Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 4, Issue 5 (2026)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

Impact Of Industry 4.0 Technologies On Sustainable Performance With Mediating Effect Of Sustainable Supply Chain Management

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ABSTRACT

Sustainable performance has become a crucial part for every organization to seek balance between economic growth, environmental and social responsibility in developing countries like Pakistan. In garment sector, it's always remains challenging to achieve sustainability due to inefficient supply chains compliance pressure and rapid technological developments in global markets. Numerous industry 4.0 technologies like Artificial Intelligence, big data analytics, Internet of Things and Block chain suggests significant potential to enhance sustainability. This research examines a conceptual framework to examine the relationships between adoption of Industry 4.0, SSCM practices, and sustainable performance. Data from 847 respondents was gathered from Punjab's garment factories and analysed using partial least-squares structural equation modelling (PLS-SEM). The results showed that SSCM practices have been greatly impacted by Industry 4.0 technologies, particularly the blockchain, which has a greater association with sustainable performance. By offering empirical data on the uptake and use of digital technologies within the framework of developing economies, the study makes a theoretical contribution. By offering actual data on the implementation of digital technology and sustainability in the setting of developing nations, this research adds to the body of literature. In order to be competitive and sustainable in the global market, executives and managers should strategically implement these industry 4.0 technologies, according to the study's practical implications.

Keywords: Industry 4.0, Artificial Intelligence, Block Chain Technology, Internet of Things, Sustainable Supply Chain Management, Sustainable Performance

INTRODUCTION

The sustainability of an organization is a strategic concern in sustainable development. A company will attain sustainable development if it takes into account the equilibrium of three factors: economic, social, and environmental. As a result, businesses should put financial and economic objectives first, consider social benefits, and protect the environment (Elkington, 1998). Additionally, every organization must

Online ISSN 3007-3197
Print ISSN 3007-3189

meet current requirements without sacrificing those of future generations in order to achieve sustainable performance. A revolutionary period in the industrial landscape has begun with the emergence of Industry 4.0, which is characterized by the introduction of cutting-edge technologies and novel ideas pertinent to value chain organization.

The industrial sector has undergone a transformation thanks to the advent of industry 4.0, which has introduced innovative technologies that maximize resource usage for best production. As compared to earlier era, industry 4.0 gaining more attention and focus from researchers and practitioners. These technologies have replaced conventional method of manufacturing by smoothly incorporating intelligent technology (Kamble et al., 2018).

The garment industry of Pakistan can improve decision making skills, enhance efficiency and optimize supply chain effectiveness by implementing these technologies (Javaid et al., 2021). Very less researches have been done on manufacturing (Sony & Naik 2018; Rehman Zhao et al., 2022). Due to difficult and varied interaction between supply chain and technologies, a focus on industry 4.0 is must (Dutta et al., 2021).

A major pillar of Pakistan is readymade garment sector which contribute extensively to employment and exports. A major contribution of the nation's export come from the garment industry. Since 1950, the Pakistan readymade garment sector has grown significantly (Pakistan apparel forum, 2021). The industry is stable and competitive as well in RMG exports. In year 2020-2021, Pakistan's RMG sector was one of the world's top exporters and for this reason, it is mandatory to address industry issues and to remain competitive in market upgradation with technology is necessary (Pakistan Bureau of Statistics 2021). In order to attain opportunities and to overcome the hurdles, the RMG sector has gone through several transformation. The industry has to make investment in technologies, production methods to achieve sustainability.

The RMG sector is essential to Pakistan's economy since it generates export revenue and provides millions of jobs. Respect for international labor norms, competition in foreign markets, and supplier change management are all major issues facing the industry. These days, Industry 4.0 AI, the Internet of things, blockchain, and other technologies are seen as management tools that may help eliminate problems through increased efficiency, improved transparency, and requirement compliance.

Examining the connection between SSCM and industry 4.0, it is therefore important to emphasize how important it is to find suitable technologies in Pakistan's ready-made clothing sector in order to support future expansion and advancement.The industry would be able to contribute to Pakistan's socioeconomic growth if the current challenges are overcome and sustainability is promoted.

The study's objective is to ascertain how Industry 4.0 technologies, which prioritize supply chain management and sustainable performance, operate. The study's objective is to ascertain how Industry 4.0 technologies, including blockchain, IoT, and artificial intelligence (AI), impact sustainable performance.

