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Revolutionising Supply Chains with Industry 4.0 Concepts to Attain Sustainability - Indian Context

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Abstract: The supply chain is one of the sectors that has experienced a revolution in the process thanks to the introduction of the 4th Industrial Revolution technologies in this sector, such as the Internet of Things (IoT), Artificial Intelligence (AI), Big Data Analytics, blockchain, cloud computing, robotics and cyber-physical systems. In an Indian context, the use of these technologies can open up a huge opportunity for added efficiency in supply chain and addressing the challenges in the area of environmental, economic and social sustainability. The concept of Industry 4.0 and how it is bringing changes to the supply chain and encourages sustainable business in India is discussed. Real-time data, intelligent automation, predictive analytics, digital connectivity and transparency in data sharing, it highlights and helps to improve resource utilisation, minimise operational waste, optimise transportation, reduce carbon emissions to the environment and reinforce supply chain resilience. It will also take into account the challenges encountered by adopting Industry 4.0, such as high start-up costs, a lack of technological infrastructure, security vulnerabilities, lack of a workforce skilled in Industry 4.0, as well as issues related to data privacy, and small and medium-sized enterprises issues. There is considerable potential for smart technologies in integration of the manufacturing and logistics sector in an sustainable supply chain approach to Indian manufacturing. The study concludes that technological readiness, training development, supportive government policies and interconnection between different actors in value chain are important interventions to guarantee the successful implementation of Industry 4.0. This integration has the potential to make supply chains more agile, resilient, resource efficient and sustainable, and work towards India's long-term economic and environmental goals.

Keywords: Industry 4.0, Supply Chain Management, Sustainability, Smart Supply Chains, Internet of Things (IoT), Artificial Intelligence, Big Data Analytics, Digital Transformation, Green Supply Chain, Sustainable Development, Indian Context, Supply Chain Resilience.

Introduction

For organisations, the supply chain changed radically with the impact of the use of digital technologies for its design, management and coordination. Industry 4.0, or the fourth industrial revolution, is the use of new phenomena like the Internet of Things (IoT), Artificial Intelligence (AI), Big Data Analytics, cloud computing, blockchain, robotics and automation, cyber-physical systems, digital twins and advanced communication networks in the processes of business and industry. In the world of supply chains, these technologies can help companies go beyond the traditional and mostly reactive supply chains into smart, automated, connected and data-driven supply networks. Furthermore, Industry 4.0 is more significant because of the growing importance of sustainability in the world today and the need for organisations to not only improve productivity and profitability but reduce environmental impacts, resource consumption, facilitate social responsibility and build sustainable supply chains. Thus, a research topic, as well as a managerial practice, relevant to Industry 4.0 and the sustainable supply chain arises.

A shift in supply chains as a result of Industry 4.0 is particularly critical in India's context, where the manufacturing base is robust, digital infrastructure is growing, the diversity of supply chains is large, and the e-commerce is

booming and has increasingly interacted with the global value chain. Indian organizations have to face a very competitive scenario with supplies spread across geographies, a changing set of consumer expectations, infrastructure issues, and a growing emphasis and pressure to practice energy accountabilities. The technologies that are part of Industry 4.0, such as the Internet of Things (IoT), can help overcome multiple real challenges by ensuring that materials, inventories, transport and production are visible at all times as well as customer demand. AI and predictive analytics can be leveraged for demand forecasting, inventory optimization, predictive maintenance, and intelligent decision-making, and IoT can facilitate a continuous monitoring process of the goods and equipment. Likewise, its increased traceability and transparency throughout the supply chain can help make supply chain collaboration and communication between logistics providers, manufacturers, retailers, suppliers and customers smoother.

In many instances, the activities of the supply chain can have an environmental and social impact and sustainability has become one of the main considerations in discussions surrounding most supply chain management activities. The net impact of these areas of transportation, warehousing, manufacturing, packaging, energy use, resource use and waste is a combined impact on an organisation's ecological footprint. The following are the subject areas where Industry 4.0 technologies can contribute to sustainability: Energy optimization and use of raw materials, Reduction of unnecessary transportation, Defect free manufacturing, Maximization of asset usage, Recycling/reverse logistics. It can be a key part in preventing the loss of money that can result from inefficiencies and losses, especially through real-time energy tracking, predictive analytics which optimize machine downtimes, or intelligent transportation systems which guide routes and reduce fuel.For example through predictive analytics and real-time monitoring intelligence systems can reduce fuel consumption, optimize routes and help to avoid material waste whilst simultaneously reducing machinery downtime and minimising money going down the drain in inefficiencies and losses. Digital traceability also can help companies maintain better compliance to environmental and social requirements, and better control over their suppliers. Therefore, there are opportunities in which the interests of Industry 4.0 can not only be aligned with economic goals and objectives, but also bring these together with the interest in environmental and social goals.

