Evaluating challenges to Industry 4.0 initiatives for supply chain sustainability in emerging economies

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Abstract: Industry 4.0 initiatives can influence whole business system via transforming the means the products are designed, produced, delivered and discarded. Industry 4.0 is relatively novel to developing nations, especially in India and needs a clear definition for proper understanding and practice in business. This paper aims to recognize key challenges to Industry 4.0 initiatives and analyze the identified key challenges to prioritize them for effective Industry 4.0 concepts for supply chain sustainability in emerging economies by taking Indian manufacturing industry perspective. Industry 4.0 initiatives can help industries to incorporate environmental protection and control initiatives as well as process safety measures in supply chains towards sustainable supply chains. However, adoption of Industry 4.0 initiatives are not so easy due to existence of many challenges. Therefore, the present research identifies 18 key challenges to Industry 4.0 initiatives for developing supply chain sustainability using an extensive literature review. These challenges were analyzed through 96 responses received from Indian manufacturing sector using a questionnaire based survey. Explanatory Factor Analysis results classified identified challenges into four key dimensions of challenges. Analytical Hierarchy Process further ranks the identified dimensions of challenges and related challenges. Findings of the study revealed that Organizational challenges holds the highest importance followed by Legal and ethical issues, Strategic challenges, and Technological challenges. This work is very useful for practitioners, policy makers, regulatory bodies and managers to develop an in-depth understanding of Industry 4.0 initiatives and eradicate the potential challenges in adopting Industry 4.0 initiatives for supply chain sustainability.

Keywords: Industry 4.0 challenges, Supply Chain Management, Sustainability, Analytical Hierarchy Process (AHP), Explanatory Factor Analysis (EFA), Emerging Economies

1. Introduction

Industry 4.0 is the current buzzword in industry (Hermann et al., 2016). In recent years, organizations are seeking to adopt sustainability aspects in their business activities (Mangla et

al., 2015; Govindan et al., 2016; Luthra et al., 2017). On the other hand, industries are struggling to fulfill the continuously changing preferences of customers along with ensuring a sustainable evolvement in business (Stock and Seliger, 2016). To create an innovative business environment, industrial managers are adopting modern technologies like 3D printing, Internet of Things, Data Analytics, Industry 4.0 (Almada-Lobo, 2016). These technologies including Industry 4.0 significantly transforming the behavior of supply chain management (SCM) (Tjahjono et al., 2017). Industry 4.0 based sustainability oriented concept helps industrial managers not only to incorporate environmental protection and control initiatives but also to couple process safety, such as resources efficiency, employee and community welfare, smarter and flexible processes measure in their supply chains.

The fourth industrial revolution provides tremendous industrialization growth, but may also disturb the sustainability of current industrial systems (Hermann et al., 2016; Liao et al., 2017). This may further causes earth ecological imbalance in terms of higher resources consumption, global warming, climate change problems, and higher energy requirements. In addition to this, rapid industrialization also contributes to degradation of health and safety of workforce. In this sense, industrial production systems need to be balanced environmentally, socially and economically in employing modern technologies. The majority of studies on Industry 4.0 considered the manufacturing sector context and ignored the supply chain system. Industry 4.0 initiatives transform a production system and supply chain into a smart production system largely based on cyber physical interaction of connected elements. This allows business process and activities to integrate and making manufacturing system more flexible, economical, and environmental friendly (Wang et al., 2016). Form an organizational supply chain context, Industry 4.0 involves several challenges like data quality and credibility, unemployment, complexity issues, less human control, and higher negative environmental impacts. Hence, rigorous research is needed to address sustainability implications in Industry 4.0 based smart industrial value chain systems (Sarkis, 2012; Schmidt et al., 2015; Stock and Seliger, 2016; Waibel et al., 2017).

Currently, Industry 4.0 is relatively novel to developing nations, especially in India and needs a clear definition for proper understanding and practice in business (Hofmann and Rüsch, 2017).

India is one of the leading emerging economies with fastest growth rate (Forbes, 2016). Indian manufacturing industry contributes 15-16% to national GDP and employs around 12% of the

working population (IBEF, 2016). Recently, to shape manufacturing sector in India, an initiative "Make in India" was launched by Honorable Prime Minister Mr. Narender Modi. The projects such as Smart City and Digital India provide enormous extent to employ Internet of things and Industry 4.0 initiatives in Indian market (Abhishek, 2017). In 2016, India's rank in the Network Readiness Index (NRI) was 91 out of 139 countries. It means that India is comparatively slow in adopting modern information technologies as compared to Malaysia and China (Grant Thornton Report, 2017). The industrial automation level in manufacturing sector is also comparatively lower in India. From managerial viewpoints, the adoption of Industry 4.0 based concepts in manufacturing is in its nascent stage in India as compared to other sectors like automotive, service management, food, energy and power sector (BRICS Business Council, 2017). Indian government seeking to develop the economy and generate employment opportunities so as employing Industry 4.0 and modern information technologies in manufacturing environment, smart cities development, and Digital India initiative (Grant Thornton Report, 2017). For developing best class manufacturing infrastructure in India, the "Make in India" initiative must be coupled with 'Industry 4.0'.

Therefore, it is important for manufacturing sector in India as an emerging economy to deal with the various challenges to Industry 4.0 initiatives in developing ecological, social, economic sustainability of supply chain. The first objective of this work is to recognize key challenges to Industry 4.0 initiatives for accomplishing sustainability orientation in supply chains. The second objective of this work is to analyze the identified key challenges with an aim to prioritize them for effective Industry 4.0 initiatives for supply chain sustainability in emerging economies in an Indian context. In this work, a questionnaire based survey is conducted (Field, 2009). This survey in conjunction with literature helps to reveals the most suitable challenges to Industry 4.0 infinitives for accomplishing sustainability orientation in supply chains. This work employs Explanatory Factor Analysis (EFA) and Analytical Hierarchy Process (AHP) based research techniques to analyze the challenges. EFA provides theoretical foundation to the challenges and classify the challenges into several dimensions for an in-depth understanding of developing supply chain sustainability through Industry 4.0 initiatives. The AHP helps to prioritize the validated challenges.

The remaining layout of the work is organized as follows. The literature related to this work is provided in the section 2. The research methodology is shown in Section 3. Data analysis and

results are presented in Section 4. Findings of the study are discussed in Section 5. Finally, conclusions along with contributions, implications of research, limitations and future potential in the area are presented in Section 6.

2. Literature Review

This section covers the literature on Industry 4.0 and sustainability in supply chain, identifies the relevant challenges to the problem and highlights the gaps for this research as well.