Problem Statement

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It is essential to comprehend how industry 4.0 technologies contribute to sustainable supply chain management and sustainable performance. The current situation of Pakistan's ready-made garment industry makes it clear that it can contribute significantly to employment and export revenue for the nation's economy. However, there are still various factors that act as a barrier to the competitiveness and sustainability in most of the industry operation such as unfavorable supply chain management, growing accuracy on the organization to meet more requirements of the international standards of labour and the environment, and advanced technological developments of the global market. Moreover, there is a prominent lack of research on industry 4.0 technologies and SSCM in Pakistan garment sector. This gap highlights the need to find out how this technological innovation can support development and improve overall industry performance.

Research Questions

How does AI, IOT and BCK affect employee work engagement in readymade garment sector of Punjab Pakistan?

Is there any positive relationship between Industry 4.0 technologies, SSCM and Sustainable Performance?

LITERATURE REVIEW

Industry 4.0 has a major effect on supply chain efficiency that goes well beyond production. In addition to drastically altering the corporate environment, this revolutionary wave has sparked a digital transformation in the supply chain sector and is essential to improving organizational decision-making (Bag, S., & Kumar, P. 2022). The industrial sector has undergone a transformation thanks to the advent of industry 4.0, which has introduced innovative technologies that maximize resource usage for best production. Industry 4.0 implementation has huge stamina to promote sustainable industrial value development.

The operational efficiency and the decision-making method has improved through AI technologies. The production scheduling and inventory management has been significantly improved by AI (Kumar et al., 2019). To match output to customer demands and minimizing surplus inventory is made easier through AI driven predictive analytics (Lee & Lim, 2020).

The product standard has been increased due to use of AI in quality control procedures. Moreover, product has been retaining its position in international markets by fulfilling export laws efficiently (Smith & Gupta, 2021). Operational efficiency has been improved by automating the repetitive jobs (Johnson, 2019).

Real-time data is the cornerstone of supply chain efficiency and transparency, and the Internet of Things makes it simple by utilizing sensors embedded in objects and machinery. IoT has empowers businesses to expand their understanding about how operations are carried out which leads to improved supply chain management and tracking (Zhou et al., 2021). Through IoT technology asset management of Pakistan garment sector has been improved by minimizes downtime and foreseeing when machinery is likely to break down (Malik & Zhao, 2020).

According to Hassan and Qadeer (2021), to monitor the workplace environment and for improving workers safety, IoT is very crucial for it and this monitoring guarantee

Online ISSN 3007-3197
Print ISSN 3007-3189

adherence to safety law and environmental practices which is the more important and prior component for international customers. Moreover, as a supplier industry dependability has been improved as IoT devices records and also enable compliance verification (Bates et al., 2021).

Another industry 4.0 technology is Block chain technology which provides businesses a strong transparency to ensure that garment is original and compliance with all regulations (Morkunas et al., 2019). The blockchain technology helps in preventing fake and illegal products. This is done by keeping safe and unchangeable record of all transactions in shared devices. (Iqbal et al., 2019).

Moreover, Block chain technology makes it easier to know about product manufacturing process and its origin which increases the customer trust in supply chains (Khan & Qadeer, 2021). The blockchain technology help Pakistani producer to compete worldwide market through ethical manufacturing practices (Jamil et al., 2020).

The relationship between sustainable performance and Industry 4.0 technology is mediated by SSCM. Industry 4.0 technologies could enhance sustainable practices in terms of resource management, efficiency, and transparency across a supply chain (Sarkis et al., 2021). Adoption of these advancements alone, however, does not guarantee long-term success and to attain sustainable results the effective supply chain along with technologies give the opportunity to achieve desired results.

By integrating the sustainability principles to the supply chain processes, organization can maximize the resource utilization and enhance social responsibility. For environmental indicator monitoring, IoT enabled sensors to find energy saving and waste reduction opportunities and compliance to sustainability standards. Real-time monitoring and compliance methods for environmental standards (Govindan et al., 2020). By ensuring supply chain transactions are transparent and traceable, blockchain technology promotes ethical sourcing methods and builds stakeholder trust (Wamba et al., 2017).

A single focus company typically lacks the resources and knowledge required to implement the underlying SSCM methodologies, despite the fact that SSCM may be a substantial source of competitive advantage. By managing supply chain (SC) flows appropriately, companies and their SC partners seek to satisfy stakeholders' economic, environmental, and social demands. This is known as SSCM (Seuring & Müller, 2008). To achieve sustainability objectives, SSCM methods enable cooperation and communication among supply chain participants and encourage their team efforts (Sarkis & Cohen, 2016).

Industry 4.0 technologies have significant influence on sustainable performance especially in garment sector. When these technologies implemented in to manufacturing processes can give massive improvements in social responsibility, environmental sustainability and economic efficiency (Sarkis et al., 2021). IoT made possible the real time resource usage monitoring and allows manufacturers to identify areas for improvement and adopt sustainable practices throughout the entire production process (Govindan et al., 2020).

