Industry 4.0 Technologies for Sustainable Performance in Indian Manufacturing MSMEs

Darshan Pandya
Research Scholar, Operations Management
Indian Institute of Management Raipur
Raipur, India
darshan.fpm2018@iimraipur.ac.in

Gopal Kumar
Associate Professor, Operations Management
Indian Institute of Management Raipur
Raipur, India
gopalkumar@iimraipur.ac.in

Abstract

The competitiveness of a manufacturing firm largely depends on the flexibility it shows in catering sustainably to the market demands. With very little to no awareness about the global trends in sustainability, the MSMEs in developing nations are facing massive competition globally, posing a threat to their survival. Despite the potential of Industry 4.0 to make them flexible and sustainable, the managers of MSMEs find it difficult to adopt it in their firms because of their limited resources. Therefore, unbundling Industry 4.0 into its constituent technologies and prioritizing them becomes a crucial step for MSMEs. This paper aims to provide an order of preference of Industry 4.0 technologies that help achieve sustainable performance in Indian manufacturing MSMEs with the help of Analytic Hierarchy Process and Utility-function based Goal Programming. Three Industry 4.0 technologies – Predictive Analytics, Machine Learning, and Real-Time Computing – are found to be the most important Industry 4.0 technologies for sustainable performance. Sensitivity analysis of the results further confirmed the robustness of the results. Several managerial implications have been proposed along with contributions to the body of knowledge, limitations, and future research directions.

Keywords
Industry 4.0, Sustainable Performance, Sustainable Manufacturing, Indian MSMEs, MCDM.

1. Introduction
The Indian manufacturing sector is deemed to be the spine of the Indian economy with a contribution of more than 18 percent to its GDP. About 29 percent of this contribution comes from the Micro, Small and Medium Enterprises (MSMEs) (Press Information Bureau, 2019). Therefore, to stay relevant in the global manufacturing market, it is crucial for the Indian manufacturing sector to focus on the competitiveness of the MSMEs. Moreover, for remaining relevant in the global competition, MSMEs must be at par with the global trends in manufacturing. One of the most important factors that can determine the competitiveness of a manufacturing firm is its sustainability. The importance of the sustainable performance (SP) of a firm for achieving competitive advantage has been widely discussed and established in the literature (Kwarteng et al., 2016; Shahbazpour and Seidel, 2006). The social and economic fronts of sustainability have a positive effect on the competitive advantage of a firm (Cantele and Zardini, 2018).

Industry 4.0 (I4.0) can improve SP of a firm, thereby improving its competitiveness. Organizations that adopt I4.0 technologies can enhance their productivity by almost 50 percent (Caylar et al., 2016). I4.0 technologies can optimally design the manufacturing processes to improve environmental performance by reducing wastage of resources, thereby saving up on the operational costs and reducing the negative impacts on the environment (Lasi et al., 2014; Vaidya et al., 2018). It can also improve safety concerns, work stress, child labor situations, stakeholder relationships, living standard of societies, hence, it can significantly enhance firm's social performance. I4.0 has significant potential to transform economic position of firms, environmental concerns, labor markets, and social issues. I4.0 revolution is predicted disrupt the conventional job market, introduce high skill-intensive jobs, and transform the way social problems are addressed by corporate social responsibility.

Despite of the good theoretical promises of I4.0 technologies, there exists a practical inability to adopt these technologies in MSMEs, that can optimally meet the requirements of the manufacturer and serve the designated purpose. A rash strategic decision may lead to exorbitant operational costs and, ultimately, plant dysfunction. Owing to the low maturity of the previous industrial revolutions, the developing nations need to overcome lot more challenges in adopting the I4.0 technologies than those by the developed nations (Guan et al., 2006). However, most of the researchers strongly believe that the study of challenges faced in the adoption of I4.0 technologies is majorly under-investigated in the extant literature (Amaral and Peças, 2021; Horváth and Szabó, 2019; Kamble, Gunasekaran, and Gawankar, 2018; Xu et al., 2018). We conducted a series of semi-structured interviews with the executives of 9 different manufacturing MSMEs in India for further investigation of the issue at hand. Lack of knowledge of the global business trends, lack of financial resources or planning, dearth of skilled labor or non-readiness of the workforce, disorganized production planning, scheduling, and staffing, infrastructural constraints, and lack of implementation of public policies were found to be the most common reasons that hinder the MSMEs to adopt I4.0 technologies. As MSMEs possess limited resources, it is critical for them to prioritize I4.0 technologies implementation and to know which technology they should implement first.

In this light, this study investigates and uncovers most important I4.0 technologies for adoption in the Indian manufacturing MSMEs along with an order of preference of these technologies using a hybrid MCDM framework for obtaining the order of preference of the I4.0 technologies for SP. The research methodology applied in both the steps is a hybrid of two widely used MCDM techniques: Analytic Hierarchy Process (AHP) and Utility-function Based Goal Programming (UBGP). Thus, the study aims at answering the following research question:

RQ1: Which I4.0 technologies are preferable in enhancing SP of Indian manufacturing MSMEs?

The major contribution of this study is that it tries to address the research gap regarding the adoption of I4.0 technologies in the MSMEs of developing economies. Most of the existing studies related to the adoption of I4.0 either approach I4.0 as a whole concept (Luthra and Mangla, 2018; Somohano-Rodríguez et al., 2020), deal with the barriers and/or enablers of the adoption of I4.0 (Hopkins, 2021; Kamble, Gunasekaran, and Sharma, 2018; Khanzode et al., 2021; Masood and Sonntag, 2020), propose some sort of readiness or maturity model for the adoption of I4.0 (Castelo-Branco et al., 2019; Pacchini et al., 2019; Saad et al., 2021), or deal with the benefits offered by one or more I4.0 technologies (Chabanet et al., 2021; Corallo et al., 2020; Silvestri et al., 2020; Zamora-Hernández et al., 2021). As the era of I4.0 is still in its infancy, its real advantages and requirements for MSMEs are under-investigated in the literature and must be investigated thoroughly (Galati and Bigliardi, 2019). This makes it crucial to assess and prioritize the I4.0 technologies for MSMEs in emerging economies according to their requirements. This study is novel in the way that it not only views I4.0 as a collection of its constituent technologies, but also assesses them individually and prioritizes them for the enhancement of SP in Indian manufacturing MSMEs, thereby strengthening their global competitiveness.