2.1 Industry 4.0

Over the past few years, industrial systems are influenced greatly by the introduction of the IoT and Cyber Physical networks concepts (Wollschlaeger et al., 2017). The fourth industrial revolution has gained considerable attention among researchers and scholars all over the globe (Liao et al., 2017). For in-depth understanding of 'fourth industrial revolution', it is significant to know previous three industrial revolutions. The first industrial revolution provides groundwork to industrialization. The second revolution provides groundwork to Power and emerges the concept of 'hard automation'. The third revolution provides groundwork to computers and emerges the idea of 'flexible automation'. The fourth revolution provides groundwork to Industry 4.0 with application of modern information and communication technology and connected with integration of industry automation, data networks, and contemporary manufacturing technologies like intelligent production, human-computer interaction, 3D printing, remote operations etc. (Basl, 2017; Khan et al., 2017; Duarte and Cruz-Machado, 2017). The concept of "Industry 4.0" was introduced by Hanover Messe in 2011.

Industry 4.0, can be understood as the "smart manufacturing" or "integrated industry" has the capability to influence the whole business in terms of products are designed, manufacture and delivered etc. (Hofmann and Rüsch, 2017). Industry 4.0 provides more efficient means to control the production system compared to traditional centralized system. In recent years, Industry 4.0 predominantly revealing the forthcoming transformations of the manufacturing industry landscape, especially in developed economy. However, the concept is comparatively novel to developing economies and needs an in-depth understanding and practice in business (Hofmann and Rüsch, 2017).

2.2 Industry 4.0 and Supply Chains and Sustainability

From an organizational context, managers are pushing to adopt modern technological development and process innovations in the value chains. The process innovations like green, lean, distributed manufacturing when coupled to modern information technology based Industry 4.0 initiatives leads to a sustainable culture in industrial supply chains. This will evolve new sustainable trends in business especially for the manufacturing environment in developing economies (Duarte and Cruz-Machado, 2017). In addition to this, Industry 4.0 can influence supply chain activities, business process and models significantly.

In today' scenario, industrial systems needs to incorporate sustainability along with improving flexibility of supply chain operations (Bechtsis et al., 2017). Industry 4.0 allows industrial systems to develop a global cyber physical network of machines, equipment, sensors, and facilities for better data exchange and control. This global cyber physical network would be highly flexible and smarter leads to a smart factory and smart value chain. This further enhances the overall performance of whole business by improvising each business activity like design, material and machine requirements, product lifecycle and supply chain management etc. (Gilchrist, 2016; Lin et al., 2017). Industry 4.0 facilitates highly organized interconnections among materials, goods and equipment, while satisfying customer requirements in a supply chain context (Branke et al., 2016). The application of Industry 4.0 technologies enables the real-time monitoring and controlling of important production parameters, such as production status, energy consumption, flow of materials, customers' orders, and suppliers' data (de Sousa Jabbour et al., 2018b). Industry 4.0 and sustainability has become the recent emerging threads for industrial supply chains for improving the productivity and developing a more sustainable culture. Industry 4.0 is assumed to be a new business mind-set that can help business organisations and society to move towards sustainable development (de Sousa Jabbour et al., 2018a).

Industry 4.0 is also termed as the future of the supply chains. Smart factories can have a variety of sustainability implications like optimal use of resources, technology etc. (Stock and Seliger, 2016; Quezada et al., 2017). This grounds the need of present research for understanding Industry 4.0 driven sustainability orientation in supply chains. For higher business gains, the term Industry 4.0 needs to be clearly understood by the managers (Brettel et al., 2014). Thus, Industry 4.0 needs a highly organized nomenclature and focal research for a specific definition.

Presently, Industry 4.0 involves several aspects and challenges in developing a sustainable business environment (Schmidt et al., 2015; Zhou et al., 2015).

2.3 Challenges to Industry 4.0 initiatives for sustainability in supply chains

Eighteen key challenges to Industry 4.0 initiatives for developing sustainability in supply chains are identified through literature review and expert's inputs (please refer Section 4 data collection for more details) as explained in Table 1.

Table 1: Challenges to Industry 4.0 for sustainability initiatives in supply chains

Challenges	**Concepts**	**Author/Source/Year**
Low understanding on Industry 4.0 implications	There is a very low understanding on Industry 4.0 implications among both the researchers and practitioners. Literature clearly demands highly organized and focal research for a specific definition of the Industry 4.0. Industrial and practicing managers undoubtedly understood the importance of Industry 4.0 adoption in manufacturing environment; however, they are still unsure on its exact consequences/implications on accomplishing sustainability objectives in supply chains.	Almada-Lobo, 2016; Hofmann and Rüsch, 2017
Poor research & development on Industry 4.0 adoption	Industry 4.0 has been inferred by different practicing managers in their own way. Mostly business organizations are facing different problematic issues in effective adoption of Industry 4.0 so as to lacking in accurate decision strategies during this business transformation. The prime reason behind this is a lack of focused research on addressing the various aspects of Industry 4.0 adoption. The scientific focused research would provide necessary theoretical foundations to Industry 4.0 driven sustainability in supply chains.	Schmidt et al., 2015; Hermann et al., 2016

Legal issues	Industry 4.0 tends to develop a cyber-physical network where various machines, sensors, facilities, and humans are interlinked to the internet and exchanges data with each other. This cyber physical network may emerge with several complex legal issues. To help industries, legal issues should be taken into account while adopting modern technological procedures and ideas. Data privacy and security issues needs to be considered in developing data driven sustainable business models of Industry 4.0	Schröder, 2016; Müller et al., 2017a
Poor company's digital operations vision and strategy	Industry 4.0 describes an innovative approach to business operations and especially the manufacturing organizations by the digital transformation, which requires a clear digital operations vision and mission. During this transformation, organizations fail to apparently illustrate its Industry 4.0 vision and strategy. So far, organizations seem to struggle when transforming the visionary ideas of Industry 4.0 to a missionary level of developing the sustainability of supply chains.	Erol et al., 2016
Low management support and dedication	In order to develop an effective Industry 4.0 concept, management support and dedication to accept the changes is very crucial. Industry 4.0 calls for a revolutionary transformation in business processes and supply chain activities, thus, most relevant management practices should be established Organizations should focus on improving their capabilities in terms of employee training and development, knowledge management	Gökalp et al., 2017; Savtschenko et al., 2017; Shamim et al., 2017