Moreover, block chain technology will improve supply chain traceability and transparency to guarantee adherence to moral principles and labor laws. According to Wamba et al. (2017), block chain promotes responsible sourcing and production

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processes by building confidence among different stakeholders by recording transactional data on an unmodified distributed ledger. Industry 4.0 technologies will increase the organization's agility and resilience. Manufacturers can react to shifting consumer demand, supply chain interruptions, and sustainability-related hazards more skilfully when they use digital technologies. Long-term sustainability and competitiveness result from the clothing manufacturer's capacity to adapt its operations to shifting consumer demands and regulatory needs.

The apparel industry's use of Industry 4.0 technology holds promise for long-term success. Garment manufacturers embrace digital innovation to ensure operational efficiency, transparency, and responsibility in the business.

RESEARCH FRAMEWORK

This section provides an explanation of the research's theoretical and conceptual basis.

Conceptual Framework

This research is intended to investigate the integration of 4.0 technologies with in Pakistan's readymade sector with mediating impact of SSCM.

Figure 1: Conceptual Framework

This research ensures a comprehensive evaluation of how technologies can revolutionize supply chain management in the garment sector. Figure 1 above depicts the graphically representation of the model.

Theoretical Framework

According to Barney's 1991 RBV theory, organization assets and resources that are valuable, unique and rare are linked to competitive advantage. These industry 4.0 technologies are regarded as rare resources and by implementing these technologies SSCM becomes more efficient and give sustainable performance. Many scholars in the domains of operations management and strategic management have developed theoretical frameworks based on the resource-based view (RBV) theory to explain how digitalization impacts corporate performance. a theoretical framework that asserts that the foundation of a business's sustained competitive advantage is its unique assets and skills.

This research model offers a very solid theoretical foundation.

Following hypotheses are developed based on the aforementioned discussion for this research;

SR No	Hypothesis
H1	AI positively influence SSCM.
H2	IoT positively impacts SSCM.
H3	Blockchain Technology positively impacts SSCM.

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H4	SSCM mediates the relationship between Industry 4.0 technologies and Sustainable Performance.

RESEARCH METHODOLOGY

This study employed a deductive and cross-sectional research design. Data was gathered via a self-administered survey targeted at managers and executives in the garment industry. A straightforward random sample method was used to ensure representativeness. The data was collected using a 5-point Likert scale questionnaire, and the analysis was done using PLS Smart software (Ringle, Wende, and Becker, 2015).

Some major constructs to be considered in this study include Industry 4.0, Sustainable Supply Chain Management, and Sustainable Performance. To maintain construct reliability and validity questions adapted from credible sources and three technologies of industry 4.0 are considered namely; artificial intelligence, Internet of things and block chain technology. The scales included a 25-item scale for 5 item for each in Artificial Intelligence (AI) (Qiu, H., et al.,2022), Block chain Technology (Treiblmaier, H., et al. 2022), Internet of Things (Lee, H. L., et al. 2022), Sustainable Supply Chain Management (Azevedo, S. G., et al. 2023) and Sustainable Performance (Golicic, S. L., et al. 2024).

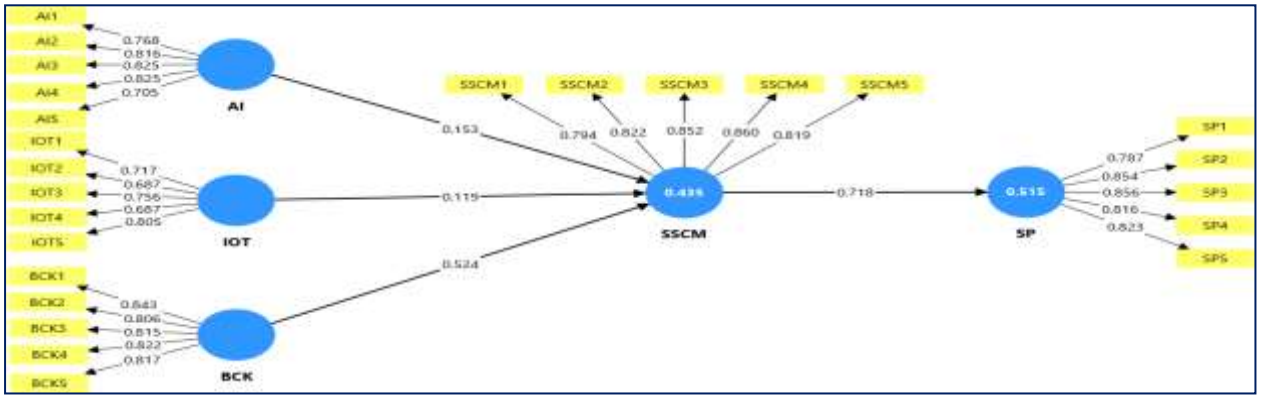
To ensure statistical power of the model, a sample size of at least 1000 managers will be selected within the garment sector. A quantitative approach is used in which data is collected through questionnaire. The collected data will be analyzed using smart PLS techniques and specialized software (Ringle et al., 2020) to examine the relationships among the variables and draw meaningful conclusions.

