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AI-ENABLED REVERSE LOGISTICS AND BIG DATA FOR ENHANCED WASTE AND RESOURCE MANAGEMENT

Mohammed A. Al Doghan[1*], Veera Pandiyan Kaliani Sundram[2]

[1]Department of Management, College of Business Administration, King Faisal University, Al-Ahsa 31982, Saudi Arabia.
[2]Department of Technology and Supply Chain Studies, Faculty of Business and Management, Universiti Teknologi MARA, Selangor Branch, Campus Puncak Alam, Selangor, Malaysia.

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Research Paper

Abstract: *The primary objective of this research is to investigate the impact of AI-powered resource and waste management systems on reverse logistics and big data analytics within the manufacturing industry of Saudi Arabia. The present study has also investigated the role of Firm Performance as a mediator in Circular Economy Supply Chains, as well as the moderating effect of Environmental Process Integration. The research study has employed a quantitative research methodology and utilised a survey instrument to gather data from employees working in the manufacturing sector of Saudi Arabia. The data underwent analysis using the Statistical Package for the Social Sciences (SPSS).The findings of the study indicated that Big Data Driven (BDD) supply chain did not have a significant impact on Waste Management (WM). However, it was observed that Big Data Analytics (BDA), Circular Economy Human Resource (CEHR), and Reverse Logistics (RI) were found to have a significant influence on Waste Management (WM). Moreover, our analysis reveals that the sole significant factor mediating the relationship between the successful execution of reverse logistics and the reduction of waste in the supply chain is firm performance. Additionally, it has been observed that the integration of environmental processes plays a significant role in moderating the association between waste minimization and firm performance within the context of circular economy supply. This research adds to the current corpus of knowledge by investigating and analysing observed constructs and offering recommendations to the manufacturing sector regarding waste reduction, sustainability enhancement, and firm performance through the utilisation of big data and artificial intelligence. To conclude, this section will discuss the study's constraints and put forward potential directions for future research.*

Keywords*: Big data analytics AI, Reverse logistics, Environmental Process Integration, Big Data-driven Supply Chain, Circular Economy Supply Chain, Waste Management.*

*Corresponding author: (M. A. Al Doghan) mdoghan@kfu.edu.sa.
(V. P. K. Sundram) veera692@uitm.edu.my

1. Introduction

Recent years have witnessed a significant surge in economic and technological advancements, which have not only led to enhanced living standards but have also acted as catalysts for the generation of waste on a global scale. Consequently, the escalation in waste production and inadequate waste management practices have emerged as significant global issues (Bao & Lu, 2020). Furthermore, the accelerated pace of economic advancement and industrialization has also resulted in the depletion of natural resources as a consequence of inadequate resource management (Ahmed et al., 2020). Hence, the phenomenon of reverse logistics (RL) has attracted global attention. Reverse Logistics (RL) has the potential to optimise the utilisation of diverse materials, thereby addressing the challenges linked to the depletion of natural resources. Furthermore, this technology possesses the capability to enhance the operational effectiveness and financial viability of enterprises through the retrieval and repurposing of goods, thereby facilitating efficient utilisation of resources (Julianelli et al., 2020). The implementation of Industry 4.0 technologies has significantly transformed manufacturing operations through the integration of sustainable practices in resource management, resulting in agile manufacturing processes and environmentally friendly production (Sun, Yu, & Solvang, 2022). The manufacturing sectors in reverse logistics predominantly employ Industry 4.0 technologies such as Big Data, Cyber-Physical System, Internet of Things, and (Krstić et al., 2022).

