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Leveraging of Industry 4.0 on Supply Chain Performance

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***Abstract*:** Businesses can meet the constantly changing demands of customers and stakeholders while optimising supply chain performance with the help of Big Data's predictive insights, IoT's real-time monitoring, and AI's intelligent automation. The main goal of this study is to examine how important dependent variables—supply chain responsiveness are impacted by Industry 4.0 technologies (Big Data, IoT, and AI) and mediating impact of technology adaption & integration. In order to gain a deeper understanding of these technologies' significance in contemporary supply chain strategies, this study aims to determine how much the adoption and integration of these technologies affect supply chain operations and customer perceptions. The process of gathering data will be done by using survey or questionnaires from industrial expert. The relationships between these variables will be evaluated using statistical techniques, such as smart PLSEM. The information can be used by policymakers to create frameworks for regulations that encourage the adoption of Industry 4.0 technologies in supply chains, promoting innovation and sustainability. Supply chain professionals will learn important information about the potential advantages of adopting new technology, which will help them make investment decisions.

Keywords: Leveraging, Industry, supply Chain, performance

1. Introduction

The development, manufacturing, distribution, and delivery of goods and services from suppliers to customers are all part of a supply chain, which is a network of businesses, people, activities, information, and resources. It includes every procedure and action needed to transfer goods or services from the original raw material supplier to the final customer. Typically, the supply chain consists of several middlemen, manufacturers, wholesalers, retailers, suppliers, and logistics companies (Büyüközkan & Göçer, 2018). The following main ideas may be used to summarise the importance of a well-managed supply chain for an organisation. By streamlining operations, cutting waste, and lowering inventory carrying costs, effective supply chain management may save money (Lambert & Enz, 2017). It enables businesses to increase overall operational efficiency and get goods at the cheapest cost. Also, facilitating a speedier reaction to shifts in the market, client wants, and emerging trends, an efficient supply chain may provide an organisation a competitive edge (Garay-Rondero, Martinez-Flores, Smith, Morales, & Aldrette-Malacara, 2020). Businesses who can produce goods more quickly, more cheaply, and of greater quality will be able to surpass their rivals. By making it easier for new goods and technology to be introduced, a responsive supply chain may promote innovation

(Wieland, 2021). It makes it possible for businesses to develop and enter new markets. Reaching sustainability objectives requires effective supply chain management. By cutting waste, choosing eco-friendly suppliers, and optimising transportation, businesses may lessen their environmental effect (Min, Zacharia, & Smith, 2019). Supply networks in the contemporary global economy frequently cross several nations and continents. Organisations may access foreign markets, source resources abroad, and capitalise on global possibilities with the help of an efficient supply chain management system. Global supply networks are essential to the functioning of the global economy (Li, 2020). Supply networks make it possible for items to go beyond national boundaries, promoting both global commerce and economic expansion. They have a key role in fostering globalisation and establishing connections across various regions of the world. Further, a large percentage of the world's workforce is employed by supply chain operations, which also considerably boost a nation's GDP (Fatorachian & Kazemi, 2021). Supply networks that operate well can promote economic growth. Also, the COVID-19 pandemic brought to light the significance of adaptable and robust supply networks. In order to effectively respond to crises in the future, governments and organisations throughout the world are attempting to improve supply chain resilience. The environment and society are greatly impacted by the global supply chain (Wieland & Durach, 2021). Concerns about fair trade, labour standards, and sustainability have spread around the world, motivating initiatives to enhance supply chains' ethical and sustainable components. In conclusion, supply chains play a crucial role in contemporary company operations, impacting an organization's profitability, competitiveness, and capacity to adjust to a fast changing global landscape. They have profound effects on certain companies as well as the world economy at large.

Supply chains in a variety of sectors have seen significant and revolutionary changes as a result of digitalization. It has completely changed the management of supply chain activities, significantly increasing responsiveness, efficiency, and visibility (Agrawal & Narain, 2018). As items travel through the supply chain, digital tools and technologies like sensors, RFID, Internet of Things (IoT) devices, and GPS give real-time data on their position and condition. Organisations can manage inventory, shipments, and order status more precisely because to this improved visibility, which lowers the possibility of stockouts, overstocking, and other supply chain interruptions (Queiroz, Pereira, Telles, & Machado, 2021). Robotics, driverless cars, and warehouse management systems are examples of automation technology that have simplified several supply chain procedures. These technologies expedite order fulfilment and logistics while increasing accuracy and lowering labour expenses (Ageron, Bentahar, & Gunasekaran, 2020). Utilising digital technologies for distant work and cooperation has grown in significance, particularly in light of the COVID-19 pandemic. Professionals in the supply chain are able to oversee operations and work together with partners remotely.