	programs, for Industry 4.0 driven sustainable business development. This could not possible without management support and dedication.	
Profiling and complexity issues	In recent years, supply chains are becoming global and characterized by highly complex structures. Therefore, workforce should be trained to know the essential processes, their dependencies, and data interpretation to accept digitization in the manufacturing environment. Business professionals generally lacks competencies on managing the complexity issues related to data analysis, space or time, usage of particular instructions, in effective Industry 4.0 adoption. This lack of roadmaps and guides supporting its implementation, as well as its high complexity makes "Industry 4.0" too uncertain for achieving sustainability in supply chains.	Erol et al. 2016; Ras et al., 2017
Lack of digital culture	Digitization is the foremost requirement for initiating Industry 4.0 in business environment. Further, Industry 4.0 generally of interdisciplinary in nature which requires digitization to connect different elements of a network.	Ras et al., 2017; Schuh et al., 2017
Reluctant behavior towards Industry 4.0	Most of industries are still unfamiliar and unsure with the topic of Industry 4.0. Due to the ignorance of possible benefits, majority of industries are reluctant to adopt Industry 4.0 based technologies.	Müller et al., 2017b; Theorin et al., 2017; Perales et al., 2018
Unclear economic benefit of digital investments	In Industry 4.0, prime emphasis is given on its technical competence and knowhow, whereas the economic discussion is still in its infancy. The lack of clearly defined return on investment could be seen as a one of major challenge to Industry 4.0	Kiel et al., 2017; Marques et al., 2017

	initiatives for accomplishing sustainability in the supply chain.	
Lack of global standards and data sharing protocols	In Industry 4.0 initiatives, systems generally coupled to an intelligence mechanism to communicate freely. To achieve success in this, industries need to follow global standards and data sharing protocols. It has been notices that industries lacks in standards and protocols in data transfers in adopting sustainability oriented modern information interface technologies in business networks.	Branke et al., 2016
Lack of infrastructure and internet based networks	High infrastructure, information technology based facilities and technologies are crucial in effective adoption of Industry 4.0 concepts. Poor internet connectivity is an imperative barrier to Industry 4.0 initiatives. Further, in Indian context, internet based technology are not to be recognized equally in urban and rural areas which can impede the sustainable business growth.	Leitão et al., 2016; Bedekar, 2017; Pfohl et al., 2017
Lack of competency in adopting/applying new business models	Current industrial system needs highly customized and flexible environment to compete globally. In this sense, industries need to adopt new business models. Integration of multiple systems pushed the data to the big data due to the deluge of data generation in the manufacturing processes. Industrial big data analytics increase the productivity of enterprises. Prediction of new events from big data provides a concrete foundation for planning new projects. As it is not necessary that all the new insights will be workable and only some events are interesting out of million	Khan et al., 2017; Saucedo-Martínez et al., 2017

	events, so revealing these insights are a challenge for data scientists to write suitable algorithms in adopting/applying new business models.	
Poor existing data quality	Data quality is one of foremost requirement in making decisions in successful Industry 4.0 adoption. In Industry 4.0, several machines, sensors, manufacturing systems and facilities are interconnected so as generates big data. The available big data may help managers to practice Industry 4.0 innovations for a sustainable future. This could not possible without higher data quality.	Santos et al., 2017)
Lack of integration of technology platforms	The integration of technology is very essential in effective communication and higher productivity. Industries are facing difficulties in designing a flexible interface to integrate various heterogeneous components. Cyber physical networks many different components, which needs to be integrated and supported for an effective data exchange and analysis in manufacturing environment. Thus, it is significant to design and develop a platform to integrate technology for developing an effective Industry 4.0 driven sustainable supply chain.	Zhou et al., 2015
Problem of coordination and collaboration	Collaboration and transparency among members is important in understanding the organizational policies in adopting concepts of Industry 4.0 and improving supply chain sustainability. The coordination and collaboration with suppliers is necessary for better communication mechanisms, with high compatibility issues of hardware and software which should require standardized	Lee et al., 2014; Duarte and Cruz-Machado, 2017; Pfohl et al., 2017

	interfaces, and synchronization of data to get better synchronization with manufacturers.	
Security issues	One of the Industry 4.0 features is the ability to connect across organizational environments, which has the potential to make the supply chain more efficient. However, the supply chain systems have inherent security vulnerabilities, which are exploited by attackers. One of the security vulnerabilities starts with the supplier, which is vulnerable to phishing attacks and the stolen of privileged credentials, resulting in mass data exposure. The major vulnerability is in the top of the supply chain, reaching the rest of the organizational processes through its dependent actors. Security is the prime requirement to transform a factory into smarter factor and a supply chain into smarter value chains.	Sommer, 2015; Wang et al., 2016; Pereira et al., 2017
Lack of governmental support and polices	Government policies and directions are crucial in developing supply chain sustainability through Industry 4.0. Clearly, there is a lack of definite government guidelines and directions on Industry 4.0 in most of the economies including India. In addition to this, governments are also unsure on probable consequences of Industry 4.0. As a resultant, policy analysts and government bodies have not revealed the roadmap for transforming the traditional business functions into smarter and sustainable processes.	BRICS Business Council, 2017
Financial constraints	In Industry 4.0, financial constraints are considered to be a very important challenge among business organizations for developing their capabilities in	Dawson 2014; Theorin et al. 2017; Nicoletti, 2018

	terms of advanced equipment and machines, facilities and sustainable process innovations.	

3. Methodology

The research methodology adopted for the present work is shown in Figure 1.

[Figure 1 about here]

For this work, we performed Systematic Literature Review (SLR) (Biel and Glock, 2016; Papadopoulos et al., 2016; Liao et al., 2017). For literature review, we used several keyword along with their combinations, including – Challenges and Barriers; Industry 4.0; Supply Chain and Sustainability; Challenges and Barriers and Industry 4.0; Industry 4.0 diffusion and Sustainability and Supply Chain; Industry 4.0 and Supply Chain Management and Sustainability and Challenges. For searching these keywords, Scopus and Google Scholar and Google databases were explored. Next, the collected articles were examined in relation to these keywords. In addition to this, we also evaluated the collected articles using some criteria, given as - (i) the articles written in English only were considered; (ii) the articles belongs to peer reviewed publications and published reports were only considered. To the last, we also used the forward snowball and backward snowball approach in literature review (Mangla et al., 2017). In this way, the literature review was performed in this research.

