Industry 4.0 and Indian Manufacturing: An AHP Approach

Hera Farooquie[a], Asif Akhtar[b]
[a]Research Scholar, [b]Assistant Professor
Faculty of Management Studies & Research
Aligarh Muslim University
Aligarh, 202002, India
herafarooquie@gmail.com

Abstract

Despite being the sixth-largest manufacturing country in the world, India lags many other countries in the adoption of I4.0 technologies. Industry 4.0 is a wide spectrum of technologies which help firms improve on their performance and customer satisfaction. Adoption of I4.0 makes a firm more competitive in terms of cost, responsiveness, value, and other such dimensions of performance. However, all I4.0 technologies are not equally beneficial. Further, firms are not capable of implementing all technologies, at least, in one go. Therefore, a firm with certain limitations needs to decide the order in which it should adopt these technologies to improve its performance. The present study is an attempt to identify and prioritize these I4.0 technologies and their benefits for manufacturing firms in Indian context. The analytic hierarchy process (AHP) technique has been used for this purpose.

Keywords
Analytic hierarchy process (AHP), Industry 4.0, Manufacturing firms.

1. Introduction and Literature Review

Industry 4.0, a term coined in Germany about 8 years back, is a wide spectrum of technologies to help firms improve on their performance and customer satisfaction. Industry has witnessed transformative changes starting right from the seventeenth century till date, in the twenty first century, and is still undergoing rapid changes which shall continue in the near future as well. According to Zhong et. al. (2017), Industry 4.0 combines embedded production system technologies with intelligent production processes to pave the way for a new technological age that will fundamentally transform industry value chains, production value chains, and business models.

To better understand Industry 4.0, we need to have a close look at the set of technologies which actually make up this entire revolution, Alcacer and Cruz-Machado (2019), for example, have included the Internet of things, cloud computing, big data, simulation, augmented reality, additive manufacturing, autonomous robots, and cyber security in their literature review on manufacturing technologies in the era of I4.0.

Industry 4.0 adoption is likely to benefit the manufacturing related firms both economically as well as technically. The Boston Consulting Group (BCG) has reported various such benefits in the context of German manufacturing firms. The benefits include improvement in productivity, employment, revenue and investment (Gerbert et. al., 2015).

Industry 4.0 technologies are not expected to bring benefits to the manufacturers without posing some challenges to them. Some important challenges to I4.0 adoption have been identified as inadequate physical and digital infrastructure, high cost of digital technologies, cyber security issues and skill gaps in workforce and leadership (KPMG, 2018; Luthra and Mangla, 2018).

The literature on I4.0 suggests that the concept is in its infancy (Rojas et.a., 2017; Marr, 2018) and that there is not a closed definition of I4.0 (Castelo-Branco et. al., 2019). Moreover, the I4.0 technologies are not equally beneficial. In the context of over 2000 Brazilian companies, Dalenogare et. al., (2018) have found using regression method that some of the I4.0 technologies are more promising than others. Regarding implementation of I4.0 technologies, a study in Germany concludes that there is a lack of understanding of how companies implement these technologies (Frank et. al., 2019).

The fourth revolution, therefore, seems to have opened several opportunities for both academic researchers and industrial practitioners to shape the future of manufacturing (Hermann et. al., 2016). The present study is an attempt to identify and prioritize the I4.0 technologies and their benefits for manufacturing firms in Indian context.

1.1 Objectives

As literature suggests, adoption of I 4.0 makes a firm more competitive in terms of cost, responsiveness, value, and other such dimensions of performance. Moreover, given the challenges of I 4.0 adoption and the capability of a firm to implement, the firm needs to prioritize the various technologies according to its requirements. Accordingly following objectives have been identified pertaining to the Indian manufacturing- (a) to determine the relative importance of I4.0 benefits, (b) to determine the ranking of I4.0 technologies with respect to each benefit, (c) to prioritize the I4.0 technologies for adoption, and (d) to perform sensitive analysis of the results.

2. Methods

The decision-making scenario as reflected by the objectives of the present study resembles to a multi-criteria decision making (MCDM) situation and hence can be addressed using analytic hierarchy process (AHP) technique. AHP, evolved and developed by Saaty (1980) has been widely used by researchers for MCDM problems (Baswaraj et. al., 2018; Luthra and Mangla, 2018; Podvezko, 2009; Al Harbi, 2001).

AHP is an effective tool for dealing with complex decision making, and may aid the decision maker to set priorities and make the best decision. By reducing complex decisions to a series of pair-wise comparisons, and then synthesizing the results, the AHP helps to capture both subjective and objective aspects of a decision. In addition, the AHP incorporates a useful technique for checking the consistency of the decision maker's evaluations, thus reducing the bias in the decision-making process. The AHP considers a set of evaluation criteria, and a set of alternative options among which the best decision is to be made. It is important to note that, since some of the criteria could be contrasting, it is not true in general that the best option is the one which optimizes each single criterion, rather the one which achieves the most suitable trade-off among the different criteria (Saaty, 1980). The *SuperDecisions* Software (version 2.2), designed by Adams (SDM, 2012) has been used for this analysis.