Even though there is a plenty of research on the critical role that Industry 4.0 plays in enhancing the success of firms, businesses are mostly unsure about how digitalization will affect Supply Chain performance. Previous study done by Umar, Khan, Yusoff Yusliza, Ali, and Yu (2022), also highlight the significance of industry 4.0 in supply chain. The objective of this study is to highlight the role and impact of industry 4.0 in supply chain operations.

2. Literature Review

Big data may significantly improve supply chain efficiency by giving businesses insightful information and practical tools to streamline their processes in a variety of ways. Large-scale historical and current data may be analysed using big data analytics to increase the precision of demand predictions. This makes it possible for businesses to optimise inventory levels, minimise stockouts and overstocking, and better predict client demand (Bag, Wood, Xu, Dhamija, & Kayikci, 2020). Through the examination of product sales, supplier performance, and lead times, companies may minimise carrying costs and maximise inventory levels. This results in reduced storage costs and better working capital management. Big data assists businesses in monitoring quality, delivery schedules, and dependability as well as the performance of their suppliers. Better supplier selection and terms negotiation are made possible by this knowledge. Delivery schedule, carrier selection, and transportation routes may all be optimised with data analytics. This may result in lower expenses, less gasoline used, and quicker order fulfilment (Gunasekaran et al., 2017). Businesses may get real-

time visibility into their supply chain operations with the use of big data. They may keep an eye on conditions, watch the flow of goods, and react quickly to any interruptions, ensuring that consumers receive their orders on schedule. This discussion lead to the following hypothesis:

Hypothesis 1: The effect of Big Data on enhancing Supply Chain Performance is significant.

By improving efficiency, accuracy, and responsiveness in a variety of supply chain management domains, artificial intelligence (AI) significantly improves supply chain performance. AI can enhance the accuracy of demand forecasts by analysing vast amounts of real-time and historical data. This makes it possible for businesses to more accurately predict changes in demand, which lowers surplus inventory and minimises stockouts (Belhadi, Mani, Kamble, Khan, & Verma, 2021). Artificial intelligence (AI) algorithms that take lead times, supplier performance, and demand trends into account can optimise inventory levels. As a result, carrying costs are lower and working capital management is better. AI may help with supply chain planning by taking a variety of factors and limitations into account. To increase overall operational efficiency, it can suggest the best production schedules, distribution routes, and resource allocation (Pournader, Ghaderi, Hassanzadegan, & Fahimnia, 2021). Organisations may schedule maintenance only when it is absolutely essential since AI and IoT sensors can anticipate equipment and vehicle faults in advance. This guarantees the dependability of assets while lowering maintenance expenses and downtime.

Hypothesis 2: The influence of Artificial Intelligence (AI) on improving Supply Chain Performance is noteworthy.

The performance of the supply chain has benefited from the Internet of Things (IoT) as it offers real-time data, increases visibility, boosts efficiency, and permits proactive decision-making. Organisations can monitor the whereabouts, state, and status of products, vehicles, and equipment in real time with the use of IoT sensors and devices (De Vass, Shee, & Miah, 2018). Organisations can detect and resolve problems more rapidly because to this increased visibility, which lowers the possibility of delays, stockouts, and disturbances. IoT enables businesses to track assets and shipments at a detailed level, enabling more precise delivery time estimations and proactive problem-solving. Customers are happier and less unsure because to this real-time tracking. IoT sensors on machinery and cars can keep an eye on their performance and condition (De Vass, Shee, & Miah, 2021). Organisations can reduce downtime and increase overall equipment dependability by scheduling maintenance or repairs prior to a breakdown occurring through the analysis of this data. This discussion lead to the following hypothesis:

Hypothesis 3: The Internet of Things (IoT) has a beneficial effect on Supply Chain Performance.

Big Data improves decision-making, increases overall efficiency and efficacy of technology installations, and offers insightful information that has a beneficial impact on technology adoption and integration. Organisations may choose and use new technologies with data-driven decision-making thanks to big data analytics. Making educated decisions is made possible by the insights it offers on consumer preferences, market trends, and the functionality of current systems (Maroufkhani, Tseng, Iranmanesh, Ismail, & Khalid, 2020). Big Data may be used to evaluate how well-performing the available technological solutions are. It assists companies in determining where technology might be improved or substituted to better suit their requirements. Real-time monitoring and evaluation of technology performance is made possible by big data (Nam, Kang, & Kim, 2015). Organisations may proactively fix problems, streamline processes, and guarantee the effective use of technological solutions by analysing data on system performance. Analysing big data can reveal information on how people utilise technology. Organisations may utilise this data to pinpoint areas where users' experiences could be improved and to customise technological solutions to meet the requirements and preferences of their users. Big Data analytics can forecast when software and hardware assets are likely to break or need repair. This proactive strategy maximises IT asset management and reduces downtime. This discussion lead to the following hypothesis:

Hypothesis 4: Big Data contributes significantly to the adoption and integration of technology.