The subsequent article is arranged as follows: section 2 presents the background for this study, section 3 discusses the research methodology elaborating upon AHP and UBGP, and data collection, section 4 presents the data analysis and results, section 5 presents the discussion, conclusions and directions for future research.

2. Literature Review

2.1 Industry 4.0 (I4.0)

The term "Industry 4.0" was initially used in the year 2011 by Germany to recognize the upcoming German Economic Policy on the development, adoption, implementation, and propagation of several innovative technological strategies (Kagermann et al., 2013). While computerization and automation had helped in creating a conducive environment for customization in the third industrial revolution, attaining the highest degree of productivity in manufacturing was still a distant dream owing to various constraints. I4.0 promises to bring about a paradigm shift in the way a traditional manufacturing unit functions, by automating, decentralizing, and optimizing all the major operations of a manufacturing unit.

Currently, I4.0 is used as an umbrella term that implies different technological configuration in different context for different firms. I4.0 has been defined in different ways by different researchers, primarily based on the technological application of its technologies. Hossain and Muhammad (2016) have focused more on the industrial IoT, Big Data analysis, cloud computing in their definition, while Kagermann et al. (2013) have oriented their definition through the lens of cyber-physical systems. It can be viewed as a cluster of many frontier technologies and novel concepts that include Predictive Analytics, Machine Learning, the Internet of Things (IoT), Radio-Frequency Identification, Cloud Computing, Big Data, Extended Reality, Additive Manufacturing, Robotics, Automated Guided Vehicles, and Additive Manufacturing (Frank et al., 2019; Li, 2018). Literature enables us to identify major I4.0 technologies which along with their definition are presented in Table 1.

Table 1. List of I4.0 technologies and their definitions/descriptions

I4.0 technologies	Definitions/Descriptions
Additive Manufacturing	"A process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies." (American Society for Testing Materials, 2012)
Automated Guided Vehicles	"Automated guided vehicles are unmanned vehicles used to transport unit loads, large or small, from one location on the factory floor to another." (Gaskins and Tanchoco, 1987)
Internet of Things	"A world where physical objects are seamlessly integrated into the information network, and where the physical objects can become active participants in business process." (Haller et al., 2009)
Extended Reality	"Extended reality (XR) is a term referring to all real-and-virtual combined environments and human-machine interactions generated by computer technology and wearables." (Fast-Berglund et al., 2018)
Auto-ID	"Automated identification involves the automated extraction of the identity of an object." (McFarlane et al., 2003)
Real-Time Computing	"Real-time systems are computing systems that must react with the precise time constraints to events in the environment." (Buttazzo, 2011)
Predictive Analytics	"Predictive analytics is a set of business intelligence (BI) technologies that uncovers relationships and patterns within large volumes of data that can be used to predict behaviour and events." (Eckerson, 2007)
Machine Learning	"Algorithms that process and extract information from data and facilitate automation of tasks and augment human domain knowledge." (Brunton et al., 2020)
Robotics	"The scientific and engineering discipline concerned with the creation, composition, structure, evaluation and properties of embodied artificial capabilities." (Redfield, 2019)
Drones	"A drone is an aircraft that can fly without a human pilot on board and are typically small aircrafts made of lightweight materials." (Hayhurst et al., 2006)
Big Data	"Big Data is a data analysis methodology enabled by recent advances in technologies that support high-velocity data capture, storage and analysis." (Zakir et al., 2015)
Cybersecurity	"Cybersecurity is the organization and collection of resources, processes, and structures used to protect cyberspace and cyberspace-enabled systems from occurrences that misalign de jure from de facto property rights." (Craigen et al., 2014)

2.2 Sustainable Performance (SP)

SP refers to the performance of a firm across three major fronts: economic, environment, and social performance (Vachon and Klassen, 2006). It is crucial for all firms to strive for SP in this era. It is also measured with various approaches like surveys, investor schemes, sustainability indices, accreditation processes, non-quantifiable sustainability initiatives (Székely and Knirsch, 2005). In earlier days, the performance assessment was focused only on the economic performance of any organization (Richardson and Gordon, 1980). With the advent of concepts like sustainability (Elkington, 1994), where environmental and social aspects were also involved, the performance was assessed based on these added aspects. For better environmental performance, technological advancement must make minimal impact on the environment. It thus brings in the concept of optimal consideration of the economic, social, and environmental performance, i.e., SP of an organization. From literature different measures of economic, environmental, and societal performance are identified as shown in Table 2.

