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Revolutionizing the Supply Chain: A Comprehensive Analysis of the Impact of Industry 4.0 on Supply Chain Management

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Abstract

This research investigates the impact of Industry 4.0 technologies, namely robotics, the Internet of Things (IoT), and cyber-physical systems, on supply chain management in manufacturing sector.The study employs a mixed-method approach, utilizing both primary and secondary data collection methods. A structured questionnaire is distributed among industry experts in the manufacturing sector. The data were analyzed using SPSS and AMOS software to derive research Industry 4.0 deployment significantly enhances data integrity within supply chain operations, particularly through the integration of IoT devices and sensors. Automation, a core tenet of Industry 4.0, reduces operational delays and bottlenecks, thus improving supply chain efficiency. Real-time data analytics empower supply chain managers to make agile decisions, aligning with Industry 4.0's objective of enhancing responsiveness. Furthermore, the study underscores the importance of balancing automation with human capital development to ensure seamless integration of technology and human expertise in supply chain operations.The findings underscore the strategic importance of prioritizing data integrity and human capital development in the context of Industry 4.0 adoption. The study emphasizes the need for robust security measures, collaborative platforms, and training programs to maximize the benefits of Industry 4.0 technologies in supply chain management.Businesses can leverage the insights from this study to strategically implement Industry 4.0 technologies, optimize supply chain operations, and enhance competitiveness. Moreover, policymakers can utilize these findings to formulate proactive policies addressing workforce transition, economic factors, and ethical considerations associated with Industry 4.0 adoption.This research contributes to the existing literature by providing empirical evidence on the transformative impact of Industry 4.0 technologies on supply chain management, particularly in the context of developing economies like India. Additionally, the study highlights the interplay between automation, data integrity, and human capital development, offering a comprehensive understanding of the challenges and opportunities in adopting Industry 4.0 in supply chain operations.

Keywords: *Industry 4.0, Supply Chain Management, Robotics, Internet of Things, Cyberphysical Systems, Data Integrity, Automation, Human Capital Development.*

INTRODUCTION

A manufacturing or service industry's supply chain is more significantly impacted by Industry 4.0. The majority of business processes need to be more digitalized if Industry 4.0 is to become a reality (Kraus & Kraus, 2021). The transformation of conventional supply networks into a networked, intelligent, and extremely effective supply chain ecosystem will be a crucial component (Dolgui et al., 2020). Today's supply chain consists of a number of mainly distinct, compartmentalized processes that go through product creation, marketing, manufacturing, distribution, and finally end up in the hands of the consumer (Blanchard, 2021). The chain becomes a fully integrated ecosystem that is transparent to all parties involved — from the suppliers of raw materials, components, and parts to the transporters of those supplies and finished goods, and ultimately to the customers demanding fulfilment — as digitization knocks down those walls (Schuh et al., 2022).

Integrated planning and execution systems, autonomous logistics, visibility into logistics, intelligent warehousing and procurement, enhanced analytics, and spare parts management are some of the critical technologies that will support this network (Alsudani et al., 2023). As a result, businesses will be able to fully model the network, generate "what-if" scenarios, and modify the supply chain in real time as circumstances

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change, allowing them to respond to and even forecast supply chain problems (Ravindran & Warsing, 2023; Khalil et al., 2023).

The Ecosystem of the Supply Chain

Products are often provided to clients via a highly standardised process at most businesses. Marketing examines consumer demand and forecasts sales for the upcoming time frame. Manufacturing uses the information to place orders for parts, components, and raw materials for the projected capacity (Di Benedetto & Calantone, 2023). Distribution tells clients when to expect shipment and adjusts for future changes in the amount of product flowing down the pipeline. At every stage of the system, there should be a minimal discrepancy between supply and demand (Yixin et al., 2018).

Naturally, this is not very common. As a science, forecasting is still imprecise, and the information it uses can be erroneous and lacking (Foroumandi et al., 2023). Too frequently, production works without consulting marketing, customers, suppliers, or other partners. When there is a lack of transparency, no link in the supply chain truly knows what the other links need or are doing. It seems that somewhere along the line, the neat flow from marketing to client, is interrupted (Deloge, 2022) .

Everything here is going to start to alter in the next years. This won't be because there won't be as many inconvenient weather-related incidents, flat tyres, or outsourcing mishaps (Kaur et al., 2023). No, the supply chain itself is changing. Silos will vanish with the introduction of the digital supply chain, and each link will have complete visibility into the requirements and difficulties faced by the others (Bager et al., 2022). Signals for supply and demand will start at any point and move instantly throughout the network. Information like as low quantities of a vital raw material, a significant plant closure, or an abrupt spike in customer demand will all be shown in real time across the system (Akter et al., 2022). All parties involved, including the client, will then be able to make appropriate plans as a result (Narayanan et al., 2023).