In many different businesses, the adoption and integration of technology is greatly aided by artificial intelligence (AI). Automation driven by AI simplifies many procedures and lessens the need for human

interaction (Chatterjee, Rana, Dwivedi, & Baabdullah, 2021). This increases productivity and facilitates the smooth integration of new technology into current procedures. Predictive analytics powered by AI can foresee how new technologies may affect an organization's day-to-day operations. Making educated judgements about which technologies to use and how best to integrate them is aided by it (Chatterjee, Ghosh, Chaudhuri, & Chaudhuri, 2021). Technology adoption may be significantly impacted by personalised user experiences, which AI makes possible. Artificial intelligence (AI) promotes a more favourable reaction to new tools and systems by customising technological solutions to each user's needs and preferences. This discussion lead to the following hypothesis:

Hypothesis 5: Artificial Intelligence plays a key role in facilitating the adoption and integration of technology.

IoT (Internet of Things) has a number of beneficial effects on technology integration and adoption, which makes it simpler for businesses to accept and use new technologies in their daily operations. Sensors and IoT devices are made to function together effortlessly. It is simpler to integrate and use different technologies inside an organization's ecosystem because of their interconnection (Brous, Janssen, & Herder, 2020). IoT acts as a bridge, facilitating efficient data sharing and communication across various systems and devices. Large volumes of data are produced by IoT from a variety of sources, and this data may be gathered, analysed, and incorporated into already-existing applications and systems. This information may be used by organisations to improve decision-making, get insightful information, and improve current procedure. Scalability is usually taken into consideration while designing IoT systems. An organisation may quickly increase its IoT installations by adding more devices or sensors as its needs change. Because of its scalability, IoT can be used in many contexts and its applications may be expanded. This discussion lead to the following hypothesis:

Hypothesis 6: IoT is a key aspect in the adoption and integration of technology.

Adoption and integration of new technologies are essential for improving supply chain performance. Organisations may improve efficiency, visibility, and responsiveness in a number of ways when they successfully integrate technology into their supply chain processes. Real-time insight into the movement and status of items is made possible by technology like sensors, RFID, GPS, and IoT devices, which enables businesses to precisely track their inventory and shipments. Decisions may be made proactively and with less uncertainty because to this awareness. Organisations may make data-driven choices with the use of sophisticated analytics, data mining, and machine learning techniques. In order to save costs and better meet consumer demand, they can optimise demand forecasting, inventory management, transportation planning, and production scheduling. Automation technologies simplify a number of supply chain operations. Examples include robots, automated material handling, and autonomous vehicles (Takahashi, Muraoka, & Otsuka, 2020). These technologies speed order fulfilment and logistics while increasing accuracy and lowering labour expenses. Organisations may optimise inventory levels with the use of technology, which lowers carrying costs and guarantees product availability (Sheel & Nath, 2019). To avoid overstock or stockouts, sophisticated inventory management systems employ real-time data to modify safety stock levels and reorder points. This discussion lead to the following hypothesis:

Hypothesis 7: The adoption and integration of technology have a positive impact on Supply Chain Performance.

The relationship between supply chain performance and big data can be favourably mediated by the adoption and integration of technology. Large volumes of data from diverse sources may be gathered, processed, and analysed by organisations thanks to big data technology. This data may come from market trends, consumer interactions, Internet of Things sensors, and other sources. But merely having access to large amounts of data is insufficient. Effective data collection, processing, and interpretation depend on the use and integration of technology. Big data processing and management require technological solutions like data warehouses, cloud computing, and data analytics tools. They offer the computing capacity and infrastructure required for

processing, storing, and analysing big datasets. These technologies assist companies in deriving useful conclusions from data. Real-time data gathering and analysis are made easier by technology, which enables businesses to make choices more quickly and intelligently. For instance, real-time information on demand swings, transportation routes, and inventory levels may be utilised to instantly optimise operations. By integrating big data with other data sources, such GPS tracking and Internet of Things sensors, technology may provide supply chain awareness. Organisations are able to keep an eye on the flow of products, identify problems, and react quickly to disturbances because to this enhanced visibility. This discussion leads to the following hypothesis:

Hypothesis 8: The adoption and integration of technology serve as a positive intermediary in the relationship between Big Data and Supply Chain Performance.

Artificial intelligence (AI) and supply chain performance are favourably correlated when technology is used and integrated. Stated differently, technology serves as a mediator that amplifies the influence of artificial intelligence on supply chain efficiency. This is how the mediation operates. Large volumes of data are necessary for AI to provide forecasts and offer insights. Technology can handle and analyse this data in an effective manner; examples of this include data management systems and analytics tools (Benzidia, Makaoui, & Bentahar, 2021). Organisations can guarantee that AI systems have access to the data they require and the processing capacity to handle it efficiently by implementing and integrating technology. Better decision-making, more precise forecasting, and enhanced supply chain performance are the outcomes of this. Real-time data collecting is made possible by technology, and this is necessary for AI systems to make quick judgements that are well-informed (Nayal et al., 2022). AI systems are able to evaluate data in real-time and suggest the best course of action, like modifying inventory levels, rerouting shipments, or streamlining manufacturing schedules. The early implementation of these recommendations through technology integration results in enhanced supply chain performance. This technology lead to the following hypothesis:

Hypothesis 9: In the relationship between AI and Supply Chain Performance, the adoption and integration of technology act as a positive mediator.