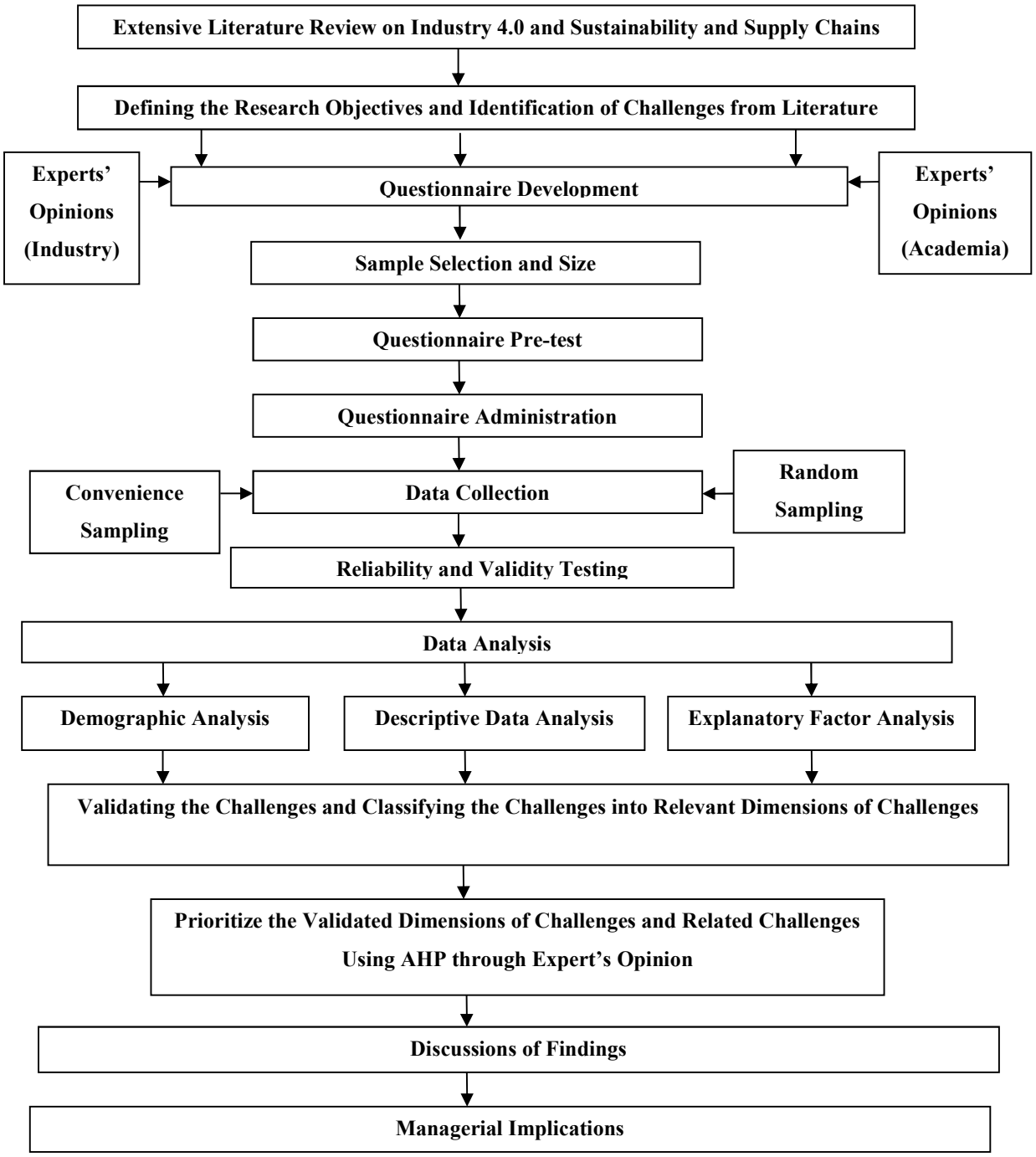

Figure 1: Research methodology for this study

We finalized key challenges using literature support and expert's inputs (please refer Section 4.1 for more details). These challenges are provided theoretical foundation using EFA. In EFA, a questionnaire based survey in Indian manufacturing sector is conducted. Various qualitative and

quantitative tools and methodologies, such as Instrument development and data collection, and various data analysis techniques, and AHP method employed in present research have been discussed in the next section.

4. Data Collection and Results

Manufacturing industries from India are considered as target population in this research. The selection of industries was made on the basis of cost, time constraints and resources requirements. The population of the present study is 96 responses from Indian manufacturing sector, and considered to be sufficient and representation of population with respect to cost, resources and time constraints. Various statistical tools and techniques have been employed to analyze the collected data. In this section, data is collected, analyzed and results are presented accordingly.

4.1 Instrument development and data collection

Development of a quality instrument is a fundamental in theoretical development (Luthra et al., 2016a). Well-designed questionnaires provide the consistency among respondents, deeper understanding of the industrial practices, and provide superior quality of the collected data (Synodinos, 2003). After a detailed review of the literature, 18 challenges for this research work were noted. The experts were asked to add/delete/modify the list according to implementation of Industry 4.0 initiatives for achieving sustainability of supply chains in Indian context. We collect responses from managers in Indian manufacturing sector, who qualified, knowledgeable and skilled based professionals in the field of advanced manufacturing systems and supply chain management. The challenges with comparatively lower rating were decided to be deleted from the list. Since the focus of this research was exploratory in nature, quantitative data collection method (survey) was used shown in Appendix - A.

Based on study of Luthra et al. (2016a), convenience and random sampling methods are opted for data collection; other details are given as below:

(i). Convenience sampling: After pretesting, questionnaire was administered to the participants of a workshop held in Dehradun. Through the workshop, 13 useful responses were received. Further, various manufacturing industries in the Northern part of India

were contacted and visited as per convenience. We used personal contacts and prior experience in domain in companies' selection. 41 usable responses from industrial experts were collected.

(ii). Random survey: A database of 200 respondents working in various types of manufacturing industries was made through various types of secondary sources i.e. Google search, various website newspapers and other sources. The targeted population was randomly selected and the mail was sent to 200 respondents. In initial mail survey, only 11 completed questionnaires were received. Four weeks later, reminder emails were sent. After several emails reminders, a total 42 completed responses were collected. This provides a satisfactory response rate of 21% (Malhotra and Grover, 1998).

Several criteria are considered for evaluating the differences in the key results of the survey. Some of the criteria are: Types of industry, Organization type, Annual turnover, Kind of business, Information about Suppliers and Level of Automation. Demographics summary of responding organizations has been shown in Table 2.

Table 2: Demographics summary of responding organizations of India

S. No.	Responding Organizations	Criteria	Number of Respondent	Percentage
1	Type of industry	Automotive	33	34.38
		Metals and machinery	26	27.08
		Electrical equipment and appliances	11	11.46
		Food and beverage	09	09.37
		Textile	05	05.21
		Others	12	12.50
2	Organization type	Private Sector	54	56.25
		Public Sector	05	05.21
		Multinational Corporation	37	38.54
		Others	00	00.00
3	Annual turnover (In Millions rupees)	Less than or equal to 500	18	18.75
		501-1000	31	32.29
		1001-5000	36	37.50
		5001 to 10000	08	08.33
		More than 10000	03	03.13
4	Kind of business	O.E.M.	38	39.58
		Supplier	58	60.42
5	Information about suppliers	Less than or Equal to 50	29	30.21
		51-100	33	34.37
		101-200	19	19.79

		More than 200	15	15.63
6	Level of Automation	Yes	74	77.08
		No	18	18.75
		In Progress	04	04.17

The survey results ensured that a variety of Indian manufacturing industries (Automotive; Metals and Machinery; Electrical equipment and appliances; Food and beverage and Textile etc.) have been covered in the survey. All the survey industries were involved in the manufacturing. The adaptation of modern information and technology can be seen in all business sectors in Indian scenario, especially in manufacturing sector where industries are transforming their business through Industry 4.0 initiatives. It is assumed that they all almost had similar behavior for the implementation of the industry 4.0 aligned with the sustainability assumptions.