Table 2. List of factors of SP for a manufacturing firm

	SP Factor	Nature	References
Environmental	CO_2 emission	Lower the better	(Garetti and Taisch, 2012)
	Waste generation	Lower the better	(Sarkis, 2001)
	Energy efficiency	Higher the better	(Yusuf et al., 2013)
	Production of hazardous substances	Lower the better	(Veleva and Ellenbecker, 2001)
	Compliance with environmental standards	Higher the better	(King and Lenox, 2017)
Economic	Product Quality	Higher the better	(Rao and Holt, 2005)
	Order Delivery and Flexibility	Higher the better	(Vachon and Klassen, 2006)
	Manufacturing Cost	Lower the better	(Carter et al., 2000)
	Market Share	Higher the better	(Yang et al., 2011)
Social	Relationships with stakeholders	Higher the better	(Falck and Heblich, 2007)
	Occupational safety	Higher the better	(Fernández-Muñiz et al., 2009)
	Work environment	Higher the better	(Hansen and Wernerfelt, 1989)
	Quality of life of surrounding communities	Higher the better	(Mustofa et al., 2021)

2.3 Industry 4.0 for SP

Productivity and, subsequently, SP can be further aided and enhanced with the implementation of emerging technologies (Fragapane et al., 2020). I4.0 promotes virtualization, decentralization, and digital network building which are expected to transform existing production environment (Schwab, 2017). I4.0 technologies can make firms more flexible and sustainable by improving product customization, automation processes, energy efficiency, product quality, productivity, sustainability, safety, decision-making processes, demand-supply of skills, etc. (Kamble, Gunasekaran, and Gawankar, 2018). Acquiring an internal process using I4.0 technologies such as blockchain can lead to the improved relational social capital of a firm by building trust between buyers and suppliers (Benzidia, 2021). Also, the potential of I4.0 technologies in developing the managerial competencies of a firm to enhance the social sustainability front is tremendous and can be boosted with other socio-behavioral competences like co-opetition, empathy, open-mindedness, and motivation (Shet and Pereira, 2021).

2.3.1 The Internet of Things (IoT)

IoT is another fundamental characteristic of I4.0 which helps establish real-time global communication and transmission of data. IoT can improve the distribution network of smart power grids, enabling smaller industrial hubs to make use of the localized sources of renewable energy instead of environmentally harmful conventional sources used in the traditional power grid models, especially during high demand of power (Babar et al., 2020). IoT can provide real-time information of the undulations in electricity generation, that can help capture the full potential of non-conventional energy sources. Hence, the applications of IoT can help the MSMEs achieve environmental sustainability. Also, IoT wearable devices can be worn by the employees of a firm that can constantly track their health vitals, location, and elevation, which can then serve as an important input for enhancing the social sustainability front. Such IoT systems can be embedded across the members of supply chain for monitoring the order delivery and quality of the raw materials, thereby enhancing the economic sustainability front.

2.3.2 Cloud Computing (CC) and Big Data (BD)

CC can help a firm use the materials efficiently, minimize the use of hazardous substances, and reduce affluents generated in the process (Schniederjans and Hales, 2016), thereby increasing the environmental sustainability of the MSMEs. Moreover, CC and BD, can create an ecosystem that allows all the participants of a firm to share important information in real-time, including the customers. This can help the MSMEs to capture consumer behavior patterns and have an edge by having a better understanding of the customer demands and strategize accordingly, thereby boosting the economic sustainability front of MSMEs. BD related technologies can be used to capture the response of their consumers on social media towards the CSR activities undertaken by the firm. The unstructured data can then be stored on cloud and analyzed to understand the nuances in the public responses, refine their CSR initiatives, and improve their social sustainability front. Therefore, CC and BD, enables transparency and empowerment, leading to improved flexibility and social sustainability front respectively.

2.3.3 Machine Learning (ML)

ML and ANN can help in virtually measuring the environmental impact due to the manufacturing unit with the addition or removal of any process during a simulation. This may reduce the need to test a process using real raw materials, the waste generated in the process, thereby leading towards a better environmental sustainability. The organizations with more savings on resources and reduced environmental impact may dedicate more financial resources for corporate social responsibility (CSR) initiatives leading to better social performance of the MSMEs. ML can also help the analysis of the data collected from the social media regarding the CSR activities and can help the firm identify the social expectations of their consumers. This can help the firm to refine their CSR objectives further, thereby leading towards better social sustainability fronts.

2.3.4 Predictive Analytics (PA)

PA can help in reducing resource usage by making accurate predictive maintenance schedules. It can significantly help in identifying the potential sources of waste generation within a system and can also come up with better models of material procurement for waste reduction, leading the MSMEs to have enhanced environmental sustainability fronts. PA can also help the firm in recognizing potentially malicious financial or inventory transactions by monitoring and analyzing the historical behavior of transactions by the actors of the supply chain and flagging the transactions that digress from the standard behavior. This can help the MSMEs along the economic sustainability front. The same technique can be applied to identify the usual occupational hazard patterns in a plant and predict potential accidents beforehand, improving the occupational safety of the workers as well as the social sustainability front of MSMEs.

2.3.5 Drones, Robots and Auto-ID

Drones have the potential to either bypass ground-based traffic congestion or avoid congestion by lifting a share of ground transportation into airspace. Similarly, autonomous robots seem to have a high impact in the hazardous chemical manufacturing industries, where either human workforce is prone to chemical hazard, or the production process needs to be rid of human touch. By classifying the production processes in terms of the risk involved, human workforce can be appointed to relatively safer departments and robots can take care of the riskier ones. This can help the MSMEs on the occupational safety and social sustainability front. Robots may be sometimes adapted in the form of automated guided vehicles to ensure a flexible internal supply chain within a manufacturing setup. Auto-ID, when clubbed with the drones and automated vehicles, can be used to extract, or track identity of products, materials, or machines. It can reduce inventory level, generate real-time inventory and product information, and support ability to rapidly customize products, thereby improving the material handling capabilities of a manufacturing unit and leading to improved economic sustainability of MSMEs.

2.3.6 Additive Manufacturing (AM)

AM deposits molten raw material layer by layer to manufacture a product. It follows a bottom-up process of manufacturing products and can minimize wastage of raw material. The cost vs benefit ratio is huge in AM, especially while working with expensive raw materials such as titanium or nickel-alloy steels, as it can significantly reduce the material and energy costs. This helps the MSMEs to achieve a better environmental as well as economic sustainability. AM has tremendous applications in making quick and affordable orthopedic casts for patients with bone. Installing such facility in a manufacturing firm, where the processes pose accidental risks to the workers, can help improve the first aid procedure, thereby enhancing the social sustainability front of the MSMEs.

