An Analytic Hierarchy Process (AHP) Approach for Prioritizing the Industries 4.0 Technologies (I4.0T)

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An Analytic Hierarchy Process (AHP) Approach for Prioritizing the Industries 4.0 Technologies (I4.0T)

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Abstract: World over, industry 4.0 (I4.0) is becoming one of the big buzzwords with transformative technologies, which refers to smart factories. Industry 4.0 technologies have the capacity to better resolve the challenges of increasing manufacturing sector complexity and competitiveness. The practitioners need to understand the emerging technologies and their effectiveness for successfully adopting them in manufacturing. This paper focuses on prioritizing the potential technologies of Industry 4.0 and ranking those using the multi-criteria decision-making (MCDM) technique. Seven I4.0 technologies were identified that have potential applications in the modernization and automation of manufacturing organizations. Further, the technologies are validated after incorporating input from academia and industrial experts. The analytical hierarchy process (AHP) is applied to rank the identified technologies, and consistency is checked for the correct result. The results reveal that "Cyber-Physical System" has the highest priority among all technologies in I4.0 with a weight of 0.402. "Cyber-Physical System" occupied first rank with 0.402 criteria weight, meaning this technology has the most significant role in the implementation of industry 4.0 concepts, followed by "Big Data Analysis" and "Internet of Things" with criteria weightages of 0.194 and 0.159.

Keywords: Industry 4.0T (I4.0T); Cyber Physical System (CPS); Internet of Things (IoT); Analytic Hierarchy Process (AHP).

1. Introduction

Now a day, global competition exits in manufacturing business. Industry 4.0 technologies (I4.0T) have the capabilities to better address the challenges of increasing complexity and competitiveness in manufacturing sector. The 'industry 4.0' refers to the computerization/ automation of the manufacturing process and interconnection among man, machine and tools[1,2)]. In the view of production point, industry 4.0, which is frequently known as *'smart manufacturing',* is referred as the introduction of intelligent, self-governing machines that can independently travel throughout the company and generate real time information[3)]. The aim of I4.0T is to improve the transparency through digital linkage of each resource involved in whole manufacture process. Industry 4.0 technologies have the power to improve sustainability of the manufacturing systems[4)]. From the market prospective, digital technologies help the organizations in providing digital solutions for customer in form of internet based facilities rooted in products[5,6)]. These advanced digital tools are used to reduce waiting time, set up time, cost and wastes to increase operational efficiency and productivity. Industry 4.0 comprises emerging technologies such as Internet of Things, Cyber-Physical Systems, 3D Printing, Cloud Computing, Horizontal and Vertical System Integration, Big Data Analysis, Artificial Intelligence, Robotics and Automation[7,8)]. Through the emergence of smart production concepts, manufacturing industries are anticipated to come to be more translucent, regionalized and more flexible in time and space. Fourth industrial revolution integrates business and production process with entire value chain including customers, suppliers. Cyber-Physical Systems (CPS) embedded with superior connectivity, is the backbone of industry 4.0. Real-time tracing, checking and optimization of the manufacturing process is possible by accumulating and communicating information through embedded systems[9)]. The industry 4.0 technologies are enablers to accumulate, examine and exploit the data information in real-time decision making. The fourth revolution of technology is based upon data information and aims to achieve enhancement in terms of automation, production competence and effectiveness. The current manufacturing industries are shifting towards smart production, smart machines, smart tools, smart scheduling and smart maintenance with the use of Internet of Things (IoT), Cloud Computing, Cyber-Physical Systems (CPS) and other I4.0 technologies.

Moreover, the application of I4.0 technologies in the manufacturing organization is smoother in developed countries than in developing countries10). Therefore, the prioritization of important I4.0 technologies and their factors using analytic hierarchy process (AHP) is needed for upcoming research concerning emerging countries.

This research work is carried out with an objective to recognize the industry 4.0 technologies and analyze their correlation to understand the applications trend in Indian manufacturing organizations. Because, these technologies enable automated decision-making, interconnected machinery, data analytics, and more to enhance the productivity and performance across the value chain and allow the efficient production system. Therefore, attempts have also been made to develop a hierarchical model that illustrates the connection among industry 4.0 technology. A variety of techniques were employed to identify the industry 4.0 technologies, and the analytic hierarchy process (AHP) is utilized to rank the industry 4.0 technologies. AHP technique that will help the manufactures, practitioners, and researchers to find out least and most critical technologies in manufacturing sector.