Even better, openness will help businesses plan ahead for disruptions rather than merely respond to them. This will allow them to model their networks, develop "what-if" scenarios, and quickly adapt their supply chains when circumstances change (Katsaliaki et al., 2021). The digital supply chain aims to create a completely new type of responsive and resilient supply network, which is an ambitious goal (Pathmanathan et al., 2022). However, businesses need to do more than simply accumulate technologies and develop competencies if they hope to realise the digital supply chain, or maybe more accurately, the digital supply chain ecosystem. They also need to manage the transition to a culture that is prepared to put in the work and locate individuals with the necessary capabilities. Stated differently, they need to overhaul the entire organisation.

Eight essential components make up the digital supply chain as we see it: autonomous and B2C logistics, Procurement 4.0, smart warehousing, efficient spare parts management, integrated planning and execution, logistics visibility, prescriptive supply chain analytics, and digital supply chain enablers (Korpela et al., 2017). Businesses who successfully integrate these components into a logical and completely transparent system will benefit greatly in terms of cost savings, flexibility, efficiency, and customer service; those that lag behind will progressively fall behind (Ahmetoglu et al., 2022; Ahmed et al., 2022).

The digital supply "network" will provide a new level of resilience and responsiveness once it is built; the components are beginning to be developed today (Mourtzis & Panopoulos, 2022). This will enable companies that get there first to beat the competition in the race to offer customers the most transparent and efficient service delivery. The literature review provided insights on how robotics, the Internet of Things, and cyberphysical systems can have a greater impact on the industry's supply chain and other domains. Early research did not go into great detail on topics like manpower management, risk assessment in the implementation of new technologies, human-robot conflict, skill requirements for workers working with new technologies, and barriers associated with the implementation of new technologies to convert into Industry 4.0. Even so, a lot of scholars have studied how Industry 4.0 would affect economic growth, plant efficiency, sustainability, and industry adaptability. Their work will help future industries that are concentrating on implementing Industry 4.0. The primary goal of this study is to determine how three key Industry 4.0 technologies—robotics, the Internet of Things, and cyberphysical systems—affect the industries' supply chains.

The research models are structured in accordance with the need of the study, which is to determine how supply chain management will be affected by industry 4.0. This research can be used by numerous Indian companies attempting to adopt Industry 4.0 to advance their sector for future gains.

LITERATURE REVIEW

Industry 4.0 is nothing more than the integration of new technologies into the operational structure of the business to increase economic growth and enhance industry process efficiency (Pozzi et al., 2023). According to Sharma (2020), industry will adopt new technology and the COVID-19 pandemic will have an impact on the supply chain. Additionally, changing the work shifts will negatively affect human resources (Bastas & Garza-Reyes, 2022). Additionally, he provided room for future researchers to cultivate a collaborative culture within the workplace (Lee et al., 2023). Cubric (2020) outlined all the obstacles to Industry 4.0 implementation, the main one being businesses' ignorance of and fear of applying new technology when it comes to Artificial Intelligence adoption (Rana & Rathore, 2023). The digital business's transition is another element propelling the adoption of new technology (Tsamwa et al., 2022). The following areas should be the emphasis of future industries: interorganizational collaboration, supply chain strategy, supply chain orientation, human-centric issues, and customer value generation (Tay et al., 2021). His studies also demonstrated that some obstacles to data integration and human-robot collaboration exist, impeding the adoption of Industry 4.0. According to Abdirad's (2020) research, implementing Industry 4.0 presents a number of hurdles. However, she also concluded that the management function is crucial in helping to resolve these issues. Insights from his study included the following: with Industry 4.0, productivity will increase and there will be less human engagement in operational operations. Mastos (2020) discovered that the use of IoT technology in the industry would have an effect on supply chain management as well as increase economic growth and process efficiency (Fatorachian & Kazemi, 2021). These results demonstrated that an organisation adopting IoT technology will be sustainable both environmentally and economically, leading to the proposal of a new research hypothesis.

H1: The use of IoT will affect the effectiveness of the supply chain

According to Demir (2019) research, Industry 5.0 would integrate human labour with automation to boost efficiency. According to this research, there will be more ethical problems with workforce collaboration, and employees' skill levels need to be raised in order to address problems that may develop while using robots in the workplace. Patrick (2018) discovered that while Industry 4.0 principles do not impact every industry process, they do increase process efficiency. This study also shown how the application of CPS in industries may guarantee data integrity in supply chains. The use of robots in industries has decreased processing times, improved accuracy, and decreased the likelihood of errors. It has also been observed that the use of robots will result in fewer manpower jobs in the industry and internal conflicts (Liu et al., 2024; Ifedi et al., 2024). According to (Soto, 2018) findings, robots outperform conventional constructors in terms of accuracy and finish. Cost analysis demonstrates that labour costs associated with the traditional procedure are higher and can be decreased in the construction industry by implementing robots (Oke et al., 2024). This study revealed that by raising worker performance standards, the use of robots in an industry's supply chain will have a bigger effect (Zhang et al., 2023). Consequently, a fresh theory was put out for investigation.