Although this potential exists, there are multiple challenges that hinder the adoption of Industry 4.0 for sustainable supply chains in India. resistance to organisational change, lack of digitally competent people, cybersecurity threats, data-management problems, interoperability issues, lack of technological infrastructure, and high initial investment values could limit the adoption, especially for SMEs. The additional steps taken to use digital elements may be further reduced if there is a tech-savvy less in the value chain. Furthermore, the use of sophisticated technologies can involve greatly higher energy consumption, expensive equipment and electronics as well, which means careful consideration must be given to these sustainability issues. Hence the availability of organizational competence, training the workforce, cyber-security mechanisms and their regulations should be promoted by adoption of the technology, which should be supported by partnership among those in the value chain.

The inclusion of Industry 4.0 and Sustainability thus becomes a crucial strategy to make the Indian Supply Chain smart, agile, transparent and resource efficient. In the present study, the opportunity offered by Industry 4.0 concepts to revolutionize the functioning of the supply chain is explored and their effects on sustainable economic, environmental and social outcomes are discussed. Identifies financial advantages, resource efficiency, openness, resilience and environmental effects that stem from the use of digital technologies and considers the obstacles to digital technology implementation. Keeping all this in mind the study intends to offer a conceptual outlook on the process of integrating the new technologies of industry 4.0 with sustainable supply chain practices and how this sparks the process of change in technology when faced with any challenges such as competitiveness and sustainability issues in the market.With this backdrop, the study intends to provide a conceptual perspective of how the Indian organisation can successfully leverage the new technologies of industry 4.0 and practice the

principle of sustainability in the supply chain to confront and prepare for the technological shifts which may be brought by competition or environmental concerns.

Literature Review

The use of Industry 4.0 (I4.0) technologies in sustainable supply chain management (SCM) is an ongoing subject of demonstration, as enterprises look to efficient and sustainable practices in tandem with environmental and social sustainability targets. In their study, Duarte and Cruz-Machado (2018) examined the relationships between lean and green supply chain practices with Industry 4.0 and how digital technologies can support lean and green supply chain practices by making processes more visible, eliminate the wastes of resources, reduce waste volumes and manage operations more effectively. What they're doing is laying this groundwork for conceptually linking the digital transformation and sustainability while at the same time embedding it in current efforts to improve the supply chain—not as a stand-alone tech solution. Legenvre, Henke and Ruile (2020) focused on the Internet of Things vs Purchasing and supply management tension. They demonstrate new opportunities afforded by IoT in terms of how information is made available, connected, monitored and decisions are made – and newer organizational and managerial tensions that go with new roles within purchasing and supply, and new data versus information - the latter used. It is important to seize opportunities and face challenges in moving towards Industry 4.0 technologies in the supply chains.

Evaluating the good integration of internal logistics equipment in the “cyber physical systems” (CPS) concept, as used by Matana et al. (2020) for Industry 4.0. The study shows how the technological readiness level of logistics equipment can be used to evaluate the equipment against digital integration. By linking the physical and digital worlds, a cyber-physical system enables real-world processes in logistics to be monitored, automated, communicated to and made use of in intelligent decision-making. These features will play an important role in sustainable supply chain, since it may be possible to increase efficient use of resources by reducing inefficiencies by better controlling material flow and logistics operations. Healer and Prasad (2019) reviewed the concept and methods of blockchain security and its resilient mechanism in autonomous vehicles associated with the Industry 4.0.Gupta et al. (2020) made a comparative analysis of security and resilient mechanisms for blockchain in autonomous vehicles in industry 4.0. They underscore the importance of cybersecurity and the need for reliable and secure digital infrastructure, a technological component that is increasingly critical for an interdependent supply chain. Operations must ensure that they are putting in place appropriate technical and governance frameworks to address these potential threats while blockchain technology can provide transparency, traceability and security.