Rest of the paper is organized as follows: the next section 2 insights into domain through literature review and section 3 depict the methodology of research and data collection technique. Further, in section 4, AHP technique is described and ranking to I4.0 technologies given. Section 5 covers results and discussions. The exploration analysis ends with conclusions, implications, and direction for forthcoming research.

2. Literature Review

An industry 4.0 technology (I4.0T) is the fourth industrial revolution, coined in year of 2011 with a strategic plan of “High-Tech Strategy 2020 Action Plan”. Furthermore, it has been promoted as the future of nation’s business and financial growth[11)]. In Industry 4.0 technology all the devices such as-sensors, machines, production center, work pieces, IT systems are connected along a value chain and control, interact each other independently[12)]. This interconnected system improves the efficiency, responsiveness and analyze data to predict failure in the manufacturing system[13)]. Six design principles, of industry 4.0 i.e. real-time capability, interoperability, virtualization, decentralization, modularity service and orientation were identified[14)]. These principles help the organizations in recognizing possible pilot projects. Many Governmental agencies started to study and adopt the I4.0T in their countries, such as US, Canada, Germany. Particularly, within the growing economies’ perspective, like Brazil, the NCI, 2016 (National Confederation of Industry) has carried out a study to find the existing obstacles for I4.0T implementation. They mentioned that high implementation cost is main internal critical obstacle while lack of skilled workers and expertise is the biggest external obstacle. The I4.0 ensures computerization and digitalization of manufacturing and business processes by using advanced ICT technologies. Its principle is to handle the value chain process, enhance the effectiveness and efficiency producing quality items and services[15)]. The automotive manufacturing sector also employs 3-D printing in their research and development center to build up prototypes and reduce time to market (KPMG-AIMA Report 2018). In 2015, the first Indian smart factory has been established in Pune by an American conglomerate to provide a platform for the development of smart factories embedded with potential technologies of industry 4.0 i.e. Internet of Things and Big Data.

Definitely, I4.0 paradigm was and is still allied with huge opportunities and advantages such as more flexible mass production system, minimization of complication price, emergence of completely innovative services and business representation or actual coordination and optimization of value chains[16)]. Furthermore, organizations are trying to analyze their actual situation with respect to I4.0 maturity.

2.1 Identification of industry 4.0 technologies

From the previous research it is observed that many researchers explore the various technologies of industry 4.0. In this research work the previous literature articles were downloaded by using search strings associated with the objective of the research. Context-intervention-mechanism-outcome approach was adopted for inclusion or exclusion[17)].

For this process primarily author applied inclusion or exclusion criteria in research title, abstract, keywords and secondary in the overview and conclusion of the article and then lastly, all nominated were read completely. The selected search strings act as input into the prominent electronic databases. The authors selected seven main I4.0 technologies that found in the previous research articles followed by qualitative survey of experts in field of I4.0T.

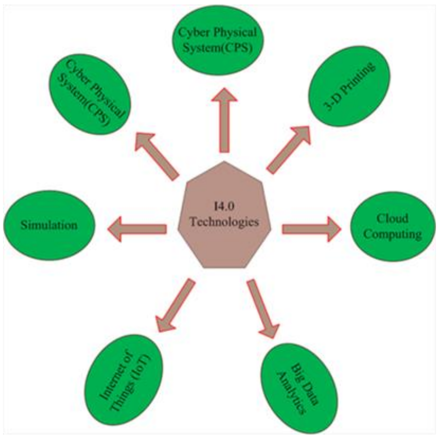

Fig.1. Industry 4.0 Technologies

These technologies are extensively deemed by authors, because these technologies can be incorporate with non-value-added activities. Figure 1 shows the most useful technologies and table 1 highlighted the summary of these technologies.

Table 1: Summary of Industry 4.0 technologies (I4.0T)

I4.0T	Overview of Technologies
Cyber Physical System(CPS)	CPS refers to linkage of physical assets of the factory to the cyber assets, known as styled cyber system. CPS connects digitally to the physical world and having six major dimensions i.e. communicating, energy needs and capability for coordination.
Internet of Things (IoT)	Internet of Things, establishes inter-connection of objects and human through internet. Manufacturing IoT make the networking of manufacturing operations, plant workers, employees, suppliers, product and customers. It is useful for real-time processing.
Big Data Analytics	A big data technique involves accumulating and recovering unstructured, raw information data which is being constantly generated in miscellaneous formats and in bulk quantities. This technique is most valuable to meet rapidly varying customer demands.
Cloud Computing	Cloud computing basically refers to on-demand delivery of computing facilities through internet. These services include data storage service, networking, databases and software services after making agreements among the service provider and customers.
3-D Printing	This is recent trend in manufacturing to produce 3-dimentional solid products using a series of layered by layered frameworks. Products of 3D printing are light in weight and minimize transportation, stocks.
Simulation	Simulation is a modeling tool that is used to forecast and evaluate the potential of complex systems and gives exclusive empowerment and autonomy to machine operator, machines and processes.
Autonomous Robots	Autonomous robots are designed to collaborate with auxiliary systems and humans in real time. These are installed with synchronized sensor, electronic software and standardized interfaces that empower them to remotely connect with web in same time with other machines and establish human cooperation.