3. Data Collection

The following technologies, extracted from the literature, have been considered for this study and are clubbed into four categories for convenience.

- Additive Manufacturing (AMG)- includes 3-D Printing, Machine Learning, Artificial Intelligence and Robotics
- Data Analytics (DTA)
- Internet of Things (IOT)
- Virtual and Augmented Realities (VAR)

Similarly, the benefits of I4.0 adoption have been grouped into the following three categories.

- Cost Reduction (CTR)- includes reduction in production, maintenance, logistics and inventory costs.
- Response Time Reduction (RTR)- includes reduction in cycle time and time to market, etc.)
- Value Enhancement (VLE)- Increase in production output, better quality output, improved quality of life of employees, and higher customer satisfaction.

A structured questionnaire was designed to gather data from the respondents for the pair-wise comparisons during AHP application. Ten experts have been identified and requested to complete the questionnaire. The number of experts recommended for pair-wise comparison ranges from 5 to 15 (Lin, et. al., 2009). These respondents were selected through judgmental sampling and considering their accessibility. Out of ten, six were from manufacturing industry, designated as plant managers or supply chain managers and four experts were approached from academics.

4. Results and Discussion

The first step in AHP is to construct the model showing all its clusters and their nodes. As shown in Figure 1, the three clusters for the present model include goal (technology prioritization), criteria (benefits of I4.0 adoption) and alternatives (I4.0 technologies). The clusters and their nodes have been discussed earlier. Figure 2 presents the software version of the model.

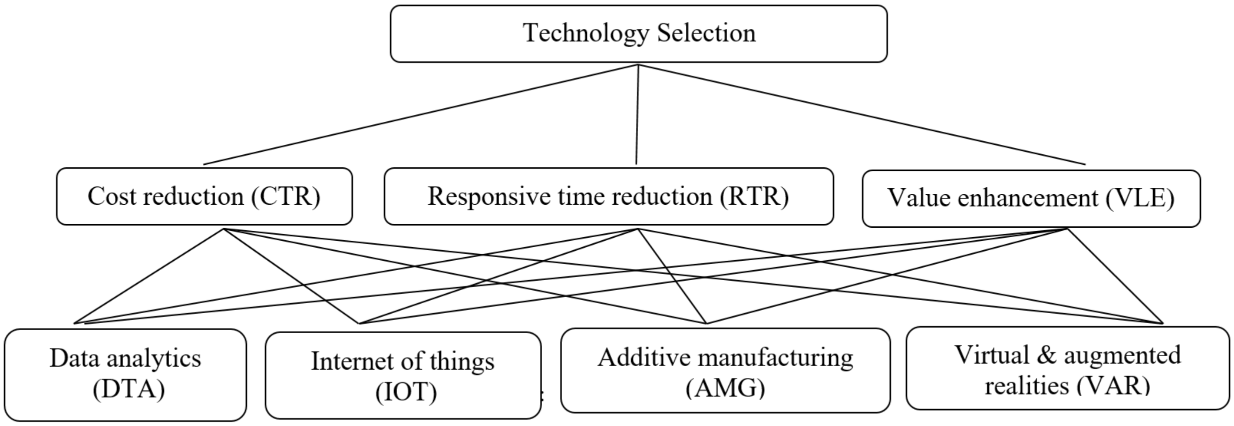

Figure 1: AHP Model

The next step in AHP is to make pair-wise comparisons of the nodes within and across the clusters. Out of ten experts two could not submit the response within the requested period. The consistency of the responses received from the each of remaining eight was tested using consistency ratio (CR). As suggested by Saaty (2008), a questionnaire with CR > 0.1 should not be analyzed further. Seven responses passed the test of consistency including five from industry and two from academics. Since the number of experts recommended for AHP ranges from 5-15 (Lin, et. al., 2009), the final sample size for this study seems to be acceptable.