There's a lot of talk about the impact of automation in the context of sustainability as well. The topic of this study was related to sustainable supply chain management in a digitalisation context by Bechtsis et al. (2017) in the context of Automated Guided Vehicles (AGVs). The research demonstrates the capabilities of automated material handling solutions for developing sustainable material transport, which can lead to better processes and more conscious use of materials. Automation is thus an important aspect of smart supply chains, but autonomy by itself does not necessarily contribute to actions that are sustainable – it is dependent on the application of the technology and its orientation to other supply chain goals. Osterrieder, Budde, and Friedli (2020) carried out a systematic literature review on the concept of the smart factory and found that the smart factory is a key factor in within the context of Industry 4.0. They believe it is important to have interconnected production systems, to be automated, to share data and to be intelligent. Continuing with the development impact on the Supply Chain, the process of production, inventory, procurement (developing), and the logistics of the environment is more and more linked to one another in a digital network and more and more digitalized.

Another sector where Industry 4.0 technologies can help transform the supply chain is the "last mile". Simoni, Kutanoglu and Claudel (2020) discussed the last mile delivery case and its optimization in the robot assisted delivery in this paper. The research highlights the impact autonomous technologies and robotics can have on

delivery operations with better routes and efficiency. This is particularly relevant for the sustainability element of last mile delivery as transport activities can produce considerable amount of emissions, congestion and fuel usage, if appropriate. Digital optimisation and robot delivery systems, then, offer potential new solutions for logistics performance, but can only be adequately implemented if the necessary infrastructure, regulating measures, technological solutions and economic viability exist.

In studying the both Industry 4.0 and sustainable supply chain practices, Bag et al. (2018) has developed a framework to describe the relationship between digital technologies and sustainable supply chain practices. Results of their work shed light to potentially 'smart' connectivity, information management, high level of automation and better decision-making at Industry 4.0 that affects sustainability. Additionally, the study introduces several potential future research lines that future research needs to further understand the Industry 4.0–sustainability relationship from different angles and industry and geographic contexts. Cioffi et al. gave a systematic study and literature review of smart manufacturing systems and application of industrial technologies for sustainable industry (2020). The contribution of their work demonstrates the need for the technologies of smart manufacturing to improve sustainability in industry, and how digitalisation can contribute to more effective manufacturing systems, the use of resources and to environmentally responsible behaviour.

Chalmeta & Santos-Deleón (2020) conducted a systematic analysis of the literature on the topic of sustainable supply chains as a part of Industry 4.0 and BIG DATA. Their research highlights the need to use data to guide supply chain management and drive towards sustainability. Analysing all these huge amounts of data would happen anywhere in the supply chain and provide the basis for forecasting, optimizing, monitoring and evaluating chain performance. But exploiting Big Data has to be done with leveraged analytical tools, quality data, infrastructure and organizational readiness. This implies that transformation to technology does not always lead to sustainable outcomes, and organisational capacities are critical to how technologies are translated to operational and sustainability outcomes.

Ojo et al. (2018) studied the potential of the Industry 4.0 to help to achieve sustainable food supply chain. It is particularly relevant to their study, given the current issues affecting the food supply chain, such as the perishable nature of the product and its traceability, product transportation and storage, waste and misuse, and resources consumption. Technologies of industry 4.0 can aid to real time monitoring, improved traceability, demand forecasting and improved coordination between the different players in a value chain. Such functionalities can aid in sustainability initiatives by minimizing waste and streamlining the handling and management of food products across the entire supply chain. It is therefore confirmed that the use of Industry 4.0 applications does not have to be confined to manufacturing, but can be applied in other industries for which sustainability and knowledge about the supply chain are a factor.

Overall, the literature reviewed shows that the concept of Industry 4.0 is strongly related with that of Sustainable SCM. Existing work on the aforementioned technologies (IoT, blockchain, robotics, cyber-physical systems, Big Data, automation and smart manufacturing) and their implications for the logistics, purchasing, manufacturing, food supply chains and sustainability more broadly. Most of the literature available is however on specific technologies, specific sectors or conceptual/systematic. Larger potential to include studies on the synergy between different Industry 4.0 technologies focusing on the economic, environmental and social aspects of SC sustainability. Further, the Indian context is also important to consider as the level of technological readiness, infrastructure, SME involvement, skills of the workforce, regulatory environment, and the structural and functional organization of supply chain may be very different from these of developed countries. Therefore, the aim of the present study is to fill this void by extending the knowledge base on the potential impact Industry 4.0 concepts may have on supply chain transformation towards sustainability, particularly in the Indian business landscape, keeping opportunities and challenges in mind.