3. Research Methodology

The research methodology adopted in the current research work is represented in Figure 2. Primarily broad review of literature based upon I4.0 technologies carried out. From the reviewed of literature and expert's opinion it has been seen that I4.0 technology is novel terminology dealing with the automation of business organizations which is quite rarely adopted by the local manufacturing organizations in developing nation such as India. Thus, there is a huge opportunity of implementing I4.0 technology in manufacturing organizations of developing nations to achieve subsequent advantages. Behalf of the finding I4.0 technologies in previous section, a survey questionnaire on 5-point Likert Scale was prepared to access the effectiveness of I4.0 technologies in Indian manufacturing Industries. Survey questionnaire was restricted in two sections, first section of survey questionnaire contained general information regarding organization and second part contained queries associated

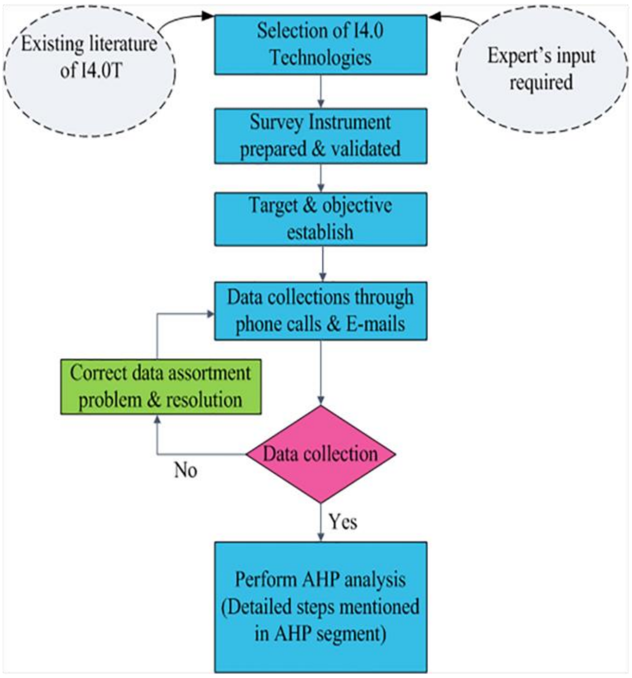

Fig. 2. General Research Methodology

with I4.0 technologies (Appendix-I). Respondents in the research were approached to grade the industry 4.0 technologies in the survey questionnaire in terms of the effect observed on I4.0 technologies to implementation of these technologies. The (5-point) Likert scale which represents opinion such as 5- Extremely important; 4-More important; 3-Important; 2-Less important; and 1-Not important for manufacturing organization. Further, to ensure the effectiveness of survey questionnaire, it was referred to total 6 researchers, academicians and industrial experts for the determination of pilot test and authentication. Every expert is having well proficient experience in the field of industry/academia. To identify the prioritization level of various technologies of industry 4.0 in Indian manufacturing organization explained in next section.

4. Analytic Hierarchy Process for Prioritizing Technologies of Industry 4.0

This segment represents the methodology adopted to rank the industry 4.0 technologies used in manufacturing organization. AHP is a multi-criteria decision making technique and it has been adopted broadly in a assortment of complicated MCDM problems associated to strategic planning of the organizational resources, prioritize the criteria and also measure the consistency of experts judgments[18,19]. Analytic hierarchy process has been used in various sectors such as education, health, finance, marketing and public policy etc. As per process of this technique, the whole problem can be resolved by breakdown it into numerous levels consists of target, criteria, sub-criteria and alternatives of the study and used to develop structural model. There are different MCDM techniques like ELECTRE, TOPSIS, ANP, ISM etc. but AHP is most popular because it provides effective, logical measures to whole supply chain professional[20]. AHP breaks a complex MCDM problem into inter-related decision elements (criteria, decision alternatives) and arrange them in a hierarchical structure like a family tree. It is also measuring the consistency of decision making and this methodology enables the managers to analyze a complicated system[21]. Ahuja and Singh[22] presented a AHP model for justification of TPM implementation in manufacturing industries. Various industry 4.0 tools used in manufacturing organization and prioritized these tools using AHP technique. Because of these advantages, the analytic hierarchy process has been mostly accepted and broadly used as a MCDM method for analyzing different fields[23,24]. However, for the study, the procedural ladder for analytic hierarchy process adopted from the studies of saaty (1980) and Rathi et al. (2016), explained as follows:

Step I: Based on previous research, discussion with academic specialists and manufacturing practitioners list of industry 4.0 technologies are finalized as listed in Table 1.

