 adoption and diffusion.

7 Conclusion

In conclusion, the adoption and diffusion of Industry 4.0 is a complex and multifaceted process that involves the integration of advanced technologies into industrial processes. The research indicates that companies that have adopted Industry 4.0 have achieved significant benefits such as increased efficiency, cost savings, and improved product quality. However, companies also face challenges such as lack of understanding of Industry 4.0 technologies and the need for significant organizational changes. The research also highlights the importance of network effects and the role of government policies in facilitating the adoption and diffusion of Industry 4.0. The results of this study provide valuable insights for companies, policymakers, and researchers seeking to understand the adoption and diffusion of Industry 4.0. However, further research is needed to gain a more comprehensive understanding of this complex phenomenon in different industries and regions.

Adoption and diffusion of Industry 4.0 should not be for the sake of external factors; it has to be approached more scientifically. Beyond the adoption of latest technologies of IoT, Cloud computing, ML, AI etc., its mirroring impact on the stakeholders needs to be analysed. Route map of Industry 4.0 adoption is always good to reach sustainable development; this really helps the Industry to sustain for a longer period. Artificial diffusion of technology, products, process will be a disaster. Henceforth, system science, smart / automation features with a blend of business model innovation considering decision automation, workload demand, policy formation and diffusion for circular economy assuredly a success pathway towards Industry 4.0.

References

- [1] Zhan Shi, Yongping Xie, Wei Xue, Yong Chen, Liuliu Fu, and Xiaobo Xu, *Smart factory in Industry 4.0*, *Systems Research and Behavioral Science* **37** (2020), no. 4, 607–617.
- [2] Ting Hou, Baihua Cheng, Rongxiao Wang, Wei Xue, and Peggy E Chaudhry, *Developing Industry 4.0 with systems perspectives*, *Systems Research and Behavioral Science* **37** (2020), no. 4, 741–748.
- [3] Zimei Liu, Kefan Xie, Ling Li, and Yong Chen, *A paradigm of safety management in industry 4.0*, *Systems Research and Behavioral Science* **37** (2020), no. 4, 632–645.
- [4] Li Da Xu, *The contribution of systems science to Industry 4.0*, *Systems Research and Behavioral Science* **37** (2020), no. 4, 618–631.
- [5] Anirudh Agrawal, *Incorporating industry 4.0 in firm strategy*, *Academy of Management Global Proceedings* **2018** (2018), 6.
- [6] Desiree Van Dun and Maneesh Kumar, *Enablers of industry 4.0 technology adoption: transformational leadership and emotional intelligence* (2021).
- [7] Christopher Slon, Vijitashwa Pandey, and Sam Kassoumeh, *Mixture Distributions in Autonomous Decision-Making for Industry 4.0*, *SAE International Journal of Materials and Manufacturing* **12** (2019), no. 2, 135–148.
- [8] Christian Burmeister, Dirk Lüttgens, and Frank T Piller, *Business model innovation for industrie 4.0: Why the 'industrial internet' mandates a new perspective on innovation*, *Die Unternehmung* **2** (2016).
- [9] Arpan Kumar Kar and L Navin, *Diffusion of blockchain in insurance industry: An analysis through the review of academic and trade literature*, *Telematics and Informatics* **58** (2021), 101532.
- [10] Jan Henrik Gruenhagen, Rachel Parker, and Stephen Cox, *Technology diffusion and firm agency from a technological innovation systems perspective: A case study of fatigue monitoring in the mining industry*, *Journal of Engineering and Technology Management* **62** (2021), 101655.
- [11] Navin K Dev, Ravi Shankar, and Sanjeev Swami, *Diffusion of green products in industry 4.0: Reverse logistics issues during design of inventory and production planning system*, *International Journal of Production Economics* **223** (2020), 107519.
- [12] Xianbing Liu, Yongbin Fan, and Chen Li, *Carbon pricing for low carbon technology diffusion: a survey analysis of China's cement industry*, *Energy* **106** (2016), 73–86.
- [13] Zhang Yu, Syed Abdul Rehman Khan, and Muhammad Umar, *Circular economy practices and industry 4.0 technologies: A strategic move of automobile industry*, *Business Strategy and the Environment* **31** (2022), no. 3, 796–809.
- [14] Anas Mahmoud Atieh, Kavian Omar Cooke, and Oleksiy Osiyevskyy, *The role of intelligent manufacturing systems in the implementation of Industry 4.0 by small and medium enterprises in developing countries*, *Engineering Reports* **5** (2023), no. 3, e12578.
- [15] Nitin Sachdeva, Rajat Kumar Obheroi, Abhishek Srivastava, and SK Nehal, *Diffusion of industry 4.0 in manufacturing sector—an innovative framework*, 2017 International Conference on Infocom Technologies and Unmanned Systems (Trends and Future Directions)(ICTUS), 2017, pp. 1–5.
- [16] Hans-Christian Pfohl, Burak Yahsi, and Tamer Kurnaz, *Concept and diffusion-factors of industry 4.0 in the supply chain*, *Dynamics in Logistics: Proceedings of the 5th International Conference LDIC, 2016 Bremen, Germany, 2017*, pp. 381–390.

- [17] Moritz Von Stietencron, Bjørnar Henriksen, Carl Christian Røstad, Karl Hribernik, and Klaus-Dieter Thoben, *Evaluation of Industry 4.0 Technology–Applications*, Enterprise Interoperability: Smart Services and Business Impact of Enterprise Interoperability (2018), 309–314.
- [18] Georg Reischauer, *Industry 4.0 as policy-driven discourse to institutionalize systemic innovation in manufacturing*, Academy of Management Proceedings, 2018, pp. 11435.
- [19] Guilherme L Tortorella, Anupama Prashar, Tarcisio A Saurin, Flavio S Fogliatto, Jiju Antony, and Guido C Junior, *Impact of Industry 4.0 adoption on workload demands in contact centers*, Human Factors and Ergonomics in Manufacturing & Service Industries **32** (2022), no. 5, 406–418.
- [20] Shu Tay, Lee Te Chuan, A. Aziati, and Ahmad Nur Aizat Ahmad, *An Overview of Industry 4.0: Definition, Components, and Government Initiatives*, Journal of Advanced Research in Dynamical and Control Systems **10** (2018), 14.
- [21] Krishnan Umachandran, Igor Jurčić, Valentina Corte, and Debra Ferdinand-James, *Industry 4.0.: The New Industrial Revolution (Book for chapter indexed in SCOPUS)* (2019), 138-156.
- [22] Saurabh Vaidya, Prashant Ambad, and Santosh Bhosle, *Industry 4.0—a glimpse*, Procedia manufacturing **20** (2018), 233–238.
- [23] Deloitte Report, *Industry 4.0 Challenges and Solution for the digital transformation and use of Exponential technologies* (2015).
- [24] Martin Prause and Christina Günther, *Technology diffusion of Industry 4.0: an agent-based approach*, International Journal of Computational Economics and Econometrics **9** (2019), no. 1-2, 29–48.