3. Research Methodology

3.1 Analytic Hierarchy Process (AHP)

AHP was established by Saaty (1980) in order to obtain the relative priorities of a group of alternatives. A significant advantage of this technique is that it enables the consolidation of a set of intangible qualitative decisions vis-à-vis tangible quantitative criteria. It deconstructs a highly complex MCDM problem into a simpler decision hierarchy with a minimum of 3 levels: alternatives of the decision at the bottom, criteria in the middle, and the goal of the problem at the top. This helps in making a pairwise comparison from the second level of the hierarchy to the lowermost level to obtain the relative importance of the elements of one level based on the elements in the immediately upper level of the hierarchy.

3.2 Utility-function Based Goal Programming (UBGP)

Goal programming (GP) is a binary integer programming formulation where the objective is to obtain the alternative from a given set of alternatives that are as close as possible to the otherwise simultaneously unattainable goals. One shortcoming of GP is that it treats all the goals and their corresponding values of acceptable levels equally. This results in minimizing only those deviation variables that are associated with larger values of an acceptable level, leading to skewed decision making. This shortcoming of GP is eliminated by normalizing the values of all the goals to fall between the range of [0,1] using the linear utility functions given by Lai and Hwang (1994). The GP formulation would now consider these normalized values in its constraints known as UBGP. The utility functions are applied to the criteria according to the category under which they fall: (a) Higher-the-better or (b) Lower-the-better. Further, UBGP requires only one deviation variable for each constraint as the values now range from 0 to 1, with 0 meaning the least preferable and 1 meaning the most preferable.

4. Analysis and Results

This research begins with the review of existing literature to understand existing studies on I4.0 technologies and related literature gaps. To get practitioners' view on I4.0 technologies, an expert decision-making team (EDMT) (Table 3) was formed that included the managers and proprietors of several manufacturing MSMEs for decision-making. The designations of the experts convey that they are informed about the I4.0 technologies. In addition, we confirmed their expertise on I4.0 technologies and then briefed them about the purpose of the study, I4.0 and SP. They were provided with the various aspects of SP and how they affect the competitiveness of a firm. Thus, it was ensured that the participants had sufficient knowledge and the background to justify the results of the study.

Table 3. Profile of the EDMT

Characteristics	Position	Frequency	Percentage
Job Title	Proprietor (Company head/top management)	11	52.38%
	Production Manager	5	23.81%
	Managing Director	3	14.29%
	Administrative Manager	1	4.76%
	Inventory Store Manager	1	4.76%
Experience (in Years)	0-5	2	9.52%
	6-10	3	14.29%
	11-15	4	19.05%
	16-20	2	9.52%
	21-25	4	19.05%
	>25	6	28.57%
Industry	Engineering Works	3	14.29%
	Plastic Products	3	14.29%
	Electrical Equipment	2	9.52%
	Food and FMCG	4	19.05%
	Others	9	42.86%

Expert team determined 8 most important I4.0 technologies to improve SP of firms. These technologies are alternatives which require to be ranked. In the next step, based on literature review, criteria to assess SP were finalized. A total of 13 essential criteria that have significant impact on the SP (Table 2) of Indian MSMEs were identified from extant literature and finalized by the expert team.

After the data collection from the experts, the AHP-UBGP analysis was carried out for identifying the best I4.0 technologies for SP. The ranking of the both the results were then subjected to sensitivity analysis to check for the robustness of the results. In first step, criteria for SP are identified. This was followed by structuring a decision hierarchy in a tree like structure that connects goal (i.e., the root node), criteria (i.e., EN1-SO4), and alternatives (i.e., B1-B8) as shown in Figure 1.