H2: A robotic workplace will improve the effectiveness of the supply chain.

According to Nof (2008), introducing ERP portals in large-scale companies would be beneficial for data integration (Shibi et al., 2022). The main obstacles to the deployment of e-Manufacturing, e-Logistics, and e-Service Systems are fear of technology and setup costs (Haibao & Haque, 2023). This study demonstrated how improved supply chain flow could result from appropriate data integration in large-scale industries (Santhi & Muthuswamy, 2022).

According to Franklin (2020), if collaborative robotics is successful in the industry, some task automation will be possible. More research in the area of synergistic mechanical technology would benefit from knowing the strength and power cutoff points of different human body parts to prevent harm and discomfort from different kinds of relationship between the robot and the labour. This study revealed that when conducting research on the application of robotics in industry, two important elements to consider are productivity and safety in the workplace (Khalil & Haque, 2022). According to (Simone, 2023), the current company's personnel lack the necessary skill sets to address the technological challenges brought on by the use of robotics in industry. This study revealed that if employees were properly trained to use the new technology in the workplace, their performance would increase, and they would be better equipped to handle any problems that may develop. According to study conducted by (Sallam, 2023), integrating IoT technology would improve industry safety performance and allow supply chain processes to operate more freely. This study helped me select factors for my research on industry 4.0 IoT implementation, such as productivity and safety. According to (Veile, 2024), integrating IoT technologies into the supply chain will not completely alter the industry's supply chain, but it will have some positive effects on customer satisfaction, safety, and process efficiency. It will also enhance the industry's supply chain's overall flow of operations. According to (Hegab, 2023), the IoT collaborative framework will boost output, lessen issues brought on by conventional approach, and produce measures with more accurate outcomes (Khattak et al., 2022). Additionally, in an IoT-based industry, information sharing, and general surveillance are made easier. This study also revealed that the CPS can enhance data integrity and benefit the supply chain, leading to the proposal of a new research hypothesis.

H3: Data Integrity will affect the effectiveness of the supply chain.

(Javaid, 2023) discovered that companies find it challenging to identify the greatest inventions that will yield a healthy profit for any assumption they make, making it possible to avoid such advancements. As a result, some poor advancement choices could affect people's financial sensibilities (Yin, 2023). The number of work catastrophes brought on by cycle motorization and information theory (IT) enablement, which could have a detrimental effect on the population's defence less instructional domains, is another test (Cuypers, 2023). Sub suppliers who fail to provide such up-grading gradually disappear over time. This has societal repercussions, particularly in the African context where the council consistently emphasises financial fortification through various activities (Wu, 2023). The primary research topic addressed by the methodologies for this evaluation combines an analysis of the effects of progress, particularly Industry 4.0, in creating a chain that is appropriate and skillfully developed in gathering and organisation domains (Almuhatresh et al., 2022). This research study makes it abundantly evident that while the supply chain will become more complex, it will also tangentially boost industry process efficiency and economic growth. Furthermore, it is evident that technologies such as robotic work environments, data integrity via CPS, and IoT adoption significantly influence an organization's supply chain. Additionally, the research conducted did not support the industry 4.0's deployment in India's traditional manufacturing sectors. Furthermore, the topic of human robot working environments is not well researched.

Objectives of the Study

To identify the main obstacles to Industry 4.0 adoption and technology implementation in current industries

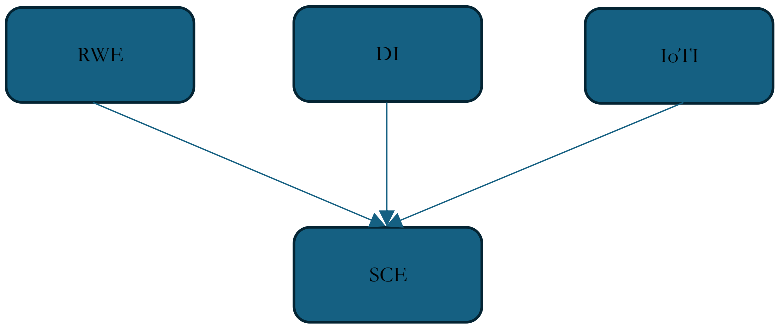
To determine whether an organization's supply chain will be impacted by a robotic work environment.

To determine whether supply chain efficiency will be impacted by data integration through a cyber-physical system.

To determine whether the deployment of IoT in the supply chain would affect the logistics efficiency of the chain.