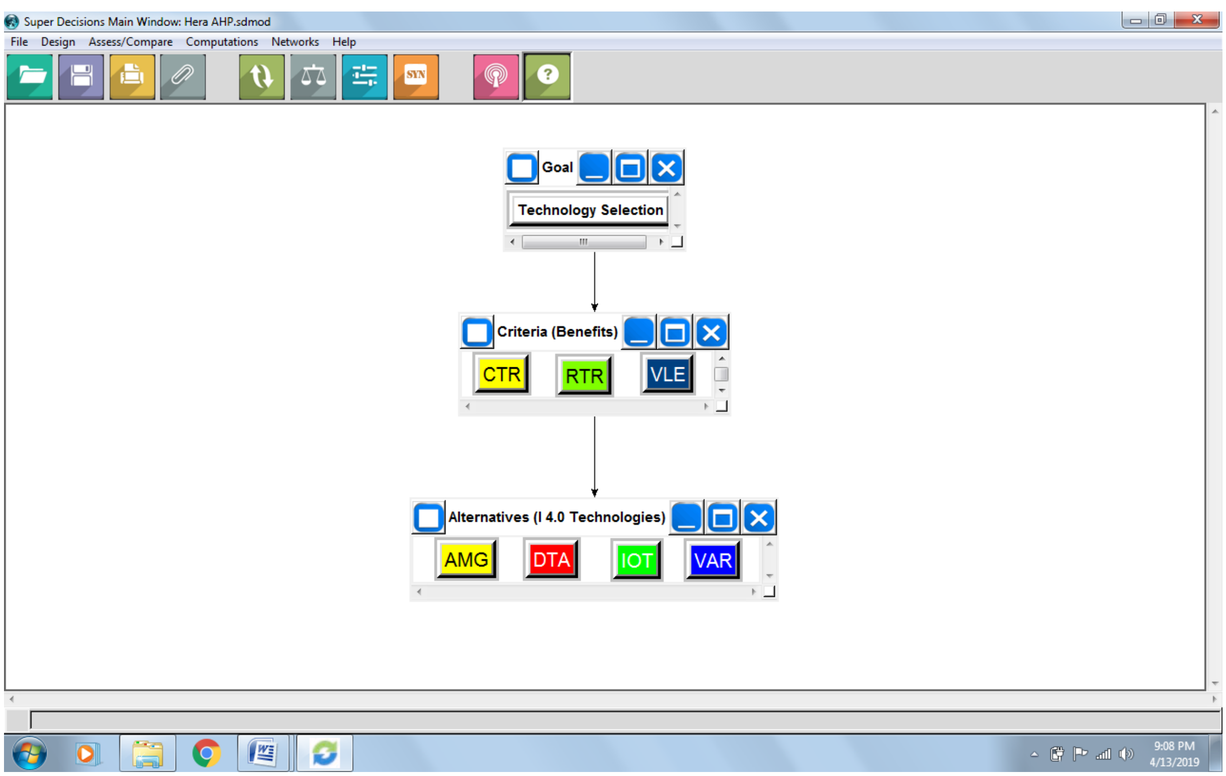

Figure 2: AHP Model (Software version)

4.1 Numerical Results

Four pair-wise comparison matrices were prepared to be filled in by the experts. At first, they were asked to compare the three benefits of I4.0 adoption in a pair-wise manner using a 9-point scale of importance (Saaty,1980). Secondly, pair-wise comparisons were made to judge the preference of one technology over the other with respect to each benefit. Figure 3 illustrates the first pair-wise comparison matrix. For example, when response time reduction (RTR) is compared with value enhancement (VLE) as a benefit of I4.0 implementation, the experts have assessed value enhancement as *strongly to very strongly more important* criterion than response time reduction (marked as 6 in the third row). The score 6 has been obtained by computing the geometric mean of the responses of the seven respondents while comparing the importance of value enhancement with that of response time reduction. The geometric means were obtained and filled similarly for all other pairs in the analysis.

On the basis of these set of comparisons, the software determines a local priority vector, using the following equation (Saaty, 1980).

$Aw = \lambda_{max} w$

Where, A is the pair-wise comparison matrix, w is the eigenvector and λ_{max} is the largest eigen value of A.

For instance, the local priorities of the three benefits of I4.0 adoption have been determined and shown as *Results* in Figure 3. It implies that value enhancement has emerged as the most important benefit (with a relative weight of 59%) that can be obtained through I4.0 adoption, followed by cost reduction (approx 28%) and responsiveness (approx 13%).