RESULTS AND ANALYSIS

A range of tests and analyses, including the Cronbach alpha reliability test, composite reliability test, goodness of fit test for the correlation analysis of both the inner and outer models, and hypothesis testing, will now be used to assess the results.

Figure 2: Model Result PLS

The partial least squares result of the model is shown in Figure 2. To establish the statistical significance of PLS-SEM, the bootstrapping test was performed. The bootstrapping results are shown in Figure 3 for additional examination.



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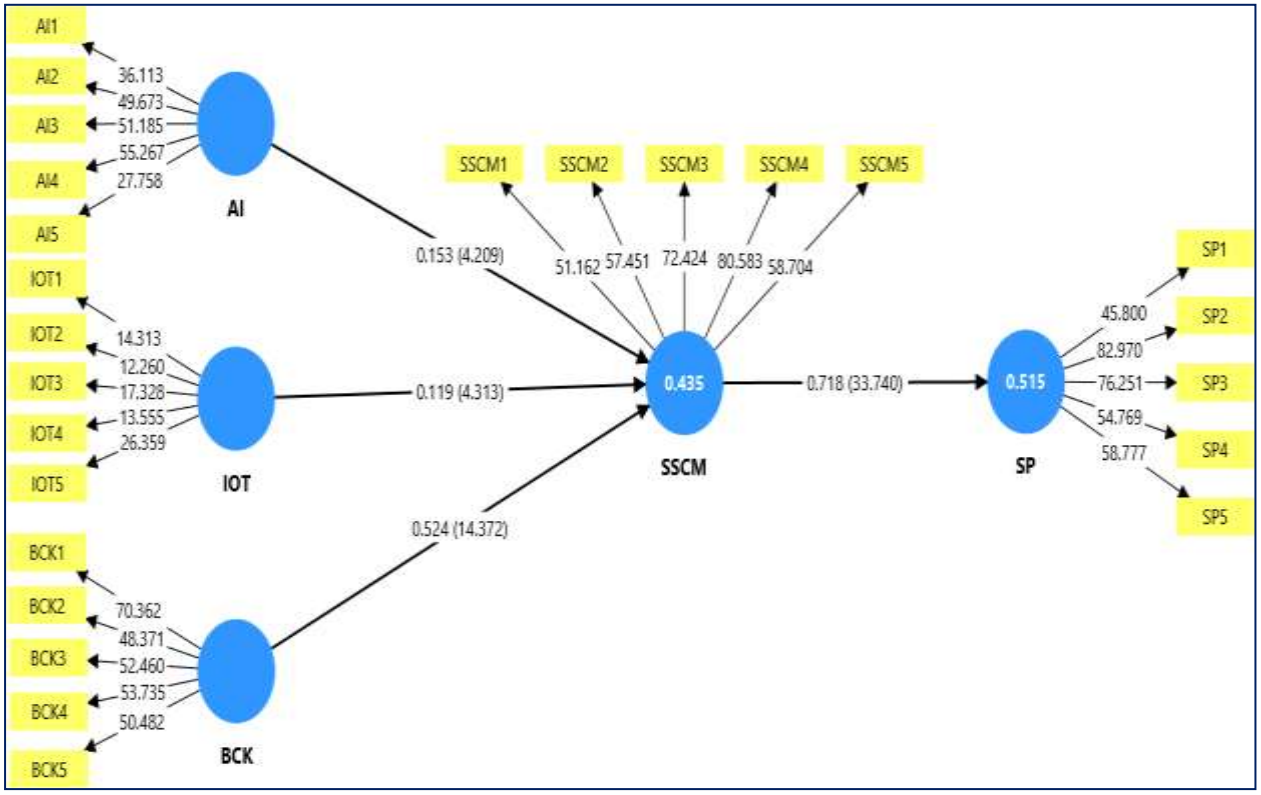

Figure 3: Bootstrapping Result

The Cronbach alpha value for the analysis is shown in Table 1. A Cronbach Alpha score of 0.6 indicates that the instrument utilized in this study is reliable and adequate for analysis, according to the literature. A scale's dependability is evaluated using its Cronbach's Alpha coefficient (α). It is known as the scale's dependability and is a measurable indicator of a scale's internal consistency (Ahmed, Q. u. A., Ahmed, A., & Sandhu, K. Y. 2025).