Technology adoption and integration are key mediators between supply chain performance and the Internet of Things (IoT). Performance gains are common for companies that successfully adopt and use IoT into their supply chain processes. Massive volumes of data are produced by IoT devices. It is possible for organisations to process, analyse, and derive actionable insights from this IoT-generated data through the adoption and integration of technology, such as business intelligence tools and data analytics (Hallikas, Immonen, & Brax, 2021). These insights may be applied to decision-making, performance enhancement, and supply chain process optimisation. Real-time data on inventory levels, equipment status, and the location and state of commodities is provided via IoT sensors. In order to optimise supply chain operations, technology adoption can be combined with IoT devices, such as automation solutions and process optimisation tools. This improves productivity while guaranteeing that IoT device data is fully utilised for operational optimisation. This discussion lead to the following hypothesis:

Hypothesis 10: The role of technology adoption and integration is positively mediating in the connection between IoT and Supply Chain Performance.

Below is the conceptual framework of this research that also elaborates all hypothesis of the study.

Figure 1: Conceptual Framework

3. Research Methodology

This research explore the effect of artificial intelligence, Internet of Things, and big data on the effectiveness of supply networks. The research utilises the framework of technology adoption and integration as a crucial component, connecting the major and supporting components. A meticulously designed questionnaire comprising of closed-ended questions was created for the purpose of gathering data. The poll was distributed via Google Forms and disseminated across several platforms including WhatsApp, Facebook Messenger, and email. Out of the 150 industry experts who were specifically focused on, a total of 126 replies were collected. The participants, selected using a meticulous sample technique, exhibited relevant skills and expertise in the sector. The survey data was analysed using descriptive statistics in IBM SPSS to provide insights into fundamental patterns and distributions. In addition, the relationships between different components were evaluated using Partial Least Squares Structural Equation Modelling (PLS SEM) with the assistance of IBM SPSS Amos.

4. Data Analysis

4.1 Descriptive Statistics

The present study employs descriptive statistical methods to examine the mean and variability (measured by standard deviation) of every variable included in the measurement model. As shown in Table 1, the emphasis is on the following five critical variables: Artificial Intelligence (AI), Big Data (BD), Internet of Things (IoT), Technology Adoption & Integration (TAI), and Supply Chain Performance (SCP). Out of the options considered, AI exhibits the highest average value of 3.795, while big data and Internet of Things (IoT) follow suit with mean scores of 3.717 and 3.701, respectively. The mean for SCP is 3.426, which is marginally lower than the mean for TAI (3.657).

Table 1: Mean and Standard Deviation of Variables

Variables	***N***	***μ***	***σ***
Big Data (BD)	126	3.717	0.905
Internet of Thing (IoT)	126	3.701	1.053
Artificial Intelligence (AI)	126	3.795	0.819
Technology Adoption & Integration (TAI)	126	3.657	0.851

supply chain performance (SCP)	126	3.426	0.887

4.2 Partial Least Squares Structural Equation Modelling (PLS SEM)

In this research, Partial Least Squares Structural Equation Modeling (PLS-SEM) statistical techniques is applied on the data. The evaluation of the measurement model is carried out through assessing convergent and discriminant validity. The revised PLS-SEM path model is illustrated in Figure 2.