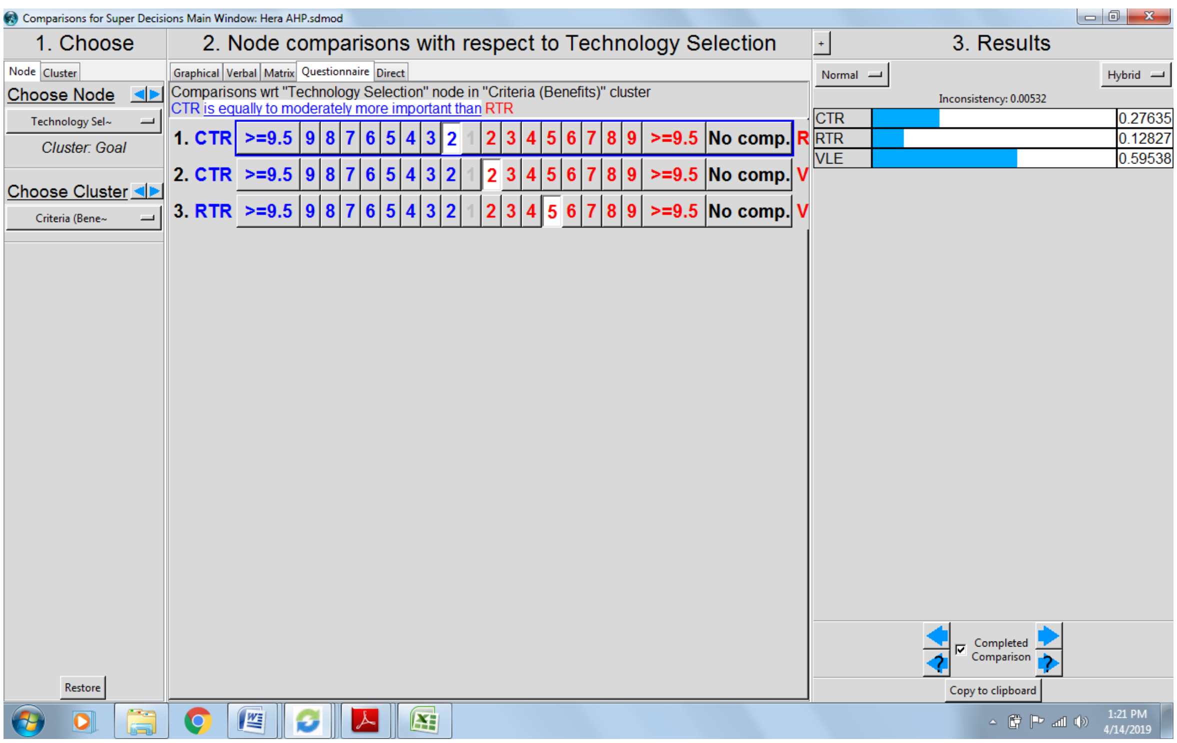

Figure 3: Pair-wise comparisons for the benefits

The next three pair-wise comparisons have been processed in a similar way. The first of them has been shown in Figure 4. The local priority vectors obtained as a result of the pair-wise comparisons are entered into a matrix called super-matrix, the format of which is shown below with three clusters, namely goal (G), benefits (B), and technologies (T). The further processing of the super-matrix results into the Tables 1–3. Table 1 shows the priorities of the benefits.

$$
w = \begin{array}{c} \\ G \\ B \\ T \end{array}
\begin{array}{c} \begin{array}{ccc} G & B & T \end{array} \\
\begin{bmatrix} w_{GG} & w_{GB} & w_{GT} \\ w_{BG} & w_{BB} & w_{BT} \\ w_{TG} & w_{TB} & w_{TT} \end{bmatrix} \end{array}
$$