In this work, mean and standard deviations for the challenges are computed as descriptive statistics as shown in Table 3.

Table 3: Descriptive statistics of challenges to Industry 4.0 initiatives for sustainability orientation in supply chains

S. No.	Challenges to Industry 4.0 initiatives for sustainability orientation in supply chains	Mean	Std. Deviation
1	Low understanding on Industry 4.0 implications	4.208	0.579
2	Poor research & development on Industry 4.0 adoption	4.000	0.681
3	Legal issues	4.417	0.660
4	Poor company's digital operations vision and strategy	4.219	0.668
5	Low management support and dedication	4.260	0.669
6	Profiling and complexity issues	4.437	0.577
7	Lack of digital culture	4.031	0.623
8	Reluctant behavior towards Industry 4.0	4.260	0.700
9	Unclear economic benefit of digital investments	4.021	0.768
10	Lack of global standards and data sharing protocols	3.833	0.627
11	Lack of infrastructure and internet based networks	3.865	0.450
12	Lack of competency in adopting/applying new business models	4.208	0.614
13	Poor existing data quality	3.854	0.562
14	Lack of integration of technology platforms	3.844	0.604
15	Problem of coordination and collaborations	4.427	0.661
16	Security issues	4.458	0.614
17	Lack of governmental support and polices	3.990	0.733
18	Financial constraints	4.281	0.644

Notably, all listed challenges obtained mean value greater than 3. This suggests that all identified challenges are significant.

4.2 Reliability, validity and non-biasness

Reliability test evaluates the accuracy of responses received from the respondents (Hair et al. 2006). In addition, for convergent validity, the factor loading of above 0.5 is desired (Field, 2009). In this work, all challenges' obtained a loading of more than value 0.5. For testing the internal consistency of conducted survey instrument, Cronbach's alpha value of above 0.5 is preferred (Nunnally, 1978). The value of Cronbach's alpha comes to be highly acceptable and confirms the internal reliability. Next, Discriminant validity of questionnaire items was checked. Next to this, convenience sampling biasness of the responses was tested. For this, we categorize the collected 96 responses into two groups i.e. early responses from convenience sampling (56.25%) and late responses from random sampling (43.75%). t-test has been used to examine the non-response bias between two groups and no significant difference in the mean values of challenges at the P> 0.05 significance level is observed.

Similarly, the 42 responses from the random sampling were divided into two groups representing the "early respondents'' and ''late-respondents''. In this work, 11 respondents are termed as early and the remaining 31 late. We used Chi-square test to test any significant difference between two categories of response. The Chi-square test rejects the presence of any significant difference between early and late responses.

4.3 Explanatory factor analysis (EFA)

Explanatory factor analysis is used for data reduction and analysis (Hair et al. 2006). The factor analysis and reliability tests were conducted for validating the challenges with the help of statistical software – SPSS Version 20.0. The KMO value obtained (0.758) is significantly more than the recommended minimum value i.e. 0.6 (Kaiser, 1974; Hair et al. 2006). Bartlett's Test of Sphericity is also significant for the challenges ($p < 0.01$). Thus, it is inferred that all the listed challenges are found highly relevant to apply EFA.

In our case, all challenges have Eigen-values of discontinuity of more than 1.0, factor loadings above 0.5 and Cronbach's alpha value of more than 0.7 (Nunnally 1978; Hu and Hsu, 2010; Luthra et al., 2016a). Table 4 explains results of factor analysis. From the given list of challenges, four dimensions of challenges (Organizational challenges (OR); Legal and ethical

issues (LE); Strategic challenges (ST) and Technological challenges (TE) have been extracted, which covers 74.379% of total variance.

Table 3: Factor analysis results for challenges to Industry 4.0 initiatives for sustainability orientation in supply chains

Dimension	Challenges to Industry 4.0 initiatives for sustainability orientation in supply chains	Item Loading	Eigen Values	Cumulative Percentage
Organizational (OR)	Financial constraints (OR1)	0.933	4.403	24.461
	Low management support and dedication (OR2)	0.908		
	Reluctant behavior towards Industry 4.0 (OR3)	0.884		
	Poor company digital operations vision and mission (OR4)	0.872		
	Lack of competency in adopting/applying new business models (OR5)	0.848		
	Low understanding on Industry 4.0 implications (OR6)	0.530		
Legal and ethical issues (LE)	Legal issues (LE1)	0.915	3.628	44.617
	Problem of coordination and collaborations (LE2)	0.898		
	Security issues (LE3)	0.888		
	Profiling and complexity issues (LE4)	0.787		
Strategic (ST)	Lack of governmental support and polices (ST1)	0.834	2.763	59.969
	Poor research & development on Industry 4.0 adoption (ST2)	0.816		
	Unclear economic benefit of digital investments (ST3)	0.771		
	Lack of digital culture (ST4)	0.735		
Technological (TE)	Lack of global standards and data sharing protocols (TE1)	0.816	2.594	74.379
	Poor existing data quality (TE2)	0.794		
	Lack of integration of technology platforms (TE3)	0.759		
	Lack of infrastructure and internet based networks (TE4)	0.637		

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization (Rotation converged in 5 iterations).
KMO measure of sampling adequacy = 0.758;
Cronbach's alpha = 0.859;
Bartlett's Test of Sphericity: Approx. Chi-Square =1422.829; df =122; Sig. = .000.

The results obtained from EFA are understood by providing different labels to the dimensions as discussed below:

- *Dimension 1*- Organizational challenges (OR): This dimension includes six challenges that explained 24.461% of the variance. These challenges represent organizational level hurdles to adopt ecological, economic and social aspects of sustainability in value chains through Industry 4.0.
- *Dimension 2*- Legal and ethical issues (LE): This dimension includes four challenges and accounted for 20.156% of the variance. These challenges deal with legal and ethical issues in adopting Industry 4.0 concepts for sustainable business.
- *Dimension 3*- Strategic challenges (ST): This dimension consists of four challenges related to strategic issues to Industry 4.0 diffusion for supply chain sustainability. This dimension covered 15.352% of the variance.
- *Dimension 4*- Technological challenges (TE): This dimension is comprised of four challenges related to the technological hurdles to Industry 4.0 diffusion for supply chain sustainability. This dimension covered 14.410% of the variance.