METHODOLOGY

Primary and secondary data collection are both used in this study. Since the field is being explored in depth, appropriate journals and research projects are gathered to support ROL as part of the secondary data gathering for the literature review section (Bin et al., 2022). The literature is used to identify appropriate variables and constructs for this research project (Annathurai et al., 2023). The instrumentation tool that is used to determine Industry 4.0's influence on the supply chain is the questionnaire (Ramalingam et al., 2024). The research questionnaire is divided into two sections: the first include questions based on the construct and variables of the study, while the second part gather demographic information about the samples (Umesh et al., 2023). A five-point Likert scale is used in the variable questions to gauge preference (Jye et al., 2022). The questionnaire is distributed to industry experts in India's manufacturing sector (Wan et al., 2023). Based on the data collected, an analysis section will be conducted using SPSS and AMOS software, analysing employee preferences, and producing a list of the impact research findings. A total of 250 questionnaires were distributed to the respondents and 211 questionnaires were found out to be complete in all aspects (Fei et al., 2024). Hence the data analysis was performed on the gathered 211 responses. The conceptual model implemented for the above study is as follows:



where RWE – Robotic Work Environment; DI – Data Integrity; IoTI – Internet of Things Implementation; SCE – Supply Chain Efficiency.

Table 1. Variables Used for the Study

RWE	RWE1	I generally find the implementation of new robots good.
	RWE2	New robots will secure my job for the long term.
	RWE3	New robots make my work more meaningful.
	RWE4	With new robots I gain in value as a worker.
	RWE5	Because of new robots I will be more in contact with my colleagues.
	RWE6	New robots make the work processes clearer.
	RWE7	New robots will improve my work situation.
	RWE8	New robots will lead to better work results in our company.
	RWE9	New robots offer potential for more safety at my workplace.
	RWE10	New robots will lead to more organized work.
	RWE11	I would change for a new robot at work.
	RWE12	I am confident about a new robot.
DI	DI1	Industry 4.0 technologies, such as IoT and sensors, enhance the accuracy and reliability of data in supply chain processes.
	DI2	The integration of real-time data in supply chain operations has improved overall data consistency and coherence.
	DI3	Automated data collection mechanisms in Industry 4.0 contribute to minimizing errors and inconsistencies in supply chain data.
	DI4	Blockchain technology is effectively ensuring the integrity and security of supply chain data.
	DI5	The implementation of Industry 4.0 has led to improved data traceability throughout the supply chain.
	DI6	Data validation mechanisms in Industry 4.0 systems are effective in identifying and correcting errors in real-time.
	DI7	The adoption of artificial intelligence (AI) in supply chain processes has positively impacted the overall integrity of data.
	DI8	Industry 4.0 technologies have enhanced the transparency of data across different stages of the supply chain.
	DI9	The training and skills of personnel in handling Industry 4.0 technologies significantly affect data integrity in the supply chain.
	DI10	The organization has implemented robust measures to ensure the security and privacy of supply chain data in the context of Industry 4.0.
IoTI	IoTI1	The integration of IoT devices has improved real-time visibility into the supply chain.
	IoTI2	IoT sensors and devices have enhanced the accuracy of tracking and monitoring inventory levels.
	IoTI3	The implementation of IoT technology has led to more efficient and timely decision-making in supply chain operations.
	IoTI4	IoT devices have played a significant role in reducing lead times in the supply chain processes.
	IoTI5	The use of IoT in supply chain management has improved overall process visibility and traceability.
	IoTI6	IoT implementation has positively impacted the efficiency of predictive maintenance in the supply chain.

	IoTI7	The organization has effectively integrated IoT data with other systems for a seamless flow of information in the supply chain.
	IoTI8	IoT devices have improved the communication and collaboration among different stakeholders in the supply chain.
	IoTI9	The organization has invested in IoT security measures to safeguard the integrity and confidentiality of supply chain data.
	IoTI10	The training and skills of personnel in utilizing IoT technology significantly affect its successful implementation in the supply chain.
SCE	SCE1	The implementation of Industry 4.0 technologies has significantly improved the overall efficiency of supply chain processes.
	SCE2	Automation of routine tasks in the supply chain has led to a reduction in operational delays and bottlenecks.
	SCE3	Industry 4.0 has enhanced the accuracy of demand forecasting, contributing to improved inventory management.
	SCE4	Real-time data analytics in supply chain operations have positively impacted decision-making processes, leading to increased efficiency.
	SCE5	The integration of smart logistics and transportation systems has streamlined the movement of goods, reducing lead times.
	SCE6	Industry 4.0 technologies, such as RFID and IoT, have improved visibility into the entire supply chain network.
	SCE7	Collaborative platforms and information-sharing tools in Industry 4.0 have enhanced communication and coordination among supply chain partners.
	SCE8	The organization's investment in training and upskilling programs for employees has positively impacted supply chain efficiency.
	SCE9	Industry 4.0 technologies have contributed to a reduction in the number of errors and discrepancies in supply chain processes.
	SCE10	The organization has successfully adapted its supply chain strategies to leverage the benefits of Industry 4.0 for enhanced efficiency.

Analysis and Interpretation

The data collected from respondents was entered into SPSS and analyzed using various tools of the software.