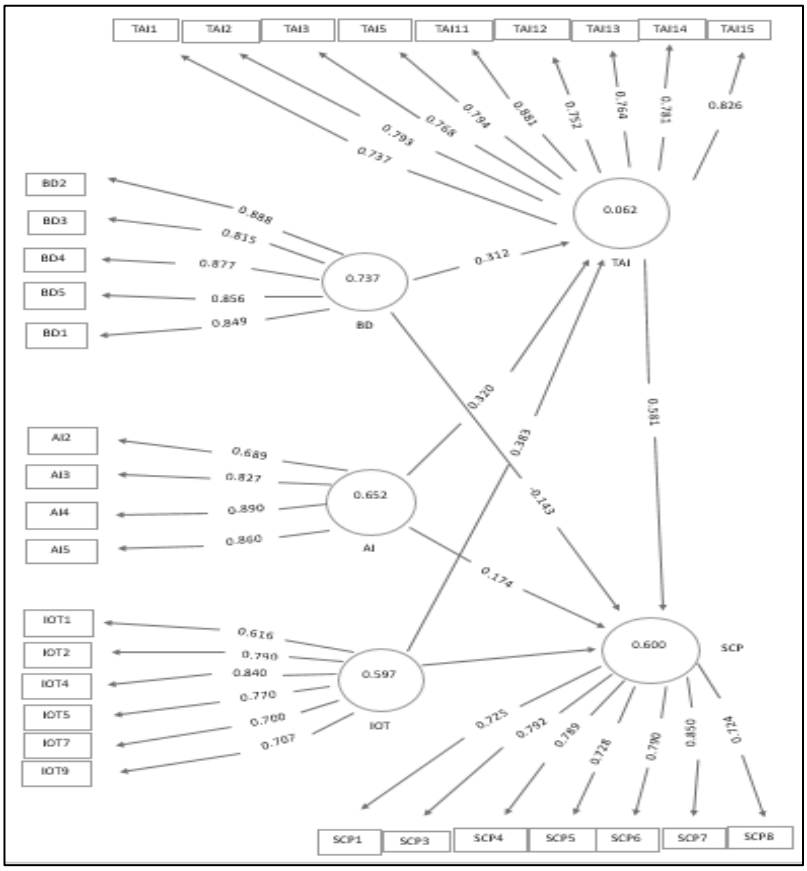

Figure 2: PLS-SEM results

Note: Analysis excluded a total of 19 items from the list. This includes several from the BD series (namely BD6, BD7, BD8, BD9, and BD10), one from the AI series (AI1), multiple from the IOT series (IOT3, IOT6, IOT8, and IOT10), numerous from the TAI series (TAI4, TAI6, TAI7, TAI8, TAI9, and TAI10), and a few from the SCP series (SCP2, SCP9, and SCP10).

4.3 Reliability

To check reliability, we assess internal consistency, for which it's essential that external loadings exceed the

threshold of 0.50, as suggested by Hair and colleagues in 2016. Items falling below this benchmark should be excluded. In the process of refining the model's measurements, 19 items exhibiting factor loadings under 0.50 were discarded. This refinement is depicted in Figure 2, where it's noted that one out of five items was removed for Artificial Intelligence (AI), three out of ten for Supply Chain Practices (SCP), six out of fifteen for Technological Advancement Impact (TAI), four for the Internet of Things (IOT), and five out of ten for Big Data (BD).

4.4 Validity

To assess convergent validity, the researcher utilized factor loading, average variance extracted (AVE), and composite reliability (CR). Convergent validity refers to the extent to which a construct explains an item's variance. For a model to be considered effective, it should have an AVE value exceeding 0.50, indicating that the construct accounts for over half of the variance. Furthermore, a CR value greater than 0.7 is required for further research, while a value above 0.90 indicates high reliability. In this study, CR values ranged from 0.881 to 0.951, and AVE values varied from 0.597 to 0.737, demonstrating strong reliability. However, as Ketchen (2013) cautions, CR values exceeding 0.90 might suggest redundant measurements. The high CR values in this case might result from interviewee distractions, yet the constructs still satisfy the criteria for convergent validity.

After establishing convergent validity, the model's discriminant validity was assessed to determine the extent of connection between its indicators. Consistent with the recommendations of Henseler and colleagues (2015), the research utilized the Heterotrait-monotrait (HTMT) ratio rather than the Fornell and Larcker (1981) criteria for a more precise evaluation of discriminant validity. As per Henseler et al.'s guidance, a HTMT value below 0.90 is indicative of adequate discriminant validity among reflective constructs. According to Table 2, all the constructs in the study adhered to these discriminant validity thresholds.

Table 2: Results of Heterotrait-Monotrait (HTMT) Ratio

Variables	Big Data (BD)	Artificial Intelligence (AI)	Internet of Thing (IoT)	Technology Adoption & Integration (TAI)	Supply Chain Performance (SCP)
Big Data (BD)					
Artificial Intelligence (AI)	0.507				
Internet of Thing (IoT)	0.624	0.613			
Technology Adoption & Integration	0.833	0.707	0.773		

(TAI) Supply Chain Performance (SCP)	0.841	0.592	0.602	0.864

4.5 Hypothesis Testing

The research applied the Bootstrapping technique in IBM SPSS Amos to evaluate seven hypotheses, setting the threshold for statistical significance at a t-value above 1.645 and a p-value under 0.05, as outlined in Table 3. Initial findings showed that hypotheses one, two and three, examining the positive effects of Big Data (BD), Artificial Intelligence (AI), and IoT on Supply Chain Performance (SCP), lacked statistical significance. This indicates that the direct effects of these technologies on Supply Chain Performance may be more complex or less predictable than anticipated.

Conversely, the subsequent hypotheses four, five six and seven, which explored the relationship between these technologies and Technology Adoption & Integration (TAI), and the influence of Supply Chain Performance and Technology Adoption & Integration, were statistically significant. This suggests that while the technologies might not directly affect Supply Chain Performance, they play a crucial role in promoting technology adoption and integration.