In this study, factor analysis is used to provide theoretical basis to the challenges. Next, the validated challenges and the corresponding dimensions of challenges have been analyzed to know their priority for successful Industry 4.0 based sustainability oriented supply chains through AHP. The results of AHP are provided in next sub section.

4.4 AHP

AHP is a decision analysis tool proposed by Prof. Thomas L. Saaty in 1980 (Saaty, 1980). The complex decision problems are converted into an ordered structure consisting of multiple levels (Papalexandrou et al., 2008; Dey and Cheffi, 2013). AHP is used as a better decision making tool compared to ANP, due to its wide acceptability and simplicity in use (Mangla et al., 2015; Luthra et al., 2017). However, AHP may involve some small inconsistency in human judgment (Gandhi et al., 2016). This study proposes to use AHP to analyze identified challenges to know their priority in accomplishing Industry 4.0 based sustainability orientated in the supply chain. The steps of AHP are given as (Luthra et al., 2016b):

Step 1: *Formation of the aim of study*

AHP helps to determine the priority of dimensions of challenges and related challenges through expert's inputs. A hierarchy of challenges with regard to objective of this work is developed in

discussion with experts. For AHP analysis, an expert panel of seven experts (three academicians and four industry professionals) is formed. Two professors from operations area, one professor from information systems, two industrial engineers, one production manager and one supply chain manager were selected. The experts selected were highly knowledgeable and skilled based professionals in the field of manufacturing systems and supply chain activities. The experts selected are having with more than 10 years of working experience. This hierarchy has three different levels (see Figure 2): Prioritize the challenges to Industry 4.0 initiatives for sustainability orientation in supply chains (Level-1), the four dimensions of challenges (Level-2) and eighteen challenges (Level-3).

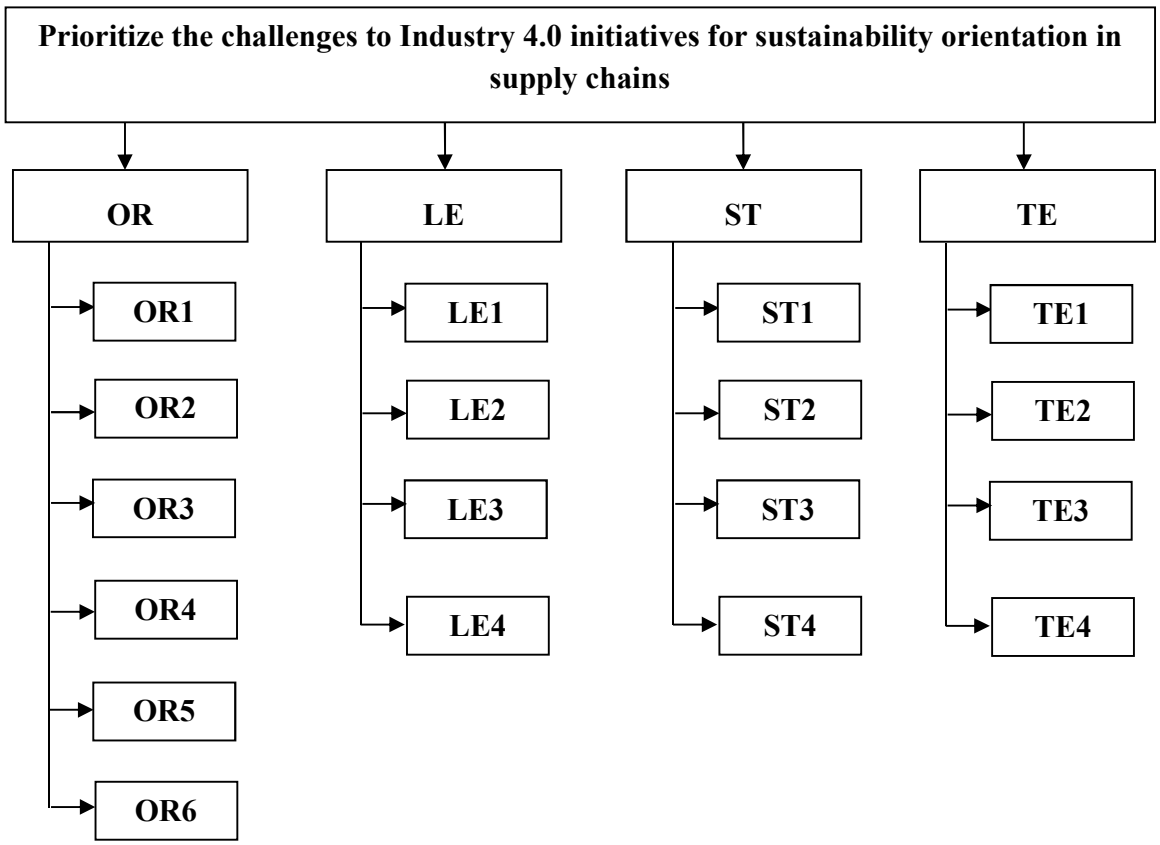

Figure 2: The developed decision hierarchy of challenges

Step 2: *Develop the pair wise comparisons among challenges*.

Based on the experts' judgment, the pair wise comparisons were made for both dimensions of challenges and the challenges through Saaty's scale (Saaty, 1980).

Step 3**:** *Compute the relative importance weights and the consistency ratio*

Based on pair wise comparisons, relative priority weights are calculated as shown in Table 5.

Table 4: Pair wise comparison matrix for four dimensions of challenges and their computed priority weights

S. No.	Major dimensions of challenges	OR	LE	ST	TE	Priority weight	Rank
1	Organisational (OR)	1	1	2	1	0.2976	1st
2	Legal and ethical issues (LE)	1	1	0.5	0.5	0.1760	4th
3	Strategic (ST)	0.5	2	1	1	0.2454	3rd
4	Technological (TE)	1	2	1	1	0.2810	2nd
Maximum Eigen Value =4.1855; C.I.=0.0618							

'Organizational challenges (OR) (0.2976)' dimension is reported as the most important challenges followed by 'Technological challenges (0.2810)'; 'Strategic challenges (0.2454)' and 'Legal and ethical issues (0.1760).

Next, the priority weights for challenges were calculated. As shown in Table 5.