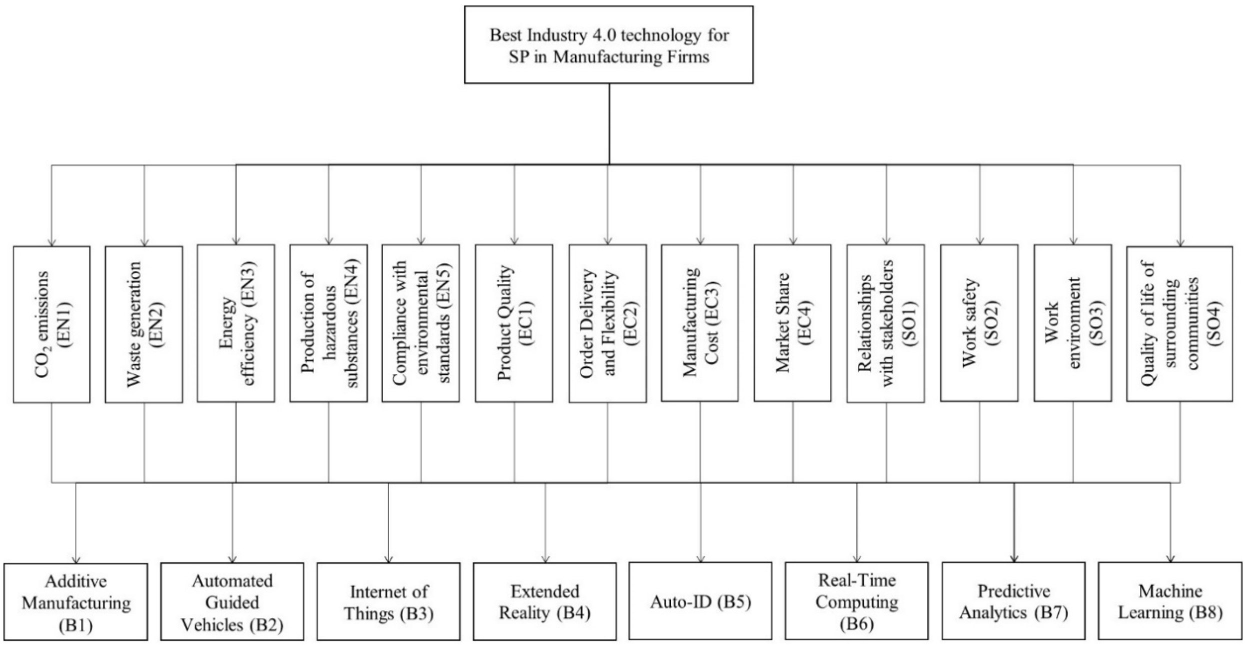

Figure 1. Decision hierarchy for the selection of I4.0 technologies in terms of SP

In the second step, pairwise comparison of alternatives (I4.0 technologies) for each factor of SP to obtain normalized principal eigenvectors was performed. Experts were then asked to make pairwise comparison matrices of the alternatives, i.e., the I4.0 technologies, based on each criterion using a standard AHP scale given by Saaty (2008). Evaluating pairwise comparison matrices of alternatives for all the criteria provided us with 13 sets of normalized principal eigenvectors (one set for each factor of SP). These were arranged to form a matrix with technologies across the rows and SP factors along the columns, as shown in Table 4.

Table 4. Composite matrix formed by arranging all the normalized principal eigenvectors

	EN1	EN2	EN3	EN4	EN5	EC1	EC2	EC3	EC4	SO1	SO2	SO3	SO4
B1	0.090	0.110	0.125	0.100	0.091	0.182	0.067	0.182	0.070	0.059	0.048	0.084	0.074
B2	0.118	0.089	0.081	0.081	0.089	0.053	0.165	0.095	0.039	0.068	0.098	0.088	0.105
B3	0.075	0.082	0.093	0.079	0.138	0.097	0.139	0.076	0.174	0.114	0.117	0.202	0.163
B4	0.070	0.098	0.053	0.104	0.076	0.060	0.065	0.053	0.100	0.098	0.101	0.121	0.097
B5	0.106	0.089	0.075	0.096	0.079	0.078	0.120	0.080	0.054	0.078	0.056	0.088	0.053
B6	0.152	0.116	0.104	0.152	0.112	0.160	0.155	0.127	0.104	0.111	0.111	0.107	0.088
B7	0.262	0.281	0.243	0.213	0.183	0.165	0.098	0.224	0.244	0.322	0.242	0.126	0.151
B8	0.150	0.170	0.247	0.147	0.195	0.168	0.141	0.141	0.222	0.198	0.230	0.146	0.315

In the third step, order of preference of I4.0 technologies for SP was obtained. The factors of SP were classified into two categories: (a) Higher-the-better and (b) Lower-the-better as shown in Table 2. Then the matrix obtained in Step 2 (i.e., Table 4) was transformed into a utility-function based normalized matrix as shown in Table 5 using the utility functions developed by Lai and Hwang (1994). This was followed by the goal programming formulation of the problem, with I4.0 technologies as the alternatives and the factors of SP as goals. The UBGP problem for obtaining the order of preference of I4.0 technologies for SP was formulated as follows:

Consider the following decision variables and parameters:

$$X_i = \begin{cases} 1, \text{if } i^{th} \text{ technology is selected} \\ 0, \text{otherwise} \end{cases} \quad \forall i \in \{1, 2, \dots, 8\}$$

d_j = deviation from the ideal solution for j^{th}goal $\forall j \in \{1, 2, \ldots, 13\}$
A_{ij} = element of i^{th} row and j^{th} column of utility function based normalized matrix $\forall i \in \{1, 2, \ldots, 8\}, \forall j \in \{1, 2, \ldots, 13\}$

Minimize : $\sum_{j=1}^{13} d_j$
Subject to : (a) $d_j + \sum_{i=1}^{8} A_{ij} X_i = 1 \; \forall j \in \{1, 2, \ldots, 13\}$ Eq. (1)
(b) $\sum_{i=1}^{8} X_i = 1$ Eq. (2)
(c) $d_j \geq 0 \; \forall j$ Eq. (3)

As discussed earlier, the process of solving the formulation was repeated eight times to obtain the order of preference of I4.0 technologies for SP of an Indian manufacturing MSME and results are shown in Table 5.

Table 5. Utility-function based normalized matrix with order of preference of I4.0 technologies for SP

	EN1	EN2	EN3	EN4	EN5	EC1	EC2	EC3	EC4	SO1	SO2	SO3	SO4	Rank
B1	0.894	0.859	0.374	0.841	0.129	1.000	0.028	0.246	0.153	0.000	0.000	0.000	0.080	5
B2	0.750	0.964	0.142	0.986	0.105	0.000	1.000	0.754	0.000	0.036	0.259	0.033	0.196	6
B3	0.973	1.000	0.205	1.000	0.516	0.343	0.736	0.863	0.660	0.211	0.358	1.000	0.420	4
B4	1.000	0.917	0.000	0.812	0.000	0.052	0.000	1.000	0.296	0.151	0.275	0.317	0.168	7
B5	0.809	0.964	0.116	0.870	0.024	0.194	0.547	0.840	0.074	0.072	0.041	0.033	0.000	8
B6	0.569	0.828	0.263	0.457	0.298	0.828	0.896	0.566	0.315	0.199	0.326	0.195	0.132	3
B7	0.000	0.000	0.979	0.000	0.895	0.866	0.330	0.000	1.000	1.000	1.000	0.358	0.372	1
B8	0.580	0.557	1.000	0.493	1.000	0.896	0.755	0.486	0.892	0.530	0.938	0.528	1.000	2