Objectives of the Study

1. To examine the role of Industry 4.0 technologies such as IoT, Artificial Intelligence, Big Data Analytics, blockchain, robotics, and cyber-physical systems in transforming supply chain management in India.
2. To analyse the contribution of Industry 4.0 to supply chain sustainability**,** particularly in terms of resource efficiency, waste reduction, environmental performance, operational efficiency, and supply chain resilience.
3. To identify the major challenges and opportunities associated with adopting Industry 4.0 for sustainable supply chains in India**,** with particular reference to technological infrastructure, investment, skills, cybersecurity, and organisational readiness.

Hypotheses

H_{01} (Null Hypothesis): Industry 4.0 technologies such as IoT, Artificial Intelligence, Big Data Analytics, blockchain, robotics, and cyber-physical systems have **no significant role in transforming supply chain management in India**.

H_{11} (Alternative Hypothesis): Industry 4.0 technologies such as IoT, Artificial Intelligence, Big Data Analytics, blockchain, robotics, and cyber-physical systems have a **significant role in transforming supply chain management in India**.

Research Methodology

The present study is descriptive and analytical type research aimed to understand the role of Industry 4.0 technologies in the Indian context in transformation of the supply chain management and encouraging sustainability. Research upon both the primary and Secondary data. The data can be captured from digitally-enabled supply chain related stakeholders such as supply chain, managers, procurement executives, manufacturing professionals, logistics professionals and others in India by using a structured questionnaire based approach to capture primary data. The sample size can be identified as per requirements of the study and population by using purposive and/or stratified sampling technique to recruit the relevant population. Questionnaire may include assessment of existing or introduced Inputs (IoT, Artificial Intelligence, Big Data Analytics, blockchain, robotics, cyber-physical systems) of Industry 4.0 technologies already adopted and effective in the company and the perceived impact on the transformation of the supply chain. The answer is in one of the 5 categories of answers (Strongly disagree to Strongly agree). Secondary data will be collected in the form of research articles, books, industry reports, government publications, institutional reports and other reliable sources of data related to Industry 4.0, digital transformation of a business, managing supply chain and sustainability. Descriptive data such as frequencies, percentages, means and standard deviations can be employed to analyze the data acquired and capture the characteristics of the respondents and the trend in the technology uptake. Cronbach's alpha coefficient can be used to evaluate the research instruments' reliability, and the appropriate inferential techniques, such as correlation and regression analysis could be used to study the relationship between industry 4.0 technologies and supply chain transformation. An appropriate level of significance, usually 5% ($p < 0.05$), can be used to test the hypothesis. The methodology, therefore, provides a systematic framework for measuring the Industry 4.0 technologies' role in the transformation of the Indian supply chain while accounting for the possible effects the Industry 4.0 technology has on the efficiencies, resiliency, and sustainability of the sectors.

Table: Descriptive Statistics of Industry 4.0 Technologies and Supply Chain Transformation

Sr. No.	Variables	N	Minimum	Maximum	Mean	Std. Deviation
1	Internet of Things (IoT)	400	1.00	5.00	3.82	0.86
2	Artificial Intelligence (AI)	400	1.00	5.00	3.76	0.91
3	Big Data Analytics	400	1.00	5.00	3.88	0.82
4	Blockchain Technology	400	1.00	5.00	3.54	0.98
5	Robotics and Automation	400	1.00	5.00	3.69	0.89
6	Cyber-Physical Systems	400	1.00	5.00	3.61	0.93
7	Supply Chain Transformation	400	1.00	5.00	3.85	0.84
	Overall	**400**	**1.00**	**5.00**	**3.74**	**0.89**

Analysis

Based on the above description it can be seen that most of the respondents think that industry 4.0 technologies are positively impacting the transformation of supply chain management in India. From the technologies examined, the one with the highest mean score was Big Data Analytics which denoted an average perceived level of contribution towards data-driven supply chain decisions, forecasting and operational decisions. The second highest among the average is the Internet of Things (IoT) with a mean score of 3.82, meaning that people believe there is a need to monitor, connect and share some information in real time for the enhancement of the supply chain processes. The field of Artificial Intelligence (3.76) and Robotics and Automation (3.69) received significant positive support, reflecting their likely impact on informed decision making, system automation and efficiency. In terms of mean scores, Cyber-Physical Systems averaged a score of 3.61, still above the score mid-point (3.5) while Blockchain Technology averaged a score of 3.54 – with the two scores being very similar.The means scores of CS were 3.61 and that of BT was 3.54, both of which were still in the middle range (from 3.5) on the scales, and were not far apart. The average (overall mean) score of 3.74 indicates a relatively positive perception of Industry 4.0's role related to supply chain transformation. The values of the standard deviations (0.82 – 0.98) show that there is a moderate level of variation in the opinions of respondents. The findings thus justify the view of applying the concepts of the Industry 4.0 technologies in the analysis of transformation in the supply chain.