Table 5: Ranking of challenges to Industry 4.0 initiatives for sustainability orientation in supply chains

Main Dimensions	Relative weights	Sub challenges	Relative weights	Relative ranking	Global weights	Global ranking
Organizational (OR)	0.2976	Financial constraints (OR1)	0.2818	1st	0.0839	3rd
		Low management support and dedication (OR2)	0.2175	2nd	0.0647	5th
		Reluctant behavior towards Industry 4.0 (OR3)	0.1087	5th	0.0324	14th
		Poor company digital operations vision and mission (OR4)	0.1754	3rd	0.0522	10th
		Lack of competency in adopting/applying new business models (OR5)	0.1010	6th	0.0301	15th
		Low understanding on Industry 4.0 implications (OR6)	0.1154	4th	0.0343	13th
Legal and ethical issues (LE)	0.1760	Legal issues (LE1)	0.1480	4th	0.0260	17th
		Problem of coordination and collaborations (LE2)	0.1630	3rd	0.0287	16th
		Security issues (LE3)	0.3629	1st	0.0639	6th
		Profiling and complexity issues (LE4)	0.3261	2nd	0.0574	9th

Strategic (ST)	0.2454	Lack of governmental support and polices (ST1)	0.3465	1st	0.0850	2nd
		Poor research & development on Industry 4.0 adoption (ST2)	0.2036	3rd	0.0499	11th
		Unclear economic benefit of digital investments (ST3)	0.2463	2nd	0.0604	7th
		Lack of digital culture (ST4)	0.2036	3rd	0.0499	11th
Technological (TE)	0.2810	Lack of global standards and data sharing protocols (TE1)	0.3301	1st	0.0927	1st
		Poor existing data quality (TE2)	0.1748	4th	0.0491	12th
		Lack of integration of technology platforms (TE3)	0.2069	3rd	0.0581	8th
		Lack of infrastructure and internet based networks (TE4)	0.2883	2nd	0.0810	4th

Consistency ratio in all pair wise comparison matrices is well below the permissible limit, thus, the results are highly acceptable. AHP results suggested that 'Organizational challenges (OR) (0.2976)' and 'Technological challenges (0.2810)' dimensions reported as key dimensions of challenges. While in process of global ranking of challenges, 'Lack of global standards and data sharing protocols (TE1)'; 'Lack of governmental support and polices (ST1)'; 'Financial constraints (OR1)'; 'Lack of infrastructure and internet based networks (TE4)'; and 'Low management support and dedication (OR2)' are recognized as top five key challenges. Out of top five key challenges, four challenges belong to Organizational and Technological dimensions of challenges.

5. Discussion

The present study conducts EFA analysis to validate and reduce the identified 18 challenges into four main dimensions of challenges - Organizational challenges; Legal and ethical issues; Strategic challenges and Technological challenges. The validated challenges were further evaluated to know their ranking using AHP. The order of priority of the identified dimensions of challenges is given as: Organizational challenges – Technological challenges – Strategic challenges – Legal and ethical issues.

"Organizational challenges (OR)" dimension is one of the most critical challenges to develop sustainability of supply chains through Industry 4.0 in Indian manufacturing sector. Onar et al.

(2018) suggested that organizations needs to develop their capabilities in terms of workforce expertise, strategic organizational policies, better leadership instruments and friendly business culture to diffuse Industry 4.0 sustainability oriented practices. Therefore, top management needs to involve proactively during such transformations. Hence, a more focused approach is suggested to manage organizational related challenges (Teodosiu and Castells, 2017). There are six challenges in this dimension. Among them, 'Financial constraints (OR1)' obtains the highest relative importance. Erol et al. (2016) suggested, especially for small and medium enterprises, challenges arise mainly due to the immense financial resources required for the acquisition of new technology for Industry 4.0. 'Low management support and dedication (OR2)' is ranked after (OR1). Management support and involvement is significant to diffuse Industry 4.0 sustainability oriented practices in production system. 'Poor company digital operations vision and mission (OR4)' comes next according to importance order. Manufacturing organization's management fails to explain their vision and roadmaps either to go with Industry 4.0 or not. 'Low understanding on Industry 4.0 implications (OR6)' is ranked after (OR4). 'Reluctant behavior towards Industry 4.0 (OR3)' comes next according to importance order. Finally, 'Lack of competency in adopting/applying new business models (OR5)' comes last in the list. McLeod (2017) suggested that human performance is key to sustainable operations. de Sousa Jabbour et al. (2018a) that organization factors, such as top management, leadership and organizational culture plays a significant role in managing of Industry 4.0 and eco-friendly sustainable manufacturing operations in value chains.

"Technological challenges (TE)" is the next important dimension. This dimension has four challenges. 'Lack of global standards and data sharing protocols (TE1)' challenge has the highest priority. Jeschke et al. (2017) stated that Industry 4.0 global standards and data sharing protocols need a common ground in developing smart production systems. Following this, 'Lack of infrastructure and internet based networks (TE3)' challenge is in the list. Higher infrastructure and efficient internet networks is crucial to manage the interconnected devices effectively. Internet connectivity also needs to be improved in Indian context especially in the rural regions. Next challenge is the 'Lack of integration of technology platforms (TE4)', which suggests that the integration of technology is required to support different heterogeneous cyber physical components. Last challenge is the, 'Poor existing data quality (TE2)', which suggests that the data quality is a critical concern to Industry 4.0. de Sousa Jabbour et al. (2018b) suggested in

their research that the concept of Industry 4.0 is fairly original and Industry 4.0 technologies has not been widely explored in the literature.

"Strategic challenges (ST)" dimension obtains the next importance level. In this dimension, 'Lack of governmental support and polices (ST1)' holds the highest importance. Governmental support and related policies can help the manufacturing systems to transform from traditional factory to factory of the future (Kagermann, 2015). Müller et al. (2018) suggested in their research that business organizations need governmental support for eradicating Industry 4.0 challenges in initial stages. Although, Government of India have taken initiatives such as 'Goods and Services Tax', 'Green Corridors' and 'Make in India' etc. Yet, lot more needed from government side to promote Industry 4.0. Industries should improve their capabilities for accepting immediate changes in their business policies. Next is 'Unclear economic benefit of digital investments (ST3)' challenge. Indian manufacturing organizations needs to understand the economic benefits of digitization for effective Industry 4.0 adoption (Hofmann and Rüsch, 2017). Following this, 'Poor research & development on Industry 4.0 adoption (ST2)' and 'Lack of digital culture (ST4)' challenges are in the importance order level. Indian manufacturing systems need to develop higher research facilities for exact understanding of Industry 4.0 and its business implications. Thus, Indian manufacturing organizations need to transform their organizational culture systematically.

"Legal and ethical issues (LE)" dimension is last in list as per priority. In this dimension, 'Security issues (LE3)' is ranked first. To meet the technological challenges raised by the Industry 4.0, it is essential to reach a consensus among all the members on security issues and the relevant architecture before implementation begins. 'Profiling and complexity issues (LE4)'comes next. Next challenge in the list is 'Problem of coordination and collaborations (LE2)'. Last, in the importance order list is 'Legal issues (LE1)'. Legal concerns are needs to be accounted to Industry 4.0 adoption. As the shared information includes sensitive data about inventories, bottlenecks, and incidents, new ethical, technical, and legal approaches are needed in Industry 4.0. Those are also required for counteracting cyber criminality, as companies are not only responsible for their own data security, but also for the data security of supply chain partners linked to them (Müller et al., 2018).