5. Discussion, Conclusion and Directions for Future Research

The manufacturing MSMEs are one of the crucial drivers of the economy, especially in the developing economies. Therefore, focusing on the competitiveness of the MSMEs is very important. Concepts like SP, which is a strong determinant of the competitiveness of a firm and is globally well known in the field of operations and production management, are pretty alien to most of the managers of MSMEs of developing economies. This poses a threat to their survival in the global competition. I4.0 has the potential to improve the SP of a manufacturing firm, but the interviews conducted by us revealed that there are several barriers that hinder the managers of MSMEs to adopt the I4.0 technologies, with the lack of financial resources and lack of knowledge of the I4.0 technologies being the most important reasons. Thus, it becomes important to understand the specific needs of a manufacturing firm and prioritize the I4.0 technologies that can cater to these needs in the best way possible. Hence, the most preferable I4.0 technologies for achieving SP in manufacturing MSMEs were identified using a combination of two methods – AHP and UBGP.

We find the order of importance of I4.0 technologies for SP in decreasing order as: Predictive Analytics, Machine Learning, Real-time Computing, Internet of Things, Additive Manufacturing, Automated Guided Vehicles, Extended Reality, and Auto-ID. The contributions of this study are as follows. Firstly, it helps the managers of manufacturing MSMEs to prioritize the adoption I4.0 technologies that can create the maximum impact on their SP, thereby their global competitiveness. Secondly, it tries to address the research gap regarding the adoption of I4.0 in developing economies. There is dearth of research in the mentioned area of research, with very few studies that aim at prioritizing the I4.0 technologies in MSMEs. This study also brings about the idea of unbundling of I4.0 into its constituent technologies, which has been hardly touched upon the existing literature.

This study has few limitations which should be addressed in future research. As we have collected data from the Indian MSMEs, other research with data from other developing economies can validate our findings. Future studies should also address technologies requirements in other sectors, such as agriculture, healthcare, mining, construction to obtain a better understanding of the utilities of such technologies in those sectors. Another scope for future research is to conduct similar studies within a specific sector of manufacturing, such as pharmaceutical, electronics, or automobile.

References

Amaral, A. and Peças, P., SMEs and Industry 4.0: Two case studies of digitalization for a smoother integration, *Computers in Industry*, vol. 125, pp. 103333, 2021.

American Society for Testing Materials, *Standard terminology for additive manufacturing technologies,* ASTM International, 2012.

Babar, M., Tariq, M. U. and Jan, M. A., Secure and resilient demand side management engine using machine learning for IoT-enabled smart grid, *Sustainable Cities and Society*, vol. 62, pp. 102370, 2020.

Benzidia, S., Impact of ambidexterity of blockchain technology and social factors on new product development: A supply chain and Industry 4.0 perspective, *Technological Forecasting*, vol. 13, 2021.

Brunton, S. L., Noack, B. R. and Koumoutsakos, P., Machine Learning for Fluid Mechanics, *Annual Review of Fluid Mechanics*, vol. 52(1), pp. 477–508, 2020.

Buttazzo, G. C., *Hard real-time computing systems: Predictable scheduling algorithms and applications*, Vol. 24, Springer Science and Business Media, 2011.

Cantele, S. and Zardini, A., Is sustainability a competitive advantage for small businesses? An empirical analysis of possible mediators in the sustainability–financial performance relationship, *Journal of Cleaner Production*, vol. 182, pp. 166–176, 2018.

Carter, C. R., Kale, R. and Grimm, C. M., Environmental purchasing and firm performance: An empirical investigation, *Transportation Research Part E: Logistics and Transportation Review*, vol. 36(3), pp. 219–228, 2000.

Castelo-Branco, I., Cruz-Jesus, F. and Oliveira, T. Assessing Industry 4.0 readiness in manufacturing: Evidence for the European Union, *Computers in Industry*, vol. 107, pp. 22–32, 2019.

Caylar, P.-L., Noterdaeme, O. and Naik, K., Digital in industry: From buzzword to value creation, *McKinsey and Company*, 2016.

Chabanet, S., Bril El-Haouzi, H. and Thomas, P., Coupling digital simulation and machine learning metamodel through an active learning approach in Industry 4.0 context, *Computers in Industry*, vol. 133, pp. 103529, 2021.

Corallo, A., Lazoi, M. and Lezzi, M., Cybersecurity in the context of industry 4.0: A structured classification of critical assets and business impacts, *Computers in Industry*, vol. 114, pp. 103165, 2020.

Craigen, D., Diakun-Thibault, N. and Purse, R., Defining cybersecurity, *Technology Innovation Management Review*, vol. 4, no. 10, 2014.

Eckerson, W. W., Predictive analytics, *Extending the Value of Your Data Warehousing Investment. TDWI Best Practices Report*, vol. 1, pp. 1–36, 2007.

Elkington, J., Towards the Sustainable Corporation: Win-Win-Win Business Strategies for Sustainable Development, *California Management Review*, vol. 36(2), pp. 90–100, 1994.

Falck, O. and Heblich, S., Corporate social responsibility: Doing well by doing good, *Business Horizons*, vol. 50(3), pp. 247–254, 2007.

Fast-Berglund, Å., Gong, L. and Li, D., Testing and validating Extended Reality (xR) technologies in manufacturing, *Procedia Manufacturing*, vol. 25, pp. 31–38, 2018.

Fernández-Muñiz, B., Montes-Peón, J. M. and Vázquez-Ordás, C. J., Relation between occupational safety management and firm performance, *Safety Science*, vol. 47(7), pp. 980–991, 2009.