Moreover, the study assessed the effect sizes, denoted as F2 values. An F2 value of 0.35 indicates a significant impact, 0.15 a moderate effect, and 0.02 a small effect. The analysis showed that four hypotheses had a moderate effect on the studied variables, whereas the other three had a minor effect. This distinction provides a nuanced understanding of the actual impact of the examined correlations.

Table 3: Results of Hypothesis Testing – Dependent and Independent Variables

	Path	**Std Beta**	**SE**	**T-value**	**P-value**	**F^2**	**Confidence** 0.05	**Interval** 0.95	**Result**
Hypothesis 1	Big Data → Supply Chain Performance	-0.143	0.154	0.926	0.177	0.013	-0.365	0087	Not Supported
Hypothesis 2	Artificial Intelligence → Supply Chain Performance	0.174	0.131	1.327	0.093	0.030	-0.036	0.377	Not Supported

Hypothesis 3	Internet of Thing (IoT) → Supply Chain Performance	0.102	0.169	0.606	0.272	0.007	-0.191	0.379	Not Supported
Hypothesis 4	Big Data → Technology Adoption & Integration	0.312	0.145	2.148	0.016	0.164	0.06	0.530	Supported
Hypothesis 5	Artificial Intelligence → Technology Adoption & Integration	0.320	0.130	2.467	0.007	0.289	0.126	0.546	Supported
Hypothesis 6	Internet of Thing (IoT) → Technology Adoption & Integration	0.383	0.101	3.801	0.000	0.260	0.208	0.530	Supported
Hypothesis 7	Technology Adoption & Integration → Supply Chain Performance	0.581	1.193	3.012	0.001	0.152	0.245	0.973	Supported

Note: The significance levels are indicated as follows: a t-value greater than 2.58 signifies a p-value less than 0.01 (***), a t-value greater than 1.96 indicates a p-value less than 0.05 ()**, *and a t-value greater than 1.65 corresponds to a p-value less than 0.10 ()*.

The study examines three intermediary effects to determine whether the variable mediates the relationship

between Technology Adoption & Integration and Supply Chain Performance, as detailed in Table 4. The findings indicate that TAI serves as a mediator between big data and Supply Chain Performance, evidenced by a t-value of 1.757 and a p-value of 0.040. Additionally, the relationship between artificial intelligence and Supply Chain Performance through Technology Adoption & Integration is substantiated by a t-value of 1.722 and a p-value of 0.043, suggesting an indirect influence of Artificial Intelligence on Supply Chain Performance via Technology Adoption & Integration. A significant secondary impact of Technology Adoption & Integration on both IoT and Supply Chain Performance is observed, with a t-value of 2.449 and a p-value of 0.007. Consequently, this supports the validity of hypotheses eight, nine, and ten.

Table 4: Results of Hypothesis Testing – Mediating Variables

	Path	**Std Beta**	**SE**	**T-value**	**P-value**	**Confidence** 0.05	**Interval** 0.95	**Decision**
Hypothesis 8	Big Data → Technology Adoption & Integration → Supply Chain Performance	0.181	0.103	1.757	0.040	0.019	0.366	Supported
Hypothesis 9	Artificial Intelligence → Technology Adoption & Integration → Supply Chain Performance	0.186	0.108	1.722	0.043	0.043	0.389	Supported
Hypothesis 10	Internet of Thing → Technology Adoption & Integration → Supply Chain Performance	0.223	0.091	2.449	0.007	0.091	0.379	Supported

4.6 Discussion

This study aimed to evaluate the effects of Big Data, the Internet of Things, and Artificial Intelligence on Supply Chain Performance in the context of Industry 4.0. Additionally, it explored the role of Technology Adoption & Integration as a mediator in understanding the indirect effects of these technologies on Supply Chain Performance.

4.6.1 Effects on Supply Chain Performance

Contrary to common expectations, the study found no direct link between Big Data, the Internet of Things, and Artificial Intelligence on Supply Chain Performance improvements. This was surprising, given the general anticipation that Industry 4.0 technologies would directly boost supply chain efficiency. The hypothesis tests for the direct impacts (H1: Big Data → Supply Chain Performance, H2: Artificial Intelligence → Supply Chain Performance, H3: Internet of Thing (IoT) → Supply Chain Performance) did not meet the necessary statistical significance levels, with p-values surpassing the 0.05 significance mark. These results suggest that the direct application of these technologies might not immediately improve supply chain efficiency.

This conclusion aligns with additional research by Zeng and Yi (2023) and Jasuja (2023). Large amounts of information from big data may be overwhelming for organisations. It can be difficult to manage, interpret, and make sense of this data, which can cause uncertainty and inefficiencies in decision-making. Errors, inconsistencies, and insufficient information can be found in big data. When supply chain planning and decision-making are done with untrustworthy data, mistakes can happen and cause interruptions, excess inventory, and other problems. Data breaches and privacy violations are more likely due to the massive volume of data being gathered and kept. Supply chain interruptions and legal ramifications can result from breaches of sensitive data, making data protection an enormous burden. Big data management frequently calls for certain knowledge and equipment. Employers may have trouble hiring and keeping personnel with the requisite experience in data analysis.