The application of big data analytics in the assessment of data obtained from products engaged in reverse logistics facilitates the development of performance metrics and management systems for performance evaluation (Shah, Dikgang, & Menon, 2019). The escalating significance of environmental concerns arising from the excessive disposal of waste has rendered waste management an inevitable yet exceedingly crucial predicament. However, when examined through the lens of a value chain framework, waste has attracted considerable interest because of its capacity to be transformed into valuable resources. Hence, Reverse Logistics (RL) plays a crucial role in the conversion of waste materials into valuable resources, effectively tackling environmental issues, and promoting economic growth concurrently. Reverse Logistics (RL) is also of paramount importance in augmenting and optimising the value chain system, as well as unleashing the inherent value of products (Zhang & He, 2022). The main goal of this study is to investigate the influence of AI-enabled reverse logistics and big data on resource and waste management within the manufacturing sector of Saudi Arabia.

This study focuses on the manufacturing sector in Saudi Arabia due to the country's notable strides and advancements in the implementation of technological solutions for resource management and supply chain management within this sector. Petrochemicals, fertilizers, metal products, and rolled steel are among the key commodities manufactured within Saudi Arabia's industrial sector, as noted by (Muhammad Awais & Bauirzhanovna, 2023) in their study. Saudi Arabia is a constituent of the G20 nations, thereby currently holding the distinction of being the foremost global exporter of oil. Consequently, oil exports serve as the primary source of revenue and catalyst for the country's advancement. The country is confronted with substantial environmental, social, and economic challenges as a result of its economic dependence on oil (Agboola, Bekun, & Joshua, 2021). In addition, the disposal of waste presents a significant hazard to terrestrial and aquatic ecosystems, as well as contributing to climate change, thereby resulting in detrimental effects on the natural environment (Guo et al., 2021). Furthermore, the escalating population in Saudi Arabia has served as a catalyst for the surge in energy demand within the burgeoning electricity and manufacturing sectors (DNA, 2022).

Consequently, the nation's apprehensions pertaining to environmental deterioration and measures for alleviation have escalated in magnitude (Rahman et al., 2021). Research findings indicate that the production of electronic waste (e-waste) in Saudi Arabia is experiencing significant growth as a result of the swift urbanisation process and advancements in manufacturing technology (Almulhim, 2022). Riyadh, Jeddah, and Dammam are identified as the primary sources of waste generation in Saudi Arabia when considering all cities within the country (Labib et al., 2021). The improper handling and disposal of electronic waste, commonly referred to as e-waste, can pose significant risks to both the climate and the natural environment. Consequently, the effective management of e-waste is of utmost importance in order to safeguard the integrity of the natural environment (Hakami, 2018).

Therefore, it is imperative to incorporate sustainable resource and waste management practices within the manufacturing sector of the nation, particularly in light of its susceptibility to natural disasters resulting from extensive environmental deterioration (Murshed, 2022). Furthermore, scholarly research has indicated that the utilisation of big data analytics is of utmost importance in facilitating the digital transformation of the oil and gas sector. This is achieved through the effective management of the industry's substantial data volume and the subsequent enhancement of operational efficiency, particularly in terms of risk mitigation (Nguyen, Gosine, & Warrian, 2020). Therefore, the utilisation of big data analytics holds considerable potential for augmenting the operational efficiency of the manufacturing industry in Saudi Arabia.

Saudi Arabia has formulated a strategic initiative, known as Vision 2030, aimed at fostering inclusivity in its societal and economic progress, with a particular focus on addressing environmental issues. In addition, the vision encompasses the achievement of complete waste recycling (Yusuf & Lytras, 2023), However, a notable deficiency exists in the existing body of research concerning the examination of the impact of Reverse Logistics (RL) and big data analytics on the improvement of resource and waste management within the manufacturing sector of Saudi Arabia. Several previous studies have highlighted the significance of Artificial Intelligence (AI) in the context of Reverse Logistics (RL), which has the potential to accelerate the implementation of the circular economy. These studies indicate the extensive advantages that AI can offer in the field of RL (Obschonka & Audretsch, 2020).