Step II: Development of pair-wise comparison matrix

In this paired assessment matrix (as shown in Table 2), comparison of two criteria (column with row) is done and rating is given according to their importance which shows importance of one criterion over another. Rating of criteria established behalf of Saaty's nine-point scale from 1: Equally significant to 9: Extremely high significant).

Table 2. Pair-wise comparison matrix of I4.0 technologies.

I4.0 Technologies							
	CPS	IoT	BDA	CC	3-D	SI	AR
Cyber Physical System	1	5	6	8	9	2	5
Internet of Things	1/5	1	1	3	3	8	5
Big Data Analytics	1/6	1/1	1	4	8	5	9
Cloud Computing	1/8	1/3	¼	1	5	7	5
3-D Printing	1/9	1/3	1/8	1/5	1	1	2
Simulation	1/2	1/8	1/5	1/7	1/1	1	1
Autonomous Robots	1/5	1/5	1/9	1/5	1/2	1/1	1

Table 3. Simplified matrix with sum of column

I4.0 Technologies							
	CPS	IoT	BDA	CC	3-D	SI	AR
Cyber Physical System	1	5	6	8	9	2	5
Internet of Things	0.2	1	1	3	3	8	5
Big Data Analytics	0.166	1	1	4	8	5	9
Cloud Computing	0.125	0.333	0.250	1	5	7	5
3-D Printing	0.111	0.333	0.125	0.2	1	1	2
Simulation	0.5	0.125	0.2	0.142	1	1	1
Autonomous Robots	0.2	0.2	0.111	0.2	0.5	1	1
Total	2.302	7.991	8.686	16.542	27.5	25	28

Step III: Development of normalize matrix through paired comparison matrix.

Pair-wise matrix was simplified with the sum of its column (as shown in Table 3) using equation 2. Furthermore, each value of simplified matrix was divided with the sum of its column using equation 3 to generate normalized matrix as shown in Table 4.

$$S_{nn} = \sum_{i=0}^{n} a_{nn} \quad = \text{Equation (2)}$$

$$C = \frac{a_{nn}}{s_{nn}} = \begin{bmatrix} C_{11} & C_{12} & \cdots & \cdots & C_{1n} \\ C_{21} & C_{22} & \cdots & \cdots & C_{2n} \\ \vdots & \vdots & \ddots & \ddots & \vdots \\ \vdots & \vdots & \ddots & \ddots & \vdots \\ C_{n1} & C_{n2} & \cdots & \cdots & C_{nn} \end{bmatrix} \quad \text{Equation}$$

(3)

Table 4. Normalized matrix for I4.0 technologies

	CPS	IoT	BDA	CC	3-D	SI	AR
Cyber Physical System	0.434	0.625	0.690	0.483	0.327	0.080	0.178
Internet of Things	0.086	0.125	0.115	0.181	0.109	0.320	0.178
Big Data Analytics	0.072	0.125	0.115	0.241	0.290	0.2	0.321
Cloud Computing	0.054	0.041	0.028	0.060	0.181	0.280	0.178
3-D Printing	0.048	0.041	0.014	0.012	0.036	0.040	0.071
Simulation	0.217	0.015	0.023	0.008	0.036	0.040	0.035
Autonomous Robots	0.086	0.025	0.012	0.012	0.018	0.040	0.035

Step IV: Criteria weights estimation

To calculate criterion weights, add each row of the normalised matrix and divide by the matrix's size using equation 4. Ranking to each criteria has been given here as shown in Table 5.