Table 1: Value of Cronbach's alpha

	Cronbach's alpha
AI	0.847
BCK	0.879
IOT	0.792
SP	0.885
SSCM	0.887

Tables 2 and 3 are used to determine the factor loading rate and AVE rate of the external model's convergent validity.

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Table 2: Factor Loading for Outer Model

	AI	BCK	IOT	SP	SSCM
AI1	0.768				
AI2	0.816				
AI3	0.825				
AI4	0.825				
AI5	0.705				
BCK1		0.843			
BCK2		0.806			
BCK3		0.815			
BCK4		0.822			
BCK5		0.817			
IOT1			0.717		
IOT2			0.687		
IOT3			0.756		
IOT4			0.687		
IOT5			0.805		
SP1				0.787	
SP2				0.854	
SP3				0.856	
SP4				0.816	
SP5				0.823	
SSCM1					0.794
SSCM2					0.822
SSCM3					0.852
SSCM4					0.860
SSCM5					0.819

In terms of evaluating convergent validity, all of the indications in Table 2 appear to be reliable. The research technique is valid for all of these variables since the AVE rates of all latent variables are larger than 0.5.

Table 3: AVE Values

	AVE VALUE
AI	0.622
BCK	0.673
IOT	0.535
SP	0.685
SSCM	0.688

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An outer model may be validated using each latent variable's total reliability. The effect of the study on the outer model's dependability is displayed in Table 4.

Table 4: Composite Reliability Values

	Composite reliability
AI	0.891
BCK	0.912
IOT	0.852
SP	0.916
SSCM	0.917

The Inner Model Goodness-of-Fit test uses the R2 value. Table 5 shows that SSCM accounts for 51.5% of the variance in SP and AI, IOT and BCK account for 43.5% of the variance in SSCM, and a variety of other factors account for the remaining 56.5%.

Table 5: R^2 Value

	R^2
SP	0.515
SSCM	0.435

Hypothesis Test

The bootstrapping test's processing results are used to validate hypotheses (figure 3). The test was used to assess if the hypothesis was accepted or rejected based on the study's findings. Table 6 shows the path coefficient value as well as the outcomes of the t-tests and hypothesis testing.

Sr No	Hypothesis	Suggested	Path Coefficient	T-Value	Confirmed
H_1	AI positively impacts Sustainable Supply Chain Management.	+	0.153	4.209	YES
H_2	IoT positively influence Sustainable Supply Chain Management.	+	0.119	4.313	YES
H_3	Blockchain Technology positively influence Sustainable Supply Chain Management.	+	0.524	14.372	YES

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H_4	SSCM mediates the relationship between Industry 4.0 technologies and Sustainable Performance.	+	0.718	33.740	YES

Although there are notable variations in each correlation, all theories show a positive link with one another.

CONCLUSION

This study's main goal was to investigate, in the context of Pakistan's readymade garments industry, the connections between technologies, sustainable supply chain management, and sustainable performance. Clarifying the connections between these components and how they impact sustainable performance was the study's main objective. The study's conclusions showed a strong and favourable correlation. The findings showed that sustainable supply chain management benefits from industry 4.0 technology. But the study also showed that supply chain management and these technologies had an even greater combined impact on sustainable performance.

All three technologies significantly influencing SSCM. Among them the blockchain technology revealed the strongest impact suggesting its crucial role in enhancing efficiency within supply chain operations. Comparatively, AI and IOT contribute positively but with smaller effect. Moreover, SSCM has shown significant and substantial impact on sustainable performance confirming its role as main driver towards organizational sustainability. The research underscores that industries seeking to enhance sustainable performance should make priority to adopt these technologies because these technologies when implemented effectively and can strengthen SSCM capabilities and overall performance of the industry.

In the context of garment sector this study makes a notable contribution by extending the theoretical framework of industry 4.0. Like developing countries in Pakistan, the impact of these technologies on sustainability performance and outcomes remains unexplored. By implementing these technologies, businesses are able to compete in the global market. This study contributes to the theoretical knowledge of how the application of industry 4.0 technologies might promote effective supply chain management and efficiency in the context of developing countries. Overall. The research highlights the roadmap to influence innovation and sustainable practices to achieve long term socio-economic development and a sustainable performance.

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