Fragapane, G., Ivanov, D., Peron, M., Sgarbossa, F. and Strandhagen, J. O., Increasing flexibility and productivity in Industry 4.0 production networks with autonomous mobile robots and smart intralogistics, *Annals of Operations Research*, 2020.

Frank, A. G., Dalenogare, L. S. and Ayala, N. F., Industry 4.0 technologies: Implementation patterns in manufacturing companies, *International Journal of Production Economics*, vol. 210, pp. 15–26, 2019.

Galati, F. and Bigliardi, B., Industry 4.0: Emerging themes and future research avenues using a text mining approach, *Computers in Industry*, vol. 109, pp. 100–113, 2019.

Garetti, M. and Taisch, M., Sustainable manufacturing: Trends and research challenges, *Production Planning and Control*, vol. 23(2–3), pp. 83–104, 2012.

Gaskins, R. J. and Tanchoco, J. M. A., Flow path design for automated guided vehicle systems, *International Journal of Production Research*, vol. 25(5), pp. 667–676, 1987.

Guan, J. C., Mok, C. K., Yam, R. C. M., Chin, K. S. and Pun, K. F., Technology transfer and innovation performance: Evidence from Chinese firms, *Technological Forecasting and Social Change*, vol. 73(6), pp. 666–678, 2006.

Haller, S., Karnouskos, S. and Schroth, C., The Internet of Things in an Enterprise Context, *Future Internet – FIS 2008*, vol. 5468, pp. 14–28, 2009.

Hansen, G. S. and Wernerfelt, B., Determinants of firm performance: The relative importance of economic and organizational factors, *Strategic Management Journal*, vol. 10(5), pp. 399–411, 1989.

Hayhurst, K. J., Maddalon, J. M., Miner, P. S., DeWalt, M. P. and McCormick, G. F., Unmanned aircraft hazards and their implications for regulation, *Ieee/Aiaa 25TH Digital Avionics Systems Conference*, vol. 1–12, 2006.

Hopkins, J. L., An investigation into emerging industry 4.0 technologies as drivers of supply chain innovation in Australia, *Computers in Industry*, vol. 125, pp. 103323, 2021.

Horváth, D. and Szabó, R. Zs., Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities?, *Technological Forecasting and Social Change*, vol. 146, pp. 119–132, 2019.

Hossain, M. S. and Muhammad, G., Cloud-assisted Industrial Internet of Things (IIoT) – Enabled framework for health monitoring, *Computer Networks*, vol. 101, pp. 192–202, 2016.

Kagermann, H., Wahlster, W. and Helbig, J., Securing the future of German manufacturing industry: Recommendations for implementing the strategic initiative INDUSTRIE 4.0, *Final Report of the Industrie 4.0*, 2013.

Kamble, S. S., Gunasekaran, A. and Gawankar, S. A., Sustainable Industry 4.0 framework: A systematic literature review identifying the current trends and future perspectives, *Process Safety and Environmental Protection*, vol. 117, pp. 408–425, 2018.

Kamble, S. S., Gunasekaran, A. and Sharma, R., Analysis of the driving and dependence power of barriers to adopt industry 4.0 in Indian manufacturing industry, *Computers in Industry*, vol. 101, pp. 107–119, 2018.

Khanzode, A. G., Sarma, P. R. S., Mangla, S. K. and Yuan, H., Modeling the Industry 4.0 adoption for sustainable production in Micro, Small and Medium Enterprises, *Journal of Cleaner Production*, vol. 279, pp. 123489, 2021.

King, A. A. and Lenox, M., Does it really pay to be green? An empirical study of firm environmental and financial performance, *Corporate Environmental Responsibility*, vol. 5(1), pp. 311–322, 2017.

Kwarteng, A., Dadzie, S. A. and Famiyeh, S., Sustainability and competitive advantage from a developing economy, *Journal of Global Responsibility*, vol.7(1), pp. 110–125, 2016.

Lai, Y.-J. and Hwang, C.-L., *Fuzzy Multiple Objective Decision Making*, Vol. 404, Springer Berlin Heidelberg, 1994.

Lasi, H., Fettke, P., Kemper, H.-G., Feld, T. and Hoffmann, M., Industry 4.0, *Business and Information Systems Engineering*, vol. 6(4), pp. 239–242, 2014.

Li, L., China's manufacturing locus in 2025: With a comparison of "Made-in-China 2025" and "Industry 4.0.", *Technological Forecasting and Social Change*, vol. 135, pp. 66–74, 2018.

Luthra, S. and Mangla, S. K., Evaluating challenges to Industry 4.0 initiatives for supply chain sustainability in emerging economies, *Process Safety and Environmental Protection*, vol. 117, pp. 168–179, 2018.

Masood, T. and Sonntag, P., Industry 4.0: Adoption challenges and benefits for SMEs, *Computers in Industry*, vol. 121, pp. 103261, 2020.

McFarlane, D., Sarma, S., Chirn, J. L., Wong, C. Y. and Ashton, K., Auto ID systems and intelligent manufacturing control, *Engineering Applications of Artificial Intelligence*, vol.16, no. 4, pp. 365–376, 2003.

Mustofa, R., Respati, H. and Natsir, M., *The Influence of Corporate Social Responsibility Goal, Corporate Social Issues, Corporate Relation Programs on Community Wellness*, vol. 6, no. 2, pp. 8, 2021.

Pacchini, A. P. T., Lucato, W. C., Facchini, F. and Mummolo, G., The degree of readiness for the implementation of Industry 4.0, *Computers in Industry*, vol. 113, pp. 103125, 2019.

Press Information Bureau, *First Advance Estimates of National Income, 2018-19*, Ministry of Statistics and Programme Implementation, Government of India, 2019.

Rao, P. and Holt, D., Do green supply chains lead to competitiveness and economic performance?, *International Journal of Operations and Production Management*, vol. 25(9), pp. 898–916, 2005.