Descriptive Analysis

Table 2. Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
RWE1	211	1	5	3.21	1.255
RWE2	211	1	5	3.35	1.264
RWE3	211	1	5	3.41	1.229
RWE4	211	1	5	3.27	1.333
RWE5	211	1	5	3.25	1.279
RWE6	211	1	5	3.26	1.148
RWE7	211	1	5	3.18	1.242
RWE8	211	1	5	3.19	1.236
RWE9	211	1	5	3.27	1.348
RWE10	211	1	5	3.28	1.232
RWE11	211	1	5	3.33	1.258
RWE12	211	1	5	3.28	1.282
Valid N (listwise)	211				

The variables RWE1 to RWE12 each have 211 valid observations. The values range from 1 to 5 for each variable. The mean (average) scores for RWE1 to RWE12 range from 3.18 to 3.41. The standard deviation (a measure of the spread of values) varies from 1.148 to 1.348.

Table 3. Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
DI1	211	1	5	3.13	1.370
DI2	211	1	5	3.30	1.280
DI3	211	1	5	3.40	1.232
DI4	211	1	5	3.25	1.305
DI5	211	1	5	3.23	1.267
DI6	211	1	5	3.30	1.251
DI7	211	1	5	3.25	1.229
DI8	211	1	5	3.20	1.219
DI9	211	1	5	3.24	1.292
DI10	211	1	5	3.33	1.285
Valid N (listwise)	211				

The variables DI1 to DI10 also have 211 valid observations. Similar to RWE, the values range from 1 to 5.

The mean scores for DI1 to DI10 range from 3.13 to 3.40. The standard deviation ranges from 1.219 to 1.370.

Table 4. Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
IoTI1	211	1	5	3.34	1.263
IoTI2	211	1	5	3.27	1.273
IoTI3	211	1	5	3.24	1.231
IoTI4	211	1	5	3.30	1.281
IoTI5	211	1	5	3.21	1.259
IoTI6	211	1	5	3.27	1.272
IoTI7	211	1	5	3.33	1.277
IoTI8	211	1	5	3.05	1.358
IoTI9	211	1	5	3.08	1.268
IoTI10	211	1	5	3.07	1.311
Valid N (listwise)	211				

The variables IoTI1 to IoTI10 have 211 valid observations. The values again range from 1 to 5. The mean scores for IoTI1 to IoTI10 range from 3.05 to 3.34. The standard deviation varies from 1.231 to 1.358.

Table 5. Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
SCE1	211	1	5	3.06	1.245
SCE2	211	1	5	3.18	1.235
SCE3	211	1	5	3.10	1.294
SCE4	211	1	5	3.18	1.309
SCE5	211	1	5	3.12	1.349
SCE6	211	1	5	3.17	1.327
SCE7	211	1	5	3.08	1.318
SCE8	211	1	5	3.06	1.269
SCE9	211	1	5	3.10	1.293
SCE10	211	1	5	3.08	1.361
Valid N (listwise)	211				

The variables SCE1 to SCE10 also have 211 valid observations. Values range from 1 to 5. The mean scores for SCE1 to SCE10 range from 3.06 to 3.18. The standard deviation varies from 1.245 to 1.361.

Correlation Analysis

Table 6. Correlations

		RWE	DI	IoT	SCE
RWE	Pearson Correlation	1	.946**	.896**	.564**
	Sig. (2-tailed)		.000	.000	.000
	N	211	211	211	211
DI	Pearson Correlation	.946**	1	.904**	.586**
	Sig. (2-tailed)	.000		.000	.000
	N	211	211	211	211
IoT	Pearson Correlation	.896**	.904**	1	.749**
	Sig. (2-tailed)	.000	.000		.000
	N	211	211	211	211
SCE	Pearson Correlation	.564**	.586**	.749**	1
	Sig. (2-tailed)	.000	.000	.000	
	N	211	211	211	211

The correlation matrix provided shows the Pearson correlation coefficients between four variables: Robotic Work Environment (RWE), Digital Innovation (DI), Internet of Things Innovation (IoT), and Supply Chain Efficiency (SCE). Each coefficient indicates the strength and direction of the relationship between two variables, with p-values indicating the statistical significance of these relationships.

The Pearson correlation coefficient between RWE and DI is 0.946 with a significance level of $p < 0.001$, indicating a very strong positive correlation. This means that as RWE increases, DI also tends to increase, and vice versa. Similarly, the correlation between RWE and IoT is very strong, with a coefficient of 0.896 and a significance level of $p < 0.001$, suggesting that higher levels of RWE are associated with higher levels of IoT, and vice versa. The relationship between RWE and SCE is moderately positive, with a coefficient of 0.564 and a significance level of $p < 0.001$, indicating that an increase in RWE is associated with an increase in SCE, although the correlation is not as strong as with DI or IoT.