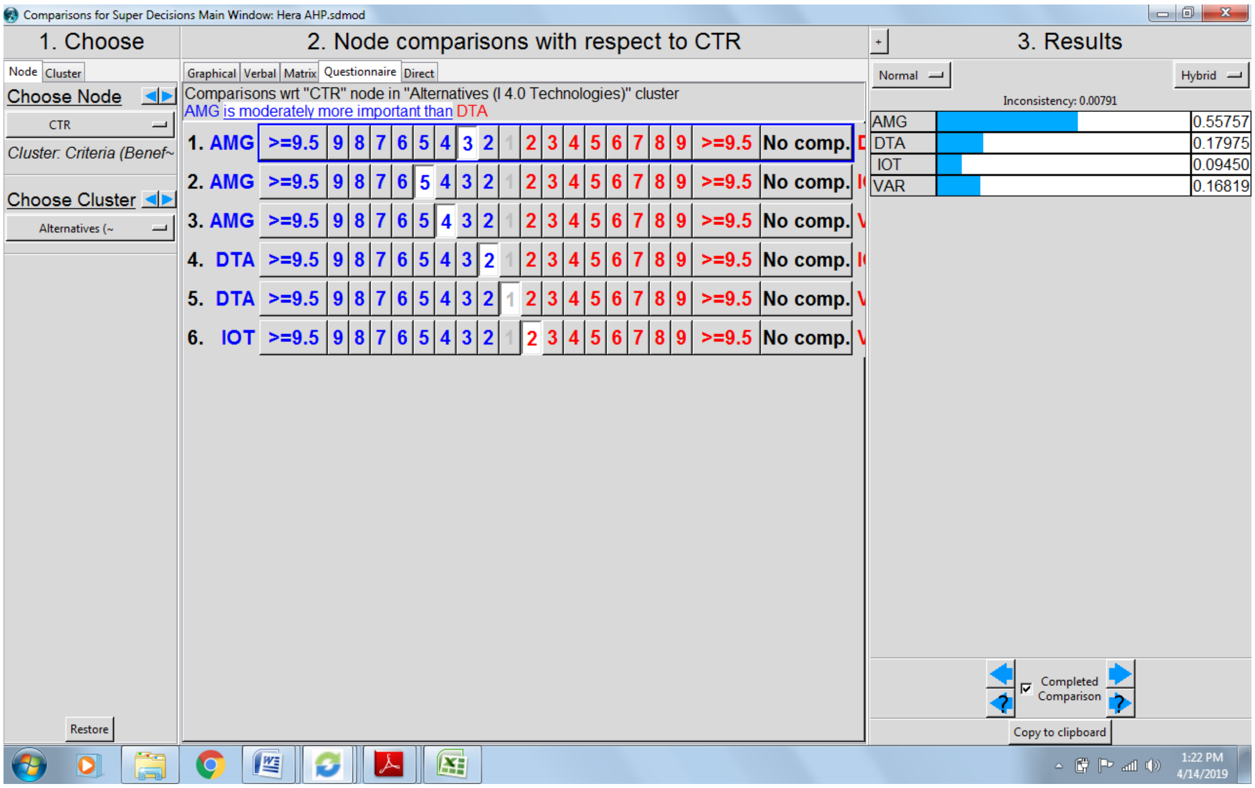

Figure 4: Pair-wise Comparisons of Technologies with respect to Cost Reduction

Table 1: Ranking of Industry 4.0 Benefits

Benefits	Weight	Ranking
Cost Reduction (CTR)	0.276	2
Response Time Reduction (RTR)	0.128	3
Value Enhancement	0.595	1

The benefit-wise ranking of the technologies has been presented in Table 2. Technologies are expected to weigh differently for different benefits. For example, additive manufacturing is not that powerful (weightage 49%) to aim at responsiveness as it is for value enhancement (weightage 56.7%).

Table 2: Ranking of Industry 4.0 Technologies with respect to each Benefit

	Benefits					
Technology	Cost reduction		Response time reduction		Value enhancement	
	Ranking	Weight	Ranking	Weight	Ranking	Weight
Additive Manufacturing (AMG)	1	0.558	1	0.490	1	0.567
Data Analytics (DTA)	2	0.180	2	0.215	3	0.133
Internet of Things (IOT)	4	0.945	4	0.106	4	0.100
Virtual & Augmented Realities (VAR)	3	0.168	3	0.189	2	0.200

4.2 Graphical Results

The initial argument in support of the present study was that it may not be advisable for any firm to adopt all I4.0 technologies in one go. Hence the technologies have been ranked for the firms to adopt them step by step to get an optimum mix of the benefits. The overall ranking of the technologies in order to achieve the three objectives (benefits) has been shown in Table 3 and Figure 5.

Table 3: Ranking of Industry 4.0 Technologies

Technology	Weight	Ranking
Additive Manufacturing (AMG)	0.554	1
Data Analytics (DTA)	0.156	3
Internet of Things (IOT)	0.099	4
Virtual & Augmented Realities (VAR)	0.190	2