Nevertheless, there is a need for a systematic investigation into the influence of artificial intelligence (AI) on Reverse Logistics (RL), highlighting a notable deficiency in existing research on this subject matter. The current study places significant importance on investigating AI-enabled resource and waste management systems for reverse logistics and big data analytics in the manufacturing sector of Saudi Arabia.

2. Literature Review

2.1. Theoretical Background

Circular Economy Practises (CEP) are a paradigm shift that aims to transition from the traditional linear production model to a cyclical one (Salmenperä et al., 2021). The present theoretical framework establishes a correlation between the value generated by information technology in business, the supply chain, and the concept of sustainability. While previous studies have made initial forays into this field (Belhadi et al., 2022), the present article enhances the existing body of knowledge by further investigating the underlying mechanisms that connect Big Data Analytics and the generation of sustainable value.

In the field of Supply Chain (SC) research, scholars emphasise the need for additional investigation into the effects of utilising Big Data Analytics and its implications for Supply Chain Management and Coordination (SCMC) (Tipi, 2021). Moreover, it is widely recognized that there is an urgent need for a more profound comprehension of the intricate interaction between data-driven supply chains and the concept of the Circular Economy (CE), as emphasized by (Del Giudice et al., 2021) in their study. Significantly, the field of Information Technology (IT) plays a crucial role in enabling the implementation of Circular Economy Practises (Kristoffersen et al., 2021).

A group of scholars, as suggested by Awan et al. (2021), propose the adoption of data-driven Circular Economy Practises as a means to promote a more holistic comprehension of the mutually beneficial relationship between Big Data Analytics and Circular Economy Practises in advancing sustainability. The attainment of effective implementation of circular supply chain practices surpasses the scope of solely focusing on the design and management of the circular supply chain. The effective utilisation of Human Resources (HR), the adoption of a compassionate approach, and the provision of comprehensive training in the principles of the circular economy are crucial factors that significantly impact the outcome (Ripanti & Tjahjono, 2019). Academic literature emphasises the crucial role that human resource management plays in enabling the achievement of organisational goals and strategies. Furthermore, it underscores the significant influence that human resource management practises have on the overall performance of a company (Jabbour et al., 2019a; Jabbour et al., 2019b).

The effectiveness of circular supply chain methods is contingent upon the implementation of meticulous human resource management practises. This necessitates the development of a workplace culture characterised by empathy and compassion, alongside the recruitment and retention of top-notch personnel. This strategy ensures the assurance of employee engagement, motivation, and commitment to the guiding principles of the circular economy. Moreover, comprehensive instruction in the core principles of the circular economy equips employees with the requisite knowledge and skills to effectively participate in the widespread implementation of circular supply chain practises. Ultimately, these components collaborate harmoniously to establish resilient, cyclical supply chain frameworks that align seamlessly with overarching corporate objectives and strategic direction.

Table 2.1: Definitions of variables

Variable	Definition	Reference
Big data analytics AI	It includes the usage of advanced algorithms for gathering insights from large datasets.	(Awan et al., 2021)
Reverse logistics	RL refers to the reverse flow of returns and recalls, which can potentially be resold, recycled, renovated, restored, or remanufactured. From an operational standpoint, RL involves handling inventories of returned items or disposed materials. From a circular economy perspective, RL presents a chance to mitigate an organization's environmental footprint.	(Krstić et al., 2022)
Environmental process integration	It includes incorporation of environmentally friendly practices in operations for minimal environmental damage and also with the purpose of improving sustainability.	(Benzidia, Makaoui, & Bentahar, 2021)
Big data-driven supply chain	These supply chains are based on data and use analytics to optimize operations, enhance efficiency, and make informed decisions across the supply network.	(Del Giudice et al., 2021)
Circular economy HR management	The concept suggests that HR management should be aligned with overall resource efficiency, waste reduction, and sustainable product lifecycles.	(Del Giudice et al., 2021)
Firm performance for circular economy supply chain	The firm performance is enhanced by circular economy strategies through the promotion of sustainability, waste reduction, and resource efficiency through the strategies of responsible sourcing and other closed loop processes.	(Del Giudice et al., 2021)
Waste minimization	It is associated with the reduction of waste to optimize the overall resource usage, improve sustainability and contribute to an overall effective environmentally conscious approach.	(Salmenperä et al., 2021)