Criteria weight = $\frac{\text{Sum of each row of normalized matrix}}{\text{Matrix size}}$

Equation (4)

Table 5. Criteria weights and ranking of I4.0 technologies

I4.0 Technologies									
	CPS	IoT	BDA	CC	3-D	SI	AR	Criteria weights	Rank
Cyber Physical System	0.402	0.795	1.164	0.936	0.333	0.106	0.16	0.402	I
Internet of Things	0.080	0.159	0.194	0.351	0.111	0.424	0.16	0.159	III
Big Data Analytics	0.066	0.159	0.194	0.468	0.296	0.265	0.288	0.194	II
Cloud Computing	0.050	0.052	0.048	0.117	0.185	0.371	0.16	0.117	IV
3-D Printing	0.044	0.052	0.024	0.023	0.037	0.053	0.064	0.037	VI
Simulation	0.201	0.019	0.038	0.016	0.037	0.053	0.032	0.053	V
Autonomous Robots	0.080	0.031	0.021	0.023	0.018	0.053	0.032	0.032	VII
Total								0.994	

Step V: Estimation of consistency index (CI)

Estimation of consistency is viewed as very critical part of analytic hierarchy process (AHP). Inconsistency leads to inaccurate results. Satisfactory range falls between 0.0 and 0.1 (Satty,1980), beyond these limits, practitioners have to put efforts to improve pair-wise matrix. In this research Maximum Eigen value (λ_{max}) is 7.125 and size of matrix (n) is 7. The consistency index (CI) calculated as follows:

Consistency Index (CI) = $\frac{\lambda max - n}{n-1}$ = Equation (5)

CI = $\frac{7.125-7}{7-1}$ = 0.02, which is less than 0.1

Step VI: Assessment for consistency ratio (CR)

The Consistency ratio is the most essential measurement of the results of pairwise comparisons in the AHP. Through pairwise comparison, element weights are to be determined.

Consistency ratio (CR) is used as a compute to judge consistency in the opinion of the practitioners.

Consistency Ratio (CR) = $\frac{CI}{RI}$ Equation (6)

Consistency Ratio (CR) = $\frac{0.02}{1.32}$ = 0.015

After estimation of consistency AHP based model for industry 4.0 technologies was developed as per ranking of industry 4.0 technologies as shown in figure 3.

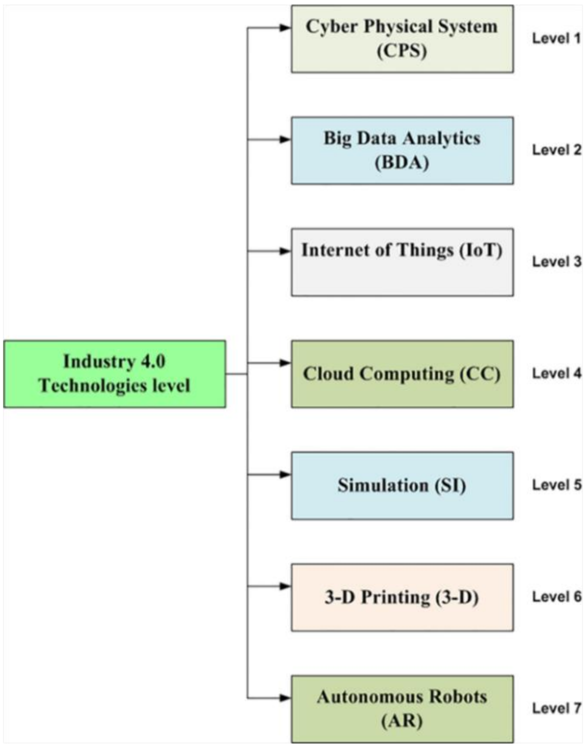

Fig. 3. Ranking of industry 4.0 technologies.

5. Results and Discussion

This present study attempts to recognize industry 4.0 technologies and examines the importance of I4.0 technologies by using analytic hierarchy process technique. This research work is based on interaction with three practitioners from academic as well as industrial domain. Seven potential technologies in the study are identified by conducting extant review of the existing literatures from database and inputs from experts were incorporated. AHP technique is followed for prioritization of the identified technologies. Pair-wise comparison matrix is devised using inputs from experts and criteria weights are calculated for getting the rank of the particular technology (see Table 6). As per criteria weight, Cyber - Physical System occupied first rank with 0.402 criteria weight, means this technology is having most significant importance in execution of smart manufacturing paradigm. The results show assimilation with the previous research by Sodhi[9] who had confirmed that CPS is heart of I4.0 technology. Goel et al.,[25] mentioned that recently the Cyber Physical System has changed overall attention of manufacturing organizations. Government of India also broadcast in Union Budget 2018-19 that Cyber Physical System is most powerful technique to support establishment of the Centre for Excellence for training in robotics and virtual manufacturing. The manufacturing organization should immensely focus on Cyber Physical System. Big Data Analytics (0.194) as it considerably emphasizes on I4.0 execution. Big Data Analytics enhance operational efficiency, optimized production process and reduce the cost[26]. It followed by an Internet of Things (0.159). Big Data Analytics and Internet of Things are two critical technologies which gives the impetus to creation of smart industries. Internet of Things and Big Data Analytics, two of the most important technologies of Industry 4.0 for India, are expected to account for approximately 20% and 32% of the global market, respectively, over the next five years[27].