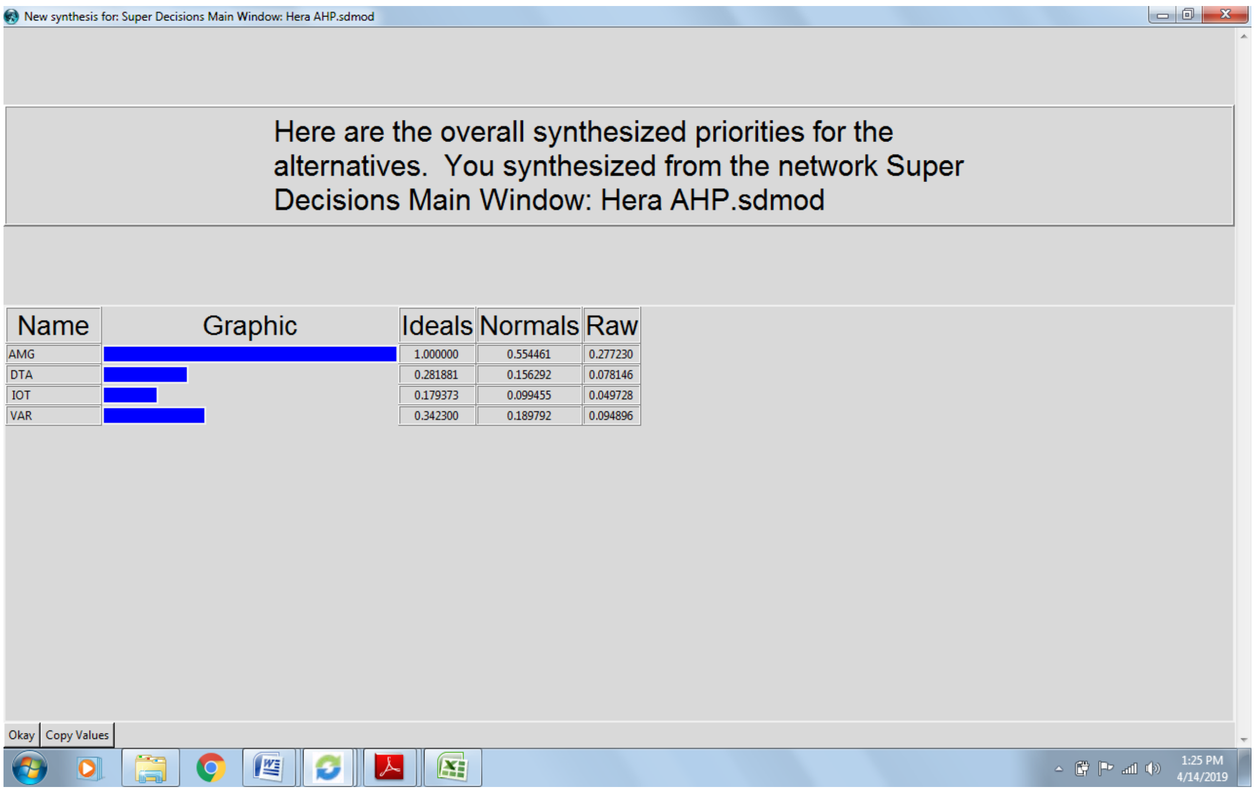

Figure 5: Overall Priorities of Technologies

4.3 Sensitivity Analysis

Since the AHP approach is based on the subjective assessment of the experts, a sensitive analysis is often carried out along with AHP to determine the robustness of the results. For instance, Figure 6 explains how the weightage of each technology changes with the change in the original importance (0.595) attached to value enhancement. It can be seen that the results are quite robust ab there is no significant change observed in the ranks of the four technologies on changing the weightage to value enhancement. Figures 7 and 8 explain the similar phenomenon when changes are made to the relative importance of responsiveness and cost reduction, respectively.