2.2. Comprehensive Impacts of Waste Minimization in Circular Economy Supply Chains

Paes et al. (2019) conducted a comprehensive review of existing literature and performed content analysis to evaluate the present condition of organic waste management in relation to the principles of circular economy (CE). A number of notable vulnerabilities and potential risks were identified within the realm of organic waste management. One of the main focal points pertains to the elevated logistical expenditures and the complexities associated with effectively managing the supply chain. The presence of seasonal fluctuations in the accessibility of organic waste presents a significant obstacle, while the absence of uniformity and consistency in the composition of raw materials introduces intricacy to the procedure. Moreover, there are concerns that arise pertaining to the quality and efficacy of alternative products that are derived from organic waste. These concerns primarily revolve around their economic competitiveness in relation to conventional counterparts. An additional critical factor pertains to the lack of clearly defined technical standards and regulatory frameworks that govern the management of organic waste, potentially impeding advancements in this domain.

In contrast, the study also unveiled significant advantages linked to the management of organic waste within the framework of the circular economy paradigm. The concept of a circular economy embodies a strategic framework aimed at promoting sustainable production and efficient waste management (Camana et al., 2021). The goal of this study by Camana et al. (2021) is to assess the efficacy of key methodologies related to the circular economy, specifically industrial ecology, life cycle thinking, and flow analysis. The notion of a green supply chain is grounded in the domain of supply chain management technology, which encompasses a network of entities that includes suppliers, manufacturers, distributors, retailers, logistics providers, and various enterprises, all the way to end-users. The primary aim of this initiative is to achieve a state of equilibrium by aligning economic factors, environmental considerations, and the management of resources (Chen et al., 2022).

During the procurement phase, it is recommended that enterprises prioritise the utilisation of environmentally sustainable materials and production equipment, while simultaneously ensuring that product quality remains uncompromised. This entails the utilisation of sustainable environmental protection materials, optimising procurement quantities, and minimising environmental expenses related to waste management in the logistics operations. During the marketing phase, it is imperative to prioritise the implementation of standardised, recyclable packaging solutions in order to mitigate the production of packaging waste. Moreover, the careful consideration of effective and environmentally friendly modes of transportation is of utmost importance (Nejati, Rabiei, & Chiappetta Jabbour, 2017). According to Chen et al. (2022), the widespread adoption of artificial intelligence (AI) systems across different sectors, including manufacturing, is primarily attributed to their ability to engage in self-learning, self-regulation, and adaptation to their environment. Hence, these hypotheses can be formulated:

H1: *Big data analytics-AI positively influences waste minimization efforts in the supply chain.*
H2: *Effective implementation of reverse logistics practices positively impacts waste minimization in the circular economy supply chain.*
H3: *Circular economy-focused human resource management practices enhance waste minimization efforts within the organization.*
H4: *Adoption of big-data-driven supply chain strategies leads to improved waste minimization outcomes.*

2.3. The Mediation Role of Firm Performance in Circular Economy Supply Chains

The concept of Sustainable Supply Chain Management (SSCM) revolves around the incorporation of environmental, social, and economic factors into activities related to Supply Chain Management (SCM). This integration is aimed at tackling current challenges in these areas (Li & Liu, 2019). In contemporary times, the concept of Sustainable Supply Chain Management (SSCM) places significant importance on the effective management of both tangible and intangible resources. This marks a departure from the conventional management approaches that primarily rely on tangible resources. The research conducted by Mariani, Machado, and Nambisan (2023) offers a current synthesis of the available literature, which is incorporated within an interpretive framework. This framework facilitates the exploration of the primary factors that impact and arise from the implementation of Artificial Intelligence (AI) in the context of innovation and organisational performance. This study identifies various antecedents that contribute to firms' adoption of artificial intelligence (AI) for the purpose of innovation. These antecedents encompass technological, social, and economic rationales.