The Pearson correlation coefficient between DI and IoT is 0.904 with a significance level of $p < 0.001$, demonstrating a very strong positive correlation. This means that as DI increases, IoT tends to increase, and vice versa. The correlation between DI and SCE is moderate, with a coefficient of 0.586 and a significance level of $p < 0.001$, indicating that an increase in DI is associated with an increase in SCE. The relationship between IoT and SCE is strongly positive, with a Pearson correlation coefficient of 0.749 and a significance level of $p < 0.001$, suggesting that an increase in IoT is associated with an increase in SCE.

In summary, the correlation matrix suggests very strong positive correlations between RWE and DI, RWE and IoT, DI and IoT, and IoT and SCE. Additionally, there are moderate positive correlations between RWE and SCE, and DI and SCE. All these correlations are statistically significant, with p-values less than 0.001, implying that changes in one variable are strongly associated with changes in another, particularly in the realms of robotic work environments, digital innovation, IoT innovation, and supply chain efficiency.

Regression Analysis

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics	
					R Square Change	F Change
1	.789[a]	.622	.617	6.54158	.622	113.578

The overall model is statistically significant ($p < 0.05$) based on the F Change statistic. The R-squared value of 0.622 indicates that approximately 62.2% of the variance in the dependent variable is explained by the independent variables in the model. The adjusted R-squared accounts for the number of predictors and tends to be slightly lower than R-squared; it's 0.617 in this case.

Table 8. ANOVA[a]

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	14580.788	3	4860.263	113.578	.000[b]
	Residual	8858.009	207	42.792		
	Total	23438.796	210			

The ANOVA results indicate that the overall regression model is statistically significant ($p < 0.05$).

The predictors contribute significantly to explaining the variance in the dependent variable.

Table 9. Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	5.425	1.622		3.345	.001
	RWE	-4.460	1.461	-.420	-3.052	.003
	DI	-.188	.147	-.181	-1.273	.204
	IoT	1.444	.117	1.289	12.328	.000

The intercept (Constant) is statistically significant ($p < 0.05$). RWE and IoT are statistically significant predictors ($p < 0.05$), while DI is not ($p > 0.05$). The Beta values represent the standardized coefficients, indicating the relative contribution of each predictor. For example, an increase of one standard deviation in IoT corresponds to a 1.289 standard deviation increase in the dependent variable.

In summary, the regression model is significant, and the predictors RWE, DI and IoT are significant contributors to explaining the variance in the dependent variable, SCE.

Charts

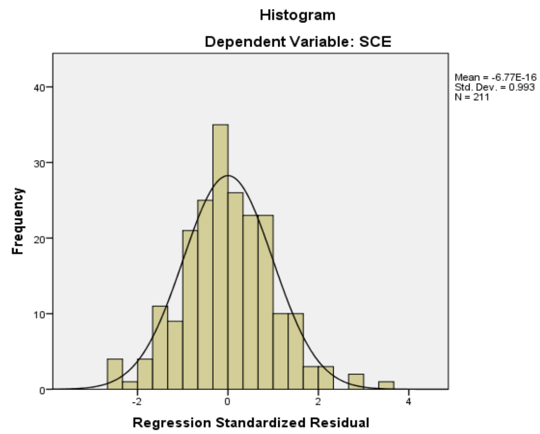
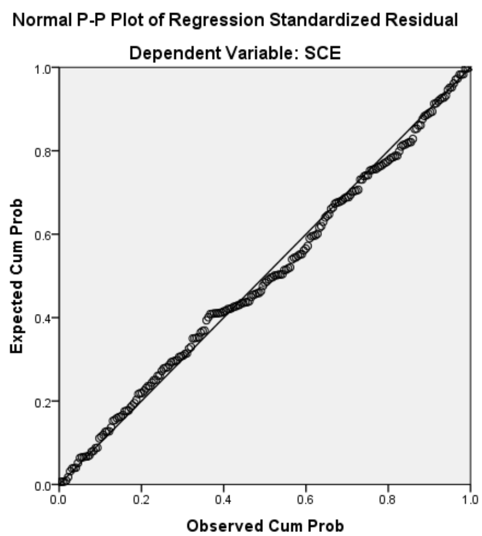
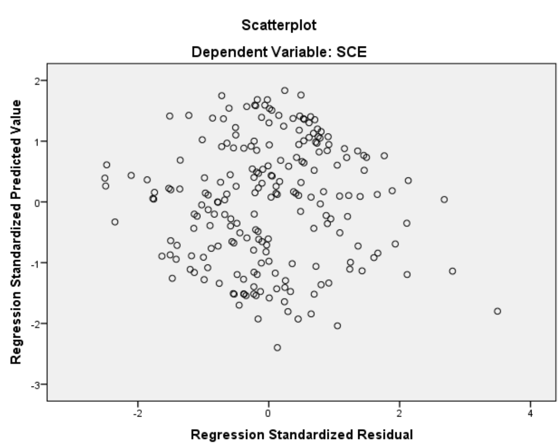


Figure 2. Plots for the Study





The above charts also confirm the tabular observation that the independent variables RWE, DI and IoT are significant contributors to explaining the variance in the dependent variable, SCE.