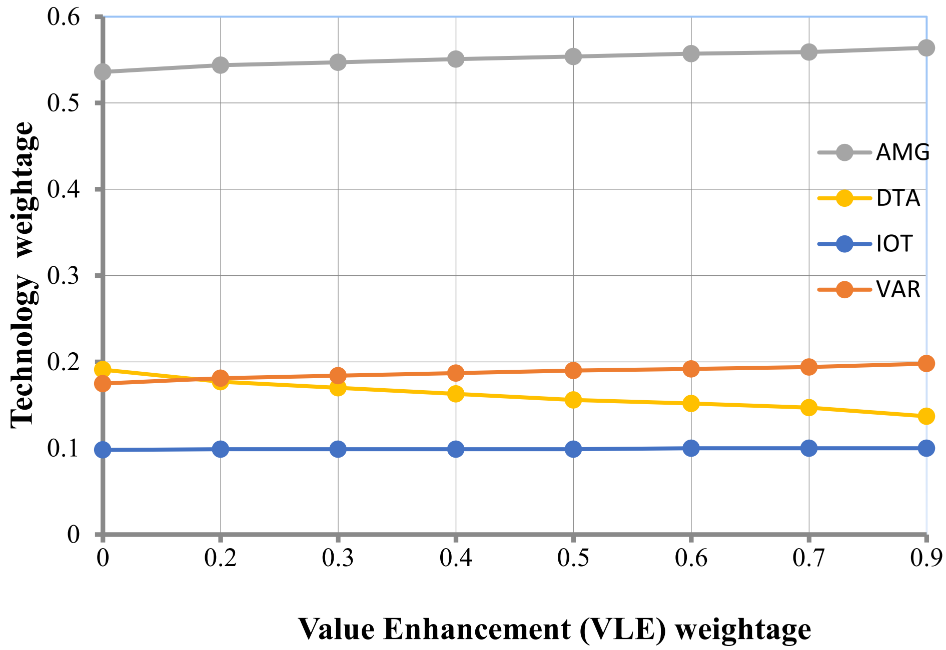

Figure 6: Sensitive Analysis w.r.t Value Enhancement

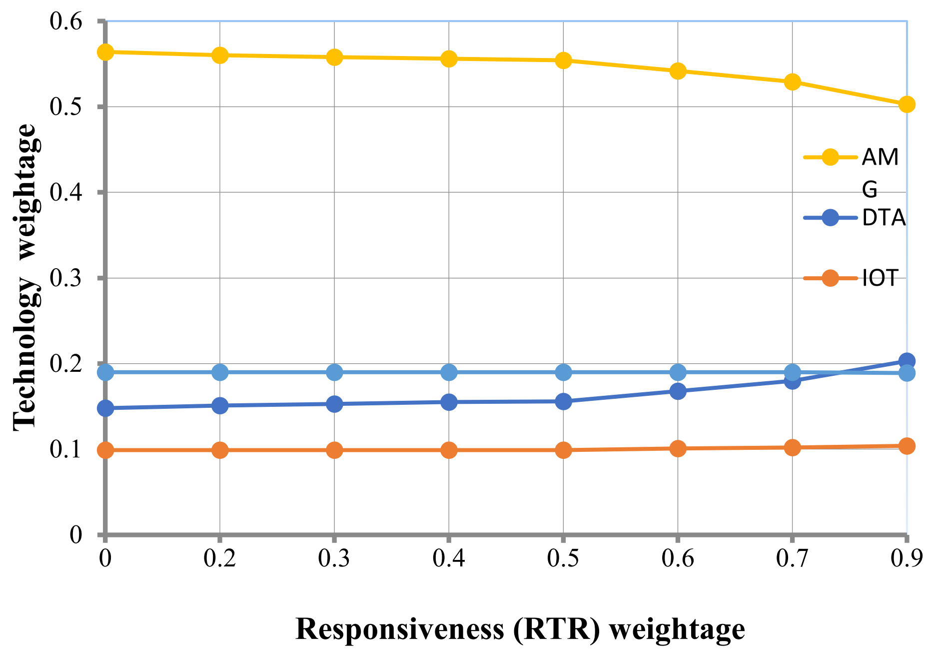

Figure 7: Sensitive Analysis w.r.t Responsiveness

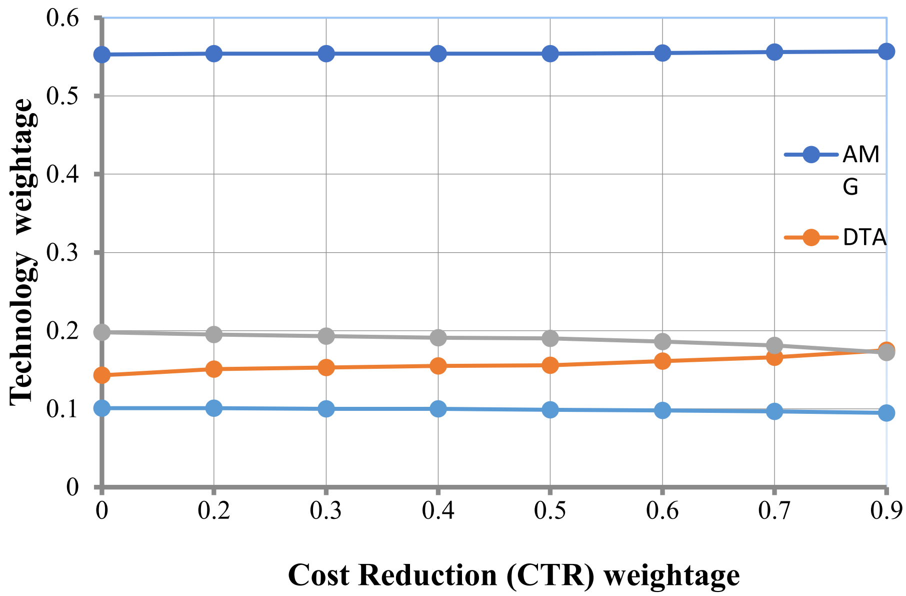

Figure 8: Sensitive Analysis w.r.t Cost Reduction

5. Conclusions

The present study had three objectives- prioritization of I4.0 benefits, benefit-wise preference of technologies, and overall ranking of the I4.0 technologies. The three benefits include reduction in production, logistics, inventory and maintenance costs; shortening of time to produce and time to market; and improvement in output, quality, quality of life and customer satisfaction. The technologies had been identified as additive manufacturing (including AI, 3D printing and robots), data analytics, Internet of things, and virtual & augmented realities. The findings of the study are concluded as below.

- Value enhancement has been judged as the most important benefit of I4.0 adoption with approximately 60% importance as compared to reduction in costs (27% weightage) and improvement is response time (nearly 13%).
- 3D printing, artificial intelligence, machine learning, and robots have emerged as the most preferred technologies in order to reap the I4.0 benefits.
- Adoption of IoT at this stage has been found as least important as compared to other three technologies with respect to all three benefits.
- Data analytics has more important role to play to achieve reduction in costs and response time as compared to that in value enhancement.
- Virtual and augmented realities are more important for value enhancement as compared to reduction in costs and response time.
- The overall ranking of the technologies indicates that 3D printing, artificial intelligence, machine learning, and robots together (AMG) have been preferred over all other technologies with 55% weightage, followed by virtual & augmented realities (VAR), data analytics (DTA), and Internet of things (IOT).

The experts were asked to judge the relative importance of the three benefits and relative ranking of four technologies to take advantage of these benefits. This was asked in the context of medium and large manufacturing firms in India. Despite being the sixth-largest manufacturing country in the world, India lags many other countries in the adoption of I4.0 technologies. Though the automotive industry in the country has taken lead in this direction, the manufacturing sector has to go a long way to transform its processes into the Industry 4.0 era. Following recommendations are proposed.