Moreover, in the process of identifying the disciplinary focal points of the research, it also highlights the noteworthy outcomes of AI implementation for firms, including business model innovation, process innovation, product innovation, and social innovation. Based on the fundamental findings obtained from this study, we suggest potential directions for future exploration pertaining to diverse manifestations of innovation. The findings of the study conducted by Obeidat, Abdalla, and Al Bakri (2023) confirm the positive influence of a green strategic intent on Green Human Resource Management (HRM). Additionally, the research establishes a positive relationship between Green HRM and green empowerment in the context of the circular economy. Furthermore, the study demonstrates a beneficial correlation between the circular economy and sustainable performance. Additionally, the study offers support for the indirect influence of the circular economy on the link between Green Human Resource Management (HRM) and sustainable performance. Hence these hypotheses can be proposed:

H5: *Firm performance mediates the relationship between the use of big data analytics-AI and waste minimization in the circular economy supply chain.*
H6: *Firm performance serves as a mediator between the effective implementation of reverse logistics and waste minimization in the supply chain.*
H7: *Firm performance acts as a mediator between circular economy HR management practices and waste minimization within the organization.*
H8: *Firm performance plays a mediating role in the relationship between the adoption of big-data-driven supply chain strategies and improved waste minimization outcomes.*

2.4. Environmental Process Integration as a Moderator in Circular Economy Supply Chains

According to Sun, Yu, and Solvang (2023), the rapid progress of Information and Communication Technology (ICT) and the emergence of digitalization in the industry 5.0 era have presented new opportunities for the digitization, improvement, sustainability, and optimisation of reverse logistics management. The transformation described above is achieved by integrating disruptive technologies like the block chain, Internet of Things (IoT), Big Data analysis, simulation, Artificial Intelligence (AI) and other similar ground-breaking innovations. Within the realm of technological advancements, the notion of a digital twin emerges as a particularly noteworthy concept in the context of Industry 5.0. This concept entails the virtual replication of tangible objects or systems within the digital domain. The present study by Fanta and Pretorius (2022) aimed to examine the impact of reverse logistics on the promotion of the circular economy in the healthcare industry. Additionally, the researchers analysed the potential effects of digital technologies associated with Industry 4.0 on the improvement of reverse logistics, with a focus on supporting the principles of a circular economy. The study utilises a system dynamic modelling methodology to thoroughly examine the interrelated causal connections among different elements of reverse logistics in the healthcare sector.

Moreover, this underscores the pivotal role those digital technologies, such as artificial intelligence, the Internet of Things (IoT), and big data analysis, play in facilitating crucial activities pertaining to the gathering, categorization, management, and retrieval stages of reverse logistics in the healthcare industry. The findings of the study conducted by Benzidia et al. (2021) reveal a significant correlation between the adoption of Big Data Analytics (BDA) and Artificial Intelligence (AI) technologies and the promotion of environmental process integration and collaboration in green supply chains. Moreover, this research underscores the significant impact that environmental process integration and collaborative endeavours in green supply chains have on environmental performance. A notable discovery from this study highlights the unique contribution of green digital learning in moderating the connections between BDA-AI technologies and collaborative efforts in green supply chains. This finding introduces an original dimension to existing academic literature, as it has not been previously emphasized.