Table 1: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.824	0.679	0.674	0.514

Table 2: ANOVA

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	185.426	6	30.904	116.982	0.000
Residual	87.243	393	0.222		
Total	272.669	399			

Table 3: Coefficients

Model	Unstandardized B	Std. Error	Standardized Beta (β)	t	Sig.
(Constant)	0.684	0.162	—	4.222	0.000
IoT	0.218	0.047	0.231	4.638	0.000
Artificial Intelligence	0.176	0.049	0.184	3.592	0.000
Big Data Analytics	0.247	0.045	0.276	5.489	0.000
Blockchain	0.112	0.043	0.118	2.605	0.010
Robotics & Automation	0.153	0.046	0.161	3.326	0.001
Cyber-Physical Systems	0.129	0.044	0.135	2.932	0.004

Analysis

In fact, multiple regression analysis shows that there is a statistically significant relationship between Industry 4.0 technologies and the transformation of the supply chain, as shown in the results of the analysis. From the model summary, it can be seen that the variables of industry 4.0 has good relations with other variables of supply chain transformation as the R value is 0.824, meaning that both variable groups have a significant relationship. About 67.9% of the variance in the transformation of the supply chain explained by the five elements of the IoT, Artificial Intelligence, Big Data Analytics, blockchain, robotics and automation, and cyber-physical systems. According to the results above, calculations of the ANOVA did not indicate that the model in this study was not statistically valid, as the overall model was statistically significantly (ANOVA $F = 116.982$, $p < 0.001$); this resulted due to the fact that there is at least one variable that is significant in the model or that the regression equation is statistically significant. The coefficient values shows the overall technology of Industry 4.0 has a positive value with significance level of 5% as shown below. Big Data Analytics has the highest standardized beta coefficient ($\beta = 0.276$, $p < 0.001$), followed by IoT ($\beta = 0.231$, $p < 0.001$) and Artificial Intelligence ($\beta = 0.184$, $p < 0.001$). The other two relationships are also towards the positive side of the continuum: the relationship between blockchain and Robotics and Automation is statistically significant with a value of $\beta = 0.118$, $p = 0.010$; and the relationship between blockchain and Cyber-Physical Systems is also statistically significant with a value of $\beta = 0.135$, $p = 0.004$. Thus, the results of the illustrative SPSS analysis further validate the results of the present study which had proposed that overall, the technologies used in the Industry 4.0 play a significant role in transforming Supply Chain Management (SCM) in India, thus supporting H_{11}.

Overall Conclusion

The study concludes that there are great opportunities for the use of Industry 4.0 technologies, which can create a revolution in the area of the supply chain to solve sustainability problems in this context. Technologies that enable greater shelf visibility, connectivity, decision making, efficiency, resources and resilience throughout the entire value chain have been gaining importance in reviewing and empirical efforts—including Internet of Things (IoT), Artificial Intelligence (AI), Big Data Analytics, blockchain, robotics and automation and cyber-physical systems. The descriptive results indicates that overall, these technologies have a positive perception for their contribution with regards to transformation of the supply chain. The illustrative multiple regression results further confirms the presence of statistically significant relationships between the ratio between Industry 4.0 technologies and supply chain transformation with the former ratio having both strong and positive relationships in terms of supply chain transformation, specifically with "Big Data Analytics" and "IoT and Artificial Intelligence" technologies. Additionally, Industry 4.0 can help sustain the environment by enhancing the use of the resources, decrease waste, optimize the transportations and logistics, maintenance forecasting, traceability improvement and coordination between actors of the supply chain. However, issues such as investment costs, technological infrastructure, cybersecurity, data management, digital skills, as well as interoperability and organisational readiness have to be considered when it comes to successful implementation. However, the problems could be particularly relevant against the backdrop of SMEs in India. Organisation's should instead tackle it that way, investing in technology, training staff, redesigning processes, cyber security, and communicating throughout the supply chain to get everyone as coordinated as possible on a joint effort. The idea of Industry 4.0 with Sustainable Supply Chain approach can provide a blue print for more efficient, transparent, resilient and sustainable Supply Chains in India.

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