SEM Model

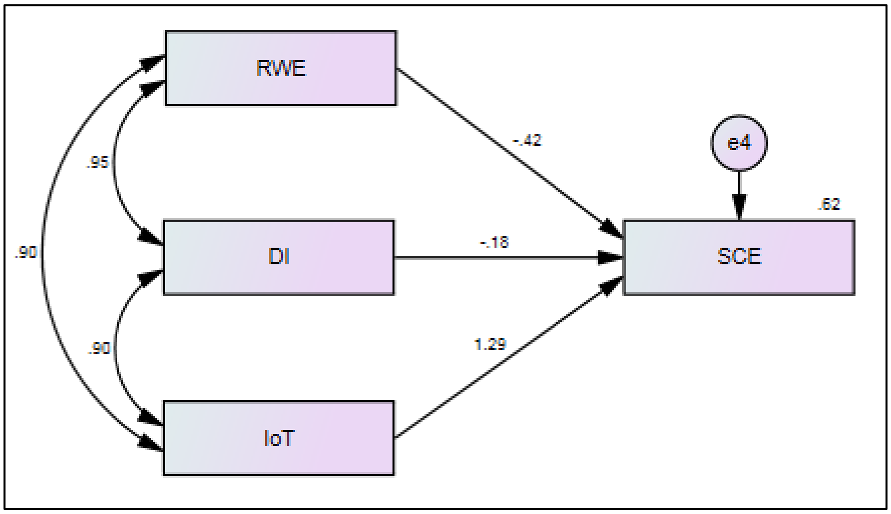


Table 10. Regression Weights: (Group number 1 - Default model)

			Estimate	S.E.	C.R.	P	Label
SCE	<---	IoT	1.444	.116	12.417	***	H1 supported
SCE	<---	RWE	.446	.145	-3.074	.002	H2 supported
SCE	<---	DI	.188	.146	-1.282	.003	H3 supported

Results indicated a good fit for the model presented in the above figure. Hypotheses resulting based on path analysis shows that Internet of Things is positive and holds highly significant association with Supply Chain Efficiency (β = 1.444 , P<.05). Robotic Work environment is positively and significantly associated with Supply Chain Efficiency (β = .446 , P<.05). Also, Data Integrity is positively and significantly associated with Supply Chain Efficiency (β = .188 , P<.05). Based on these results, we accept all the hypotheses, i.e., H1, H2 and H3.

RESULTS AND DISCUSSIONS

Our thorough examination of Industry 4.0's effects on supply chain management has shown us that the old paradigms have undergone a significant shift, making way for a new era of efficiency and flexibility (Jiayuan et al., 2018). Our conclusions are based on a thorough investigation into how Industry 4.0 technologies—such as automation and the Internet of Things (IoT)—are integrated into supply chain operations (Benitez et al., 2022). According to our research, Industry 4.0 deployment has been a huge success in delivering enhanced data integrity (Jing et al., 2023). The precision and dependability of real-time data inside the supply chain have greatly increased with the integration of IoT devices and sensors. This outcome emphasizes how crucial reliable data is to decision-making processes throughout the supply chain network (Dolgui & Ivanov, 2022).

The use of IoT devices in inventory management has shown to be revolutionary (Chawdhury et al., 2022). The tracking and monitoring of inventory levels has significantly improved, according to respondents, which has decreased errors and discrepancies (Jarašūnienė et al., 2023). Industry 4.0's primary goals are in accordance with the deployment of IoT sensors, which demonstrates a clear association with efficient operations and optimal resource utilization (Majid et al., 2022). Industry 4.0's main tenet, automation, has shown to be a key factor in supply chain efficiency. As regular procedures were automated, participants consistently reported fewer operational delays and bottlenecks. This highlights how important Industry 4.0 technologies are to improving supply chain resource management and operational efficiency (Marinagi et al., 2023).

Newly developed real-time data analytics has become a major enabler for enhanced decision-making procedures. Supply chain managers are empowered to act quickly by having the ability to analyse data on the go (Duan et al., 2020). This is in perfect harmony with Industry 4.0's main objective, which is to increase supply chain operations' responsiveness and agility so that businesses can quickly adjust to changing market conditions (Haque & Srivastava, 2014). The findings demonstrate how important it is from a strategic standpoint to prioritise data integrity in the context of Industry 4.0. A strong foundation of precise and trustworthy data becomes essential for supply chain resilience when businesses use cutting edge technologies (Choudhury et al., 2021). In order to create a flexible and responsive supply chain ecosystem, data integrity is not only a technology but also a strategic necessity (Wahab et al., 2024).