Furthermore, the study proposes that Simulation and 3-D printing/ additive manufacturing taking place at fifth and sixth position with the weights of 0.037 and 0.053 respectively followed by Autonomous Robots (0.32). System simulation provides evaluation of many scenarios. When scenarios are evaluated, cost-effective answers can be designed, tested, and implemented more rapidly, resulting in cost savings, and accelerated time to market[28]. In current scenario the opportunities provided by the internet revolutionized the use of robots and their service which they provided in the previous decades. Anand and Nagendra[29] claims that the integration of intelligent systems in industries improves the productivity, flexibility and promotes flexible robot- based automation solution. The results of the present study are acceptable as the inconsistency ratio of pair-wise comparison is between 0.0 and 0.1 (CI<0.1).

5.1 Theoretical Implications

With the emergence of intelligent technologies, the prioritizing of these intelligent technologies is assuming heightened significance. In the past, numerous researchers employed various MCDM methodologies to solve multi-standards problems; however, the AHP is used to compute the individual evaluations of decision makers. It is finished by assigning corresponding mathematical values based on the comparative significance of standards under consideration. The usage of AHP is widespread and has been adopted in numerous locations to optimize decisions; for identifying and prioritizing the various implementation variables of Industry 4.0.[30,31]. This research focuses to prioritize the potential technologies of industry 4.0 and their application towards modernization and automation of manufacturing organizations. To finalize the smart technologies, a comprehensive literature review was conducted in conjunction with enterprise experts. Previously assessment was made on adoption of individual smart technology with their critical factors and implementation variables[32] which is now extended to recognize the industry 4.0 technologies and analyze their correlation to understand the implementation trend in Indian manufacturing organizations. The implementation of I4.0 technologies unlocks the new path for producing customized products and services as per continuously changing demand and preferences. I4.0 has assets of CPSs, BDA, IoT, Data Science, AI, etc. which can create ideal and optimized process flow in production systems. Adopting AHP model on Industry 4.0 technologies in business organization will enable managers, experts, and decision-makers of Industry 4.0 to effectively prioritize these smart technologies and focus on smart technologies while applying Industry 4.0 paradigm in their respective organization. Through the new Industry 4.0 technologies, organizations are anticipated to become more translucent, regionalized, much less hierarchical and high flexible in time and space.

5.2 Practical Implications

As industrialists examine for effective and economic production methods, new smart technologies can make a contribution to boost up their competitiveness. Smart manufacturing can assist the growth of greater performance via innovative corporate models and services. Though, its implementation requires extra challenges for organizations, particularly those in developing economies. Tortorella et al.,[33] mentioned that if organizations installed many flow-related lean production techniques then they should prioritize the goods/service-oriented technologies such as cloud computing, internet of things and 3-D printing, in order to accomplish extraordinary operational performance levels. Therefore, our proposed AHP model offers a systematic approach for decision-makers and specialists to understand and analyze the various industry 4.0 technologies and strategies for successful implementation of Industry 4.0 technologies[34].

6. Conclusions and Future Research

Government entities must prioritise the industry 4.0 effective implementation since it provides a path to global competitiveness. With the assistance of a thorough literature review and expert feedback, seven I4.0 technologies were identified. These technologies were contrasted pair-by-pair in order to comprehend their contextual relationship. This research used an analytic hierarchy process approach to rank the importance of I4.0 technologies, and results were evaluated for consistency and accuracy. The technologies identified in this study can serve as the basis for an agenda that comprehensively addresses the possible success technologies connected with I4.0 implementation, paving the door for some new directions in I4.0 implementation. On the basis of AHP rankings level, the significance of each technology can be determined.