Redfield, S., A definition for robotics as an academic discipline, *Nature Machine Intelligence*, vol. 1(6), pp. 263–264, 2019.

Richardson, P. R. and Gordon, J. R. M., Measuring Total Manufacturing Performance, *Sloan Management Review*, vol. 21(2), pp. 47–58, 1980.

Saad, S. M., Bahadori, R. and Jafarnejad, H., The smart SME technology readiness assessment methodology in the context of industry 4.0, *Journal of Manufacturing Technology Management*, vol. 32(5), pp. 1037–1065, 2021.

Saaty, T. L., The analytical hierarchy process, planning, priority, *Resource Allocation,* RWS Publications, USA, 1980.

Saaty, T. L., Decision making with the analytic hierarchy process, *International Journal of Services Sciences*, vol. 1, pp. 83, 2008.

Sarkis, J., Manufacturing's role in corporate environmental sustainability Concerns for the new millennium, *International Journal of Operations and Production Management*, vol. 21(5–6), pp. 666–686, 2001.

Schniederjans, D. G. and Hales, D. N., Cloud computing and its impact on economic and environmental performance: A transaction cost economics perspective, *Decision Support Systems*, vol. 86, pp. 73–82, 2016.

Schwab, K, *The Fourth Industrial Revolution,* Currency, 2017.

Shahbazpour, M. and Seidel, R. H., *Using Sustainability for Competitive Advantage*, vol. 6, 2006.

Shet, S. V. and Pereira, V., Proposed managerial competencies for Industry 4.0 – Implications for social sustainability, *Technological Forecasting and Social Change*, vol. 173, pp. 121080, 2021.

Silvestri, L., Forcina, A., Introna, V., Santolamazza, A. and Cesarotti, V., Maintenance transformation through Industry 4.0 technologies: A systematic literature review, *Computers in Industry*, vol. 123, pp. 103335, 2020.

Somohano-Rodríguez, F. M., Madrid-Guijarro, A. and López-Fernández, J. M., Does Industry 4.0 really matter for SME innovation?, *Journal of Small Business Management*, vol. 1, pp. 28, 2020.

Székely, F. and Knirsch, M., Responsible leadership and corporate social responsibility: Metrics for sustainable performance, *European Management Journal*, vol. 23(6), pp. 628–647, 2005.

Vachon, S. and Klassen, R. D., Extending green practices across the supply chain: The impact of upstream and downstream integration, *International Journal of Operations and Production Management*, vol. 26(7), pp. 795–821, 2006.

Vaidya, S., Ambad, P. and Bhosle, S., Industry 4.0 – A Glimpse, *Procedia Manufacturing*, vol. 20, pp. 233–238, 2018.

Veleva, V., and Ellenbecker, M. (2001). Indicators of sustainable production: Framework and methodology. *Journal of Cleaner Production*, *9*(6), 519–549. https://doi.org/10.1016/S0959-6526(01)00010-5

Xu, L. D., Xu, E. L. and Li, L., Industry 4.0: State of the art and future trends, *International Journal of Production Research*, vol. 56(8), pp. 2941–2962, 2018.

Yang, M. G. (Mark), Hong, P. and Modi, S. B., Impact of lean manufacturing and environmental management on business performance: An empirical study of manufacturing firms, *International Journal of Production Economics*, vol. 129(2), pp. 251–261, 2011.

Yusuf, Y. Y., Gunasekaran, A., Musa, A., El-Berishy, N. M., Abubakar, T. and Ambursa H. M., The UK oil and gas supply chains: An empirical analysis of adoption of sustainable measures and performance outcomes, *International Journal of Production Economics*, vol. 146(2), pp. 501–514, 2013.

Zakir, J., Seymour, T. and Berg, K., Big Data Analytics, *Issues in Information Systems*, vol. 16(2), 2015.

Zamora-Hernández, M.-A., Castro-Vargas, J. A., Azorin-Lopez, J. and Garcia-Rodriguez, J., Deep learning-based visual control assistant for assembly in Industry 4.0, *Computers in Industry*, vol. 131, pp. 103485, 2021.

Biographies

Darshan Pandya, B.Tech. (Mechanical Engineering), is a full time Research Scholar in the Operations Management Department at the Indian Institute of Management Raipur, India. He has completed his graduation as a Mechanical Engineer form the Charotar University of Science and Technology, Anand, India. Currently, he is working under Prof. Gopal Kumar in Industry 4.0 technology management at the Indian Institute of Management Raipur. His primary research interests include supply chain collaboration, sustainable and green supply chain collaboration, sourcing, product-service systems, big data analytics, business process automation, and information technology application in improving and optimizing operations of SMEs.

Gopal Kumar, Ph.D. is Assistant Professor of Operations Management at the IIM Raipur. He received his PhD in supply chain collaboration from the IIT Kharagpur and M. Tech. in Industrial Engineering and Management from IIT Kharagpur. He carried postdoctoral research at Dublin City University (DCU), Ireland. He has shop floor industrial experience in improving operations and process flow. He worked on facilitating easy access of advanced predictive modelling for improving productivity of SMEs in Europe in collaboration with various European SMEs—Ceramicx Ireland, Vistakon, ICMR—and University of Edinburgh, UK. Based on open-source philosophy, he developed a commercial tool, for European Union, which largely streamlined the expertise and time required for predictive modelling along with process optimization. He also has experience in ERP and Forecasting Module development. He has good experience in deploying various W3C standards for making operations smooth. His research articles are published in various prestigious peer reviewed journals. He presented his research work at several globally recognized Operations and Supply Chain Management forum. His primary research interests include supply chain collaboration, sustainable and green supply chain collaboration, sourcing, product-service systems, big data analytics, business process automation, and information technology application in improving and optimizing operations of SMEs.