Although supply chain management may greatly benefit from artificial intelligence (AI), there are drawbacks and difficulties that organisations may encounter when putting AI solutions into practise. AI supply chain implementation frequently necessitates large initial expenditures in infrastructure, technology, and qualified labour. The budget of an organisation may be strained by these expenses, especially for smaller businesses. It can be difficult and time-consuming to integrate AI systems with legacy systems, current supply chain procedures, and other technology. Compatibility problems might occur and cause delays and interruptions in the installation process. Because AI is primarily dependent on data, its accuracy and dependability can be significantly impacted by the quality of the data used. Predictions and choices that are inaccurate might result from poor data quality. Furthermore, there are security issues with private supply chain information that must be shielded from online attacks.

Although the Internet of Things (IoT) has the potential to significantly improve supply chain performance, its adoption and implementation might potentially have drawbacks and present difficulties. An initial large investment is necessary for the supply chain to adopt IoT technology. This covers the price of software development, network infrastructure, sensors, IoT devices, and training. This might be a major barrier to entrance for smaller businesses with tighter funds. It can be difficult and complex to integrate IoT devices and data into current supply chain systems. Implementation delays and challenges can be caused by compatibility problems, data standardisation, and guaranteeing interoperability between different IoT components and legacy systems.

4.6.2 Effects on Technology Adoption & Integration

The research found a distinct pattern when examining how Big Data, artificial intelligence, and the Internet of Things affect the adoption and integration of technology. Statistical testing of hypotheses four, five and six revealed statistically significant impacts from these innovations on Technology Adoption & Integration. This suggests that the major value of Big Data, artificial intelligence, and IoT may not lie in the direct improvement of supply chain efficiency, but rather in how they shape and drive the adoption and integration of technology inside an organisation. Aryal et al. (2018), Zamani et al. (2022), and Hader et al. (2022) all discover similar results.

Big Data is essential to the adoption and integration of technology because it offers insightful information, facilitates well-informed decision-making, maximises the performance of the technology, and improves user experiences. Dubey, Gunasekaran, Childe, Blome, and Papadopoulos (2019), also supported this hypothesis. According to them, businesses that successfully use big data are better able to adjust to rapidly evolving technological environments, increase operational effectiveness, and maintain their competitiveness in today's tech-driven marketplace. Big Data may be used to locate waste and inefficiencies in technology-related processes. Organisations can achieve cost reductions via streamlining needless spending and optimising resource use. Big Data provides feedback on technology performance and opportunities for development, which promotes a culture of continuous improvement. This iterative process encourages continued acceptance and advancement of technologies.

Through increasing productivity, delivering data-driven insights, improving user experiences, and automating several elements of technology management, artificial intelligence (AI) plays a critical role in streamlining and expediting the adoption and integration of new technologies. Chatterjee, Rana, et al. (2021), also supported this hypothesis. According to them, it enables businesses to take full advantage of the newest technology and use them efficiently. AI makes it simpler to supervise and maintain numerous systems and devices by enabling remote monitoring and administration of interconnected technologies. AI ensures that integrated technologies may grow with an organisation by dynamically scaling resources and capacity as needed. This allows AI to react to changing demands in the technological space. By evaluating data and seeing patterns and possibilities that might result in the uptake of novel and revolutionary technologies, AI can foster innovation.

Adoption and integration of technology improves efficiency, visibility, and reactivity, which have a significant beneficial effect on supply chain performance. Businesses that successfully integrate technology into their supply chain operations are better able to save operating costs, better serve their clients, and adjust to shifting market conditions. Brous et al. (2020), also supported this hypothesis. According to them, enhancing transparency and traceability in the supply chain is made possible by technologies like block chain and digital records. This is especially important for businesses where there are strict regulations or where product authenticity is required. Technology monitors and controls manufacturing processes, including real-time quality checks and warnings, to help ensure product quality and compliance with quality standards. Supply chain experts may now operate remotely and engage with partners, oversee operations, and make choices from any location thanks to technology.

4.6.3 Technology Adoption & Integration as a Mediator

The research indicates that Big Data, artificial intelligence, and IoT have an indirect effect on supply chain performance by means of Technology Adoption & Integration. While the technologies themselves may not

have a direct impact on Supply chain performance, the validation of the intermediate hypothesis eight, nine, and ten suggests that they substantially affect it via Technology Adoption & Integration. This was corroborated by Aryal et al. (2018) and Hader et al. (2022). Technology adoption and use throughout the supply chain are the primary determinants of supply chain performance.