- Challenges like, large investments, different leadership and skills, and better physical and IT infrastructures need to be taken care by the policy makers and industry experts.

- In order to move gradually towards fourth industrial revolution along with these challenges, the study proposes that the industry should first focus on 3D printing, artificial intelligence, machine learning, and robots.
- Intense and efficient use of data to make processes more responsive and efficient may be the next priority.
- Adoption of other advanced technologies shall follow in the due course of time.

There is a wide range of technologies which re coming up under the umbrella of Industry 4.0, nine of them are more popular. Also the benefits of I4.0 implementation are many-fold. Since the concept is new and even experts in this area may not be fully aware of the technologies and their implementation, only some of them were included in the study. Similarly, benefits have been clubbed into three to make comparisons easy. The study is likely to suffer from the following limitations- simplification and consideration of limited variables, the number of experts who have participated in the survey, and subjective measurement of the variables. Future researchers may take care of such limitations by increasing the number of experts, considering specific technologies and benefits, limiting the scope of industry with in the manufacturing sector, and choosing other MCDM techniques like Analytic network process (ANP).

References

Alcacer, V. and Cruz-Machado, V. (2019), Scanning the Industry 4.0: A Literature Review on Technologies for Manufacturing Systems, *Engineering Science and technology: An Int Journal*, Jan 31.

Al-Harbi, K.M.A. (2001), Application of the AHP in Project Management, *Int J of Project Management*, 19(1), 19-27.

Baswaraj, A., Rao, M.S., Pawar, P.J. (2018), Application of AHP for Process Parameter Selection and Consistency Verification in Secondary Steel Manufacturing, Materialstoday: Proceedings, 5(13), 27166-27170.

Castelo-Branco, I., Cruz-Jesus, F., Oliveira, T. (2019), Assessing Industry 4.0 Readiness in Manufacturing: Evidence for the European Union, *Computers in Industry*, 107(May), 22-32.

Dalenogare, L.S., Benitez, G.B., Ayala, N.F., Frank, A.G. (2018), The expected contribution of Industry 4.0 Technologies for Industrial Performance, *Int J of Production Economics*, 204(Oct), 383-394.

Frank, A.G., Dalenogare, L. S., Ayala, N.F. (2019), Industry 4.0 technologies: Implementation Patterns in Manufacturing Companies, *Int J of Production Economics*, 210(Apr), 15-26.

Gerbert, P., Lorenz, M., Rubmann, M., Waldner, M., Justus, J., Engel, P., Harnisch, M. (2015), Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries, https://www.bcg.com/en in/publications/2015/engineered_products_project_business_industry_4_future_productivity_growth_manufacturing_industries.aspx

Hermann, M., Pentek, T., Otto, B. (2016), Design Principles for Industrie 4.0 Scenarios, *49th Hawaii International Conference on System Sciences (HICSS), Koloa, HI*, 2928-3937.

KPMG (2018), Industry 4.0: India Inc Gearing Up For Change, KPMG-AIMA report, March.

Lin, Y.H., Tsai, K.M., Shiang, W.J., Kuo, T.C., Tsai, T.H. (2009), Research on Using ANP to Establish a Performance Assessment Model for Business Intelligence Systems, Expert System application, 36, 4135-4146.

Luthra, S. and Mangla, S.K. (2018), Evaluating Challenges to Industry 4.0 Initiatives for Supply Chain Sustainability in Emerging Economies, *Process Safety and Environmental Protection*, 117(Jul), 168-179.

Marr, B. (2018), What is Industry 4.0? Here's A Super Easy Explanation For Anyone, Sep,

Podvezko, V. (2009), Application of AHP Technique, *J of Business Economics and Management*, 10(2), 181-189.

Rojas, R.A., Rauch, E., Vidoni, R., Matt, D.T. (2017), Enabling Connectivity of Cyber-physical Production Systems: A Conceptual Framework, *Proceedia Manufacturing*, 11, 822-829.

Saaty, T.L. (1980), *The Analytic Hierarchy Process*, McGraw-Hill, New York.

Saaty, T.L. (2008), Decision Making with the Analytic Hierarchy Process, *Int J of Services Sciences*, 1(1), 83–98.

SDM (Super Decisions Manual), (2012), Version 2.2, Creative Decisions Foundation,

Zhong, R.Y., Xu, X., Klotz, E., Newman, S.T. (2017), Intelligent Manufacturing in the Context of Industry 4.0: A Review, *Engineering*, 3(5), 616-630.

Biography

Asif Akhtar is working as Assistant Professor in the Department of Business Administration at AMU. He looks after the courses in the area of Operations Management and Islamic Finance. Dr Akhter, with his basic degree Engineering, has several publications to his credit in the area of Operations and Finance.