This investigation demonstrates a whole structure of I4.0 technologies including with their weighs and ranking. The administrators of the industries can be capable to perceive the necessary capabilities with a particular aim to accomplish and keep up their upper hand. In the shortage of adequate resources, it is typically impossible for management to implement all technologies simultaneously. Thus, with the ranking of technologies, researchers and practitioners will be able to determine which technologies they should prioritise based on their respective needs. The results indicate that Smart Factory System, Big Data Analysis, and the Internet of Things are the three most important technologies for the administration to prioritise. The main motivation of the projected approach is that it has been implemented and validated in various complex appliances. AHP depreciates the complicated issues into easy progressive steps which exposes the simplicity in the choice of the judgment makers and can be easily perceived at the operating level. Very few researchers have been analyzed and prioritized I4.0 technologies which give strengthen to this study. This research work also has some restrictions, which suggested the way for future exploration. Primarily, the investigation is based on the judgment of the six specialists, which may be more than six. Secondary, the information data can be collected from various manufacturing organizations and type of organizations for better generalization of outputs. Third, the outputs can be contrasted to other MCDM techniques like ELECTRE, TOPSIS, ANP, ISM and it can be validated through interpretive ranking process (IRP) using dominance graph.

References

1) H. Lasi, H. G. Kemper, P. Fettke, T. Feld and M. Hoffmann, “Industry 4.0”, Business and Information Systems Engineering, Vol. 6, No. 4, pp. 239-242 (2014).
2) S.A. Khan, R. Arora, H. Kumar and P.K. Arora, "A Perspective on Advances in Cloud-based Additive Manufacturing." EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, Vol.9(3), pp861-869 (2022). https://doi.org/10.5109/4843119
3) H. Ning and H. Liu, “Cyber-physical-social-thinking space based science and technology framework for the Internet of Things”, Science China Information Sciences, Vol. 58, No. 3, pp. 1-19 (2015).
4) F. Yang and S. Gu, “Industry 4.0, a revolution that requires technology and national strategies,” Complex & Intelligent Systems, 7, 1311-1325 (2021).
5) N. F. Ayala, C. A. Paslauski, A. Ghezzi and A. G. Frank, “Knowledge sharing dynamics in service suppliers' involvement for servitization of manufacturing companies”, International Journal Production Economics, Vol. 193, pp. 538–553 (2017).
6) W. Coreynen, P. Matthyssens and W. Van Bockhaven, “Boosting servitization through digitization: pathways and dynamic resource configurations for manufacturers”, Industrial Marketing Management, Vol. 60, pp. 42–53 (2017).
7) L. S. Dalenogare, G. B. Benitez, N. F. Ayala and A. G. Frank, “The expected contribution of Industry 4.0 technologies for industrial performance”, International Journal Production Economics, Vol. 204, pp. 383–394 (2018).
8) T. C. Ng, S. Y. Lau, M. Ghobakhloo, M. Fathi, and M. S. Liang, “The Application of Industry 4.0 Technological Constituents for Sustainable