6. Conclusions

This work seeks to recognize and analyse the challenges to Industry 4.0 initiatives for accomplishing sustainability orientation in supply chains. Industry 4.0 based sustainability oriented concept helps industrial managers not only to incorporate environmental protection and control measures but also to couple process safety and employee and community welfare measure in their supply chains.

6.1 Theoretical contribution

The integration of Industry 4.0 and sustainability is in its very initial stages (de Sousa Jabbour et al., 2018a). Currently, Industry 4.0 is relatively novel to developing nations, especially in India and needs a clear definition to for proper understanding and practice in business. To help manufacturing systems, 18 key challenges to Industry 4.0 based sustainability oriented supply chains are identified using an extensive literature survey. These challenges were further analyzed through 96 responses received from Indian manufacturing sector using a questionnaire based survey.

EFA provides theoretical foundation to the challenges. AHP ranks the identified dimensions of challenges and related challenges using responses received from the experts. Findings of the study reveal that among the four dimensions of challenges - Organizational challenges holds the highest importance followed by Legal and ethical issues, Strategic challenges, and Technological challenges. This work is an initial effort to contribute in theory to Industry 4.0 diffusion leads to smarter and sustainable manufacturing system and value chain.

Industry 4.0 initiatives have the full potential of unlocking supply chain sustainability in emerging economies by developing green products, green production operations and processes, etc. It may act as a ready reckoner for the practitioners and policy makers of developing economies for an in-depth understanding of Industry 4.0 initiatives and eradicate the potential challenges and hurdles in effective Industry 4.0 adoption while developing environmental, human and community welfare, economic gains and overall sustainability in supply chains.

6.2 Managerial contribution

Industry 4.0 is a vision for the sustainable future of the value chains. This research work offers several implication for process engineers and industrial managers. This study provides theoretical basis to understand the potential challenges to Industry 4.0 to develop sustainability of supply chains. The knowledge of challenges can assist process engineers and industrial managers to focus on the design, operation, control and optimization of processes and operations crucial to sustainable business development. This work facilitate process design and practicing managers to accurately understand and eradicate the potential hurdles in selecting appropriate material and adopting modern information technologies, such as IoT, cloud computing and robotics for designing and manufacturing the products in a most sustainable way. This will further help process design and practicing managers to employ superior industrial control through robots, sensors, to achieve a higher productivity, improved economy and safety in a sustainability oriented manufacturing environment. This study suggests that cyber physical network is largely depends on Industry 4.0 and possess different implications for sustainability in business.

Managers need to consider sustainability aspects while adopting modern technologies i.e. Industry 4.0 in value chains. Such revolutionary transformations may improve business flexibility and productivity, while can also disrupt environment in terms of higher resources consumptions and energy requirements. To help industries in such situations, this work attempts to address the sustainability aspects in manufacturing systems particularly their value chains thorough Industry 4.0. This work may assist process engineers, managers and relevant stakeholders to understand the exact status and implications of Industry 4.0 based sustainable practices in Indian manufacturing system. This knowledge can be very crucial in managing the negative impacts of Industry 4.0, such as less job satisfaction, poor process safety and control, higher resources and energy needs etc. India is recognized as one of the superpower globally. In this sense, Industry 4.0 provides enormous opportunities to develop India economy that generate employment and prosperity, improve quality of life for communities and present sustainable business environment for smarter manufacturing.

6.3 Limitations and future directions

This study has few limitations that can be considered opportunities for future work. The work suggests eighteen challenges; some of the other challenges in different country context may be included in future studies. This work has been conducted in Indian context; however, findings could be extended to other developing nations with marginal modifications. Further, we seek to compare the findings between different developing nations in future studies. The statistical procedures used in this work suggest sufficient validity. However, large and more geographically diversified sample throughout India may be taken in future studies. The key challenges were ranked using expert's views. Experts were not randomly selected. The opinion of the experts may be biased. In future work, sensitivity analysis may be performed. In future research, the identified challenges may be examined further to know their causal and dependencies. In addition, authors also seeking to develop/test a detailed conceptual framework of challenges using Structural Equation Modeling (SEM) in future studies.

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Annexure -I

SURVEY QUESTIONNAIRE

SECTION A: General Information

Please tick (✓) only one choice in each question as follows:

1. How will you classify your manufacturing organization?
(a) Automotive
(b) Metals and machinery
(c) Electrical equipment and appliances
(d) Food and beverage
(e) Textile
(f) If any other, please specify……

2. How will you classify your sector?
(a) Private Sector
(b) Public Sector
(c) Multinational Corporation
(d) If any other, please specify……

3. What is approximate annual turnover of your organization (In millions rupees)?
(a) Less than or Equal to 500
(b) 501-1000
(c) 1001-5000
(d) 5001 to 10000
(e) More than 10000

4. What type of organization you have?
(a) Original Equipment Manufacturer (OEM)
(b) **Supplier to OEM**

5. How many average numbers of suppliers your organization has?
(a) Less than or Equal to 50
(b) 51-100
(c) 101-200
(d) More than 200

6. Is there currently any kind of manufacturing automation in your organization?
(a) Yes
(b) **No**
(c) In Progress

SECTION B: Significance of the challenges to Industry 4.0 diffusion to achieve sustainability in the supply chain in Indian Manufacturing Industry

7. Rate the following challenges to Industry 4.0 diffusion to achieve sustainability in the supply chain on 5 point Likert scale (1- not significant, 2-somewhat significant, 3-significant, 4-very significant and 5-extremely significant) (Please tick only ONE in each row).

S. No.	Challenges to Industry 4.0 diffusion to achieve sustainability in the supply chain	Rating				
		1	2	3	4	5
1.	Low understanding on Industry 4.0 implications					
2.	Poor research & development on Industry 4.0 adoption					
3.	Legal issues					
4.	Poor company's digital operations vision and strategy					
5.	Low management support and dedication					
6.	Profiling and complexity issues					
7.	Lack of digital culture					
8.	Reluctant behavior towards Industry 4.0					
9.	Unclear economic benefit of digital investments					
10.	Lack of global standards and data sharing protocols					
11.	Lack of infrastructure and internet based networks					
12.	Lack of competency in adopting/applying new business models					
13.	Poor existing data quality					
14.	Lack of integration of technology platforms					
15.	Problem of coordination and collaborations					
16.	Security issues					
17.	Lack of governmental support and polices					
18.	Financial constraints					
19.	If any other, please specify					

Name and Signature of Respondent
Designation:
Organization:
Mobile Number:
Email:
Date:
Place:

Thank you very much for completing this questionnaire

If you have any comments about this questionnaire or issues involved please write them in the box given below