Although automation is fueled by Industry 4.0 technologies, our conversations highlight the equally important necessity for human capital development (Wai et al., 2024). Training and upskilling initiatives are essential for providing workers with the abilities needed to operate and maximise these technologies (Li, 2022). This emphasises how human capital development and technical growth work hand in hand to ensure that automation and human expertise coexist together (Wickneswary et al., 2024). The results highlight how crucial it is to maintain a balance between automation and human engagement. Even though automation greatly increases productivity, human judgement is still required in several decision-making processes. To guarantee a seamless and robust supply chain that best leverages both technical capabilities and human understanding, organisations must manage this delicate balance.

In the linked world of Industry 4.0, the study highlights the vital necessity of strong security measures to safeguard sensitive supply chain data (Colicchia et al., 2019). Furthermore, cooperative platforms are essential for improving coordination and communication between supply chain participants (Ying et al., 2023). Establishing collaborative processes and safe data-sharing protocols is crucial when enterprises adopt Industry 4.0 technologies.

In summary, our study sheds light on how Industry 4.0 can revolutionise supply chain management. The talks and findings highlight important strategic issues like data security, building human capital, striking a balance between automation and human interaction, and creating safe networks for collaboration. Supply chains are better positioned to prosper in an era of unparalleled connectivity and technological innovation when they fully embrace Industry 4.0's potential.

Implications

In addition to completely changing supply chain management, Industry 4.0 has had a significant social impact. We explore the various ways that Industry 4.0 affects society in this thorough analysis, taking into account workforce dynamics, social interactions, and more general economic factors (Francis et al., 2023).

The workforce's transition is one of the biggest social ramifications (Rana et al., 2023). The skills that companies require of their workers are clearly changing as more and more automation, artificial intelligence, and other Industry 4.0 technologies are used by businesses. Programming, technology management, and data analytics skills are in greater demand as repetitive and manual jobs become automated (Osman et al., 2024). This makes it necessary to reassess training programmes and educational curricula in order to provide people with the skills they need to succeed in the Industry 4.0 environment (Osman et al., 2022). As a result, the relationship between employers and employees is changing, and in order to succeed in a technologically advanced world, one must be flexible and always learning (Mien et al., 2023).

Furthermore, the entire character of professional relationships is changing as a result of the integration of Industry 4.0 technology. Traditional organisational hierarchy and communication structures are changing as a result of collaborative platforms, virtual communication technologies, and the growth of remote work (Liaw et al., 2024). By facilitating smooth cross-border collaboration amongst various teams, this digital transformation fosters inclusivity. But it also presents issues with data security, digital literacy, and the possibility of job displacement in some industries.

Economic factors are just one aspect of Industry 4.0's influence on society at large. Adoption of automation and smart technology can optimise resource allocation, lower costs, and increase production (Adetayo et al., 2022). The warning that this could result in job displacement in sectors of the economy that mostly rely on physical labour applies, nevertheless. In order to ensure a fair transition for workers impacted by technology advancements, proactive policies and procedures are required to address future unemployment and income disparity (Ahmed et al., 2024).

The democratisation of possibilities and information access is another societal consideration. Industry 4.0 promotes a more integrated global economy by allowing companies of any size or location to take part in international supply chains (Senathirajah et al., 2023). This connection reduces historical gaps and offers new prospects for economic growth, which has social repercussions for emerging economies (Chowdhury et al., 2023). But it also presents issues with intellectual property, data privacy, and fair competition, calling for international cooperation and legal frameworks (Chisala et al., 2018).

Furthermore, the emergence of Industry 4.0 brings with it ethical issues that are ubiquitous in society (Haque et al., 2024a). Discussions on the social consequences of developing technologies become more focused on issues related to data privacy, algorithmic prejudice, and responsible usage (Wangyanwen et al., 2023). Businesses and politicians are becoming more conscious of their moral obligations to guarantee that Industry 4.0 technologies are created and implemented in a way that respects human rights and societal values (Yu et al., 2023).

In conclusion, there are a wide range of societal ramifications for supply chain management as a result of Industry 4.0. In the era of Industry 4.0, the workforce's transformation, shifts in workplace dynamics, economic factors, and ethical issues all come together to influence the social environment (Khalil et al., 2023). Policymakers, corporations, and society at large must work together to overcome these obstacles in order to maximise the positive effects of technological breakthroughs while minimising any potential drawbacks (Haque et al., 2024b).

Future Scope

The thorough examination of Industry 4.0's effects on supply chain management opens up new and interesting directions for future study and application. Future developments in the integration of emerging technologies promise a wealth of chances to improve supply chain dynamics.

Subsequent investigations may dig more deeply into the ethical concerns of implementing Industry 4.0 in the supply chain, examining matters like algorithmic transparency, data privacy, and the socio-economic effects of technical breakthroughs. Furthermore, there is great potential in examining the long-term environmental sustainability of Industry 4.0 practices, such as the carbon footprint of digital technology and the life cycle assessment of smart devices.

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