Manufacturing: A Content-Centric Review", Sustainability, Vol. 14, No. 7, pp. 1-21 (2022).
9) H. S. Sodhi, "An Investigation for Prioritizing Industry 4.0 Tools Using Analytic Hierarchy Process", International Journal of Advance Science and Technology, Vol. 29, 10S, pp. 5619-5629 (2020).
10) D. C. Fettermann, C. G. S. Cavalcante, T .D. D. Almeida and G. L. Tortorella, G. L., "How does Industry 4.0 contribute to operations management?", Journal of Industrial and Production Engineering, Vol. 35, No. 4, pp. 255-268 (2018).
11) H. Kagermann, W. Wahlster and J. Helbig, "Securing the Future of German Manufacturing Industry: Recommendations for Implementing the Strategic Initiative INDUSTRIE 4.0", Final Report of the Industrie 4.0 Working Group, pp.1-79 (2013).
12) S. Weyer, M. Schmitt, M. Ohmer and D. Gorecky, "Towards Industry 4.0 - Standardization as the crucial challenge for highly modular, multivendor production systems", IFAC-Papers On Line, Vol. 48, No. 3, pp. 579–584 (2015).
13) Sunaryo, Sunaryo, and Muhammad Athallah Aidane. "Development Strategy of Eco Ship Recycling Industrial Park." EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, Vol.9(2), pp524-530 (2022). https://doi.org/10.5109/4794183
14) M. Hermann, T. Pentek and B. Otto, "Design principles for industrie 4.0 scenarios", In Proceedings of the 2016 49th Hawaii International Conference on System Sciences (HICSS), Koloa, HI, USA, pp. 3928–3937 (2016).
15) M. Silva, E. Vieira, G. Signoretti, I. Silva, D. Silva and P. Ferrari, "A customer feedback platform for vehicle manufacturing compliant with industry 4.0 vision", Sensors, Vol. 18, No.10, pp. 1-25 (2018).
16) F. Galati and B. Bigliardi, "Industry 4.0: emerging themes and future research avenues using a text mining approach", Computers in Industry, Vol. 109, pp. 100-113 (2019).
17) J. A. Garza-Reyes, "Lean and green-a systematic review of the state of the art literature", Journal of Cleaner Production, Vol. 102, pp. 18-29 (2015).
18) T. L. Saaty, "The Analytic Hierarchy Process", McGraw-Hill, New York, NY (1980).
19) R. Rathi, D. Khanduja and S. K. Sharma, "Efficacy of fuzzy MADM approach in Six Sigma analysis phase in automotive sector', Journal of Industrial Engineering International, Vol. 12, No. 3, pp. 377-387 (2016).
20) V. Gupta and A. Jayant, "A novel hybrid MCDM approach followed by fuzzy DEMATEL-ANP-TOPSIS to evaluate Low Carbon Suppliers," EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, Vol.8(3), pp544-555 (2021). https://doi.org/10.5109/4491640
21) J. Bhadu, P. Kumar, J. Bhamu and D. Singh, "Lean production performance indicators for medium and small manufacturing enterprises: modelling through analytical hierarchy process," International Journal of System Assurance Engineering and Management, 13(2), 978-997 (2022).
22) I. P. S. Ahuja and P. Singh, "Application of analytical hierarchy process for justification of TPM implementation in manufacturing organizations", International Journal of Technology, Policy and Management, Vol. 12, No. 1, pp. 37 (2012).
23) S. K. Mangla, K. Govindan and S. Luthra, "Prioritizing the barriers to achieve sustainable consumption and production trends in supply chains using fuzzy analytical hierarchy process," Journal of Clean Production, Vol.151, pp. 509–525 (2017).
24) P. Saraswat, R. Agrawal and M. L. Meena, "An Analysis of Critical Success Factors Using Analytical Hierarchy Process for Implementation of Lean with Industry 4.0 in SMEs," In Recent Advances in Smart Manufacturing and Materials: Select Proceedings of ICEM 2020 (pp. 255-262). Springer Singapore (2021).
25) P. Goel, R. Kumar, H. K. Banga, S. Kaur, R. Kumar, D. Y. Pimenov and K. Giasin, "Deployment of Interpretive Structural Modeling in Barriers to Industry 4.0: A Case of Small and Medium Enterprises", Vol. 15, No. 4, pp. 1-22 (2022).
26) J. Wang, C. Xu, J. Zhang and R. Zhong, R., "Big data analytics for intelligent manufacturing systems: A review". Journal of Manufacturing Systems, 62, pp.738-752 (2022).
27) K. Garg, C. Goswami, R. S. Chhatrawat, S. K. Dhakar and G. Kumar, "Internet of things in manufacturing: A review". Materials Today: Proceedings, 51, pp.286-288 (2022).
28) S. Chouhan, P. Mehra and A. Dasot, "India's readiness for industry 4.0: A focus on automotive sector", CII-Grant Thornton 2017, https://www.grantthornton.in /globalassets/1.memberfirms/india/assets/pdfs/indias_readiness_for_industry_4_a_focus_on_automotive_sector.pdf.
29) P. Anand and E. Nagendra, "Industry 4.0: India's Defence industry needs smart manufacturing", International Journal of Innovative Technology and Exploring Engineering, Vol. 8, pp. 2278-3075 (2019).
30) J. Bhadu, J. Bhamu and D. Singh, "Critical success factors of lean manufacturing for Indian ceramic industries: Modelling through interpretive ranking process", Indian Journal of Engineering & Materials Sciences, Vol. 28, No. 3, pp. 271-281 (2021).
31) D. Nimawat and B. D. Gidwani, "Prioritization of important factors towards the status of industry 4.0 implementation utilizing AHP and ANP techniques", Benchmarking: An International Journal, Vol. 28, No. 2, pp. 695-720 (2021).

32) V. A. Wankhede and S. Vinodh, "Analysis of barriers of cyber-physical system adoption in small and medium enterprises using interpretive ranking process," International Journal of Quality & Reliability Management, 39(10), 2323-2353 (2022).
33) G. L. Tortorella, R. Giglio and D. H. van Dun, "Industry 4.0 adoption as a moderator of the impact of lean production practices on operational performance improvement", International Journal of Operations & Production Management, Vol. 39, No. 6/7/8, pp. 860-886 (2021).
34) R. S. Sakataven, S. A. Helmi, and M. Hisjam. "Lean implementation barriers and their contextual relationship in contract manufacturing machining company." EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, Vol. 8(2), pp499-508 (2021). https://doi.org/10.5109/4480735