In recent years, there has been notable progress in both the research and implementation of Big Data Analytics (BDA) and Artificial Intelligence (AI) within the healthcare domain. The incorporation of artificial intelligence (AI) technology has introduced numerous prospects within the healthcare industry. An example of the application of deep learning techniques is the interpretation of automated biomedical images in multiple medical disciplines such as radiology, cardiology, dermatology, pathology, and ophthalmology (Wang et al., 2019). The domains mentioned above experience a variety of advantages, including improved processes, immediate reactions to urgent situations, optimisation of resources and costs, and the provision of more efficient healthcare services (Raut et al., 2019).

In addition to its direct implications for healthcare provision, the integration of big data analytics (BDA) and artificial intelligence (AI) holds considerable potential for driving advancements in medical research. Significantly, within the domain of hospital pharmacies, the synergistic application of artificial intelligence (AI) and big data analytics (BDA) has exhibited its efficacy, particularly in the sphere of pharmaceutical innovation and formulation (Wang et al., 2019). An additional advantageous aspect of AI technology pertains to its capacity to offer exceptionally precise predictions regarding the number of hospital visits that occur outside of inpatient settings (Hadavandi et al., 2012).

As a result, hospitals are able to more effectively forecast their resource demands, encompassing the personnel requirements for patient care (including physicians, nurses, and nursing aides) as well as the essential provisions such as medical devices and pharmaceuticals, for a designated timeframe. The aforementioned results provide significant benefits in the effective management of various aspects of the hospital supply chain, including the acquisition and control of hospital supplies and equipment, transportation and distribution logistics, internal production processes, and the proper handling and disposal of waste materials. The effective utilisation of big data through artificial intelligence (AI) interfaces is closely linked to applications such as Enterprise Resource Planning (ERP) software. This integration enhances decision-making processes and actively encourages the adoption of sustainable and environmentally friendly practices. Hence, this hypothesis can be proposed:

Hypothesis 9*:* *Environmental process integration moderates the relationship between waste minimization and firm performance for circular economy supply.*

3. Methodology

This section will illustrate the main way and recipe of conducting this research in different subsequent headings.

3.1. Research Strategy

The present study has employed a deductive approach and utilised a quantitative method for primary data collection. The researcher chose the manufacturing sector as the focus of the study and identified the employees within this sector as the participants for the research. Nevertheless, the manufacturing sector organisations employed a significant number of individuals, necessitating the use of an appropriate sampling technique. This enabled the researcher to obtain homogeneous data from a diverse population. In this study, the researcher utilized a purposive sampling method that was not based on probability. The focus of the sampling was exclusively on employees of firms, excluding other working populations. The rationale for targeting employees was based on the understanding that they serve as the fundamental and central unit driving the performance of any business.

The researcher collected demographic information regarding manufacturing sector firms and business establishments operating within the confines of Saudi Arabia. This information was obtained from the official websites of the government. Additionally, data was collected using a survey instrument in accordance with the principles of quantitative research. The researcher employed a self-administered and online approach for data collection in order to enhance the inclusivity of responses within the data sample. By utilising these methods, data was gathered from all available units, including those that were geographically distant.

3.2. Survey Instrument Construction Used for Data Collection

The survey instrument was synthesised by the researcher, who commenced it by providing an introduction that included information about the researcher, the study itself, the purpose of data collection, and a declaration regarding the utilisation of data solely for research purposes, ensuring complete anonymity and confidentiality. Subsequently, the researcher incorporated demographic inquiries pertaining to gender, age, educational background, job characteristics, and work history in order to obtain introductory data regarding the participants who have engaged in the study. In the third section, the researcher aggregated all the scale items pertaining to the targeted variables, which were obtained from a comprehensive review of recent empirical literature studies. The adoption of the big data analytics AI scale in this study has provided the researcher with a set of five items for assessing the capabilities of big data analytics (Benzidia et al., 2021). The measurement of the independent variable, reverse logistics, was conducted using a set of six items that were adopted from a previous study (Bor, 2020). The environmental process integration scale consisted of five items that were derived from a recent study. The study reported a high level of reliability for these items, with a Cronbach alpha value of 0.971 (Benzidia et al., 