Adoption and integration of technology act as a moderator between supply chain performance and big data. Big data offers the raw data, but in order to handle, process, and incorporate this data into supply chain processes, technology is required. Wang and Ali (2023), also supported this hypothesis. According to them, it makes real-time decision-making, automation, collaboration, and visibility possible, which eventually improves the efficacy, responsiveness, and cost-effectiveness of the supply chain. Big data may be used to detect possible supply chain problems, but proactive risk management and mitigation need the use of new technologies. This entails keeping an eye on things like demand swings, geopolitical concerns, and weather-related occurrences in real time. More customer-centric supply chains may result from fusing technology-driven personalization and customisation tools with big data insights on consumer behaviour and preferences. Improved client loyalty and satisfaction are the outcomes of this.

Technology improves the efficacy of AI-driven solutions, making them sensitive to real-world supply chain issues and actionable. It does this by mediating the relationship between AI and supply chain performance. Naway and Rahmat (2019), also supported this hypothesis. According to them, AI and technology together give businesses the ability to save operating costs, improve customer service, adjust to shifting market conditions, and maximise supply chain performance. AI may assist businesses in finding chances for sustainability, such maximising transit routes to cut carbon emissions. Organisations may actively pursue their goals of social responsibility and the environment thanks to technology integration, which makes it possible to implement sustainability policies. AI is capable of real-time monitoring of industrial operations and quality control. Technology integration guarantees the presence of AI-driven quality control tools that quickly identify and correct any violations from established norms.

The relationship between IoT and supply chain performance is mediated by technology adoption and integration, which allow businesses to fully use the data supplied by IoT devices. AlMulhim (2021), also supported this hypothesis. According to them, better decision-making, increased effectiveness, enhanced visibility, enhanced cooperation, and the capacity to optimise supply chain procedures are the outcomes of this. Higher supply chain performance may therefore be attained by businesses, which eventually leads to lower costs, happier customers, and a competitive edge in the marketplace. IoT gadgets can keep an eye on product compliance and quality all the way through the supply chain. Technology integration enables businesses to gather, examine, and respond to quality data, guaranteeing that goods fulfil legal and quality standards and improving supply chain efficiency and customer satisfaction.

5. Conclusion

Several crucial factors are highlighted by the study's findings. It hints that supply chain performance may not always increase with the straightforward use of Industry 4.0 technology. Instead, the use and incorporation of these technologies is the key to improving supply chain efficiency. This highlights the necessity of choosing the correct tools and providing an environment favourable to their efficient integration into existing processes. In addition, the results provide novel and useful insights for business leaders to consider. Focusing on adoption and integration of technology rather than merely improving the technology itself may be the best way to improve supply chain efficiency. The success of Technology Adoption and Integration (TAI) strategies may depend on a number of aspects that might be investigated in future studies. Such knowledge would be priceless for businesses who want to get the most out of their technical investments.

5.2 Implications

5.2.1 Theoretical Implications

By examining the complex linkages between Industry 4.0 technologies, technological adaption, supply chain responsiveness, and customer happiness, the study advances the field of supply chain theories. The results can help create new theoretical models and improve the ones that already exist. Through an exploration of the mediating function of technological integration and adaptation, the research advances theoretical knowledge. This helps to provide a more complex understanding of how supply chain dynamics and consumer perceptions are affected by the integration of Big Data, IoT, and AI. The study uses sophisticated statistical methods to assess the correlations between variables, including smart PLSEM. By validating these methods within the framework of Industry 4.0 technologies, research procedures gain theoretical support and insights into their dependability and applicability are revealed. The research connects multidisciplinary topics by looking at how supply chain, technology, and consumer happiness interact. This integration offers theoretical insights across business, technical, and customer-centric viewpoints, contributing to a comprehensive knowledge of the complex dynamics in modern supply chain strategies.

5.2.2 Managerial Implications

By utilising AI's intelligent automation, IoT's real-time monitoring, and Big Data's predictive insights, business executives may make well-informed strategic decisions. Managers will be able to match technology adoption with overall company objectives if they have a thorough understanding of how Industry 4.0 technologies affect customer happiness and supply chain responsiveness. The integration of Industry 4.0 technology can enhance the performance of the supply chain for managers. This entails integrating predictive analytics, real-time monitoring, and intelligent automation to streamline processes, shorten lead times, and improve overall productivity. The study's conclusions make it feasible to allocate resources efficiently. By prioritising technology adoption investments according to how they affect customer happiness and supply chain responsiveness, managers may ensure that Industry 4.0 technologies are implemented in a way that is both cost-effective and balanced.

5.3 Limitations

This study has several limitations which can be overcome in future. In this study researcher has used several variables such as big data, artificial intelligence, and IoT. In future, researchers can also use block chain technology, cloud computing. Further, the only mediator used in this research is technology adoption and integration. For future reference, innovation and green technology can be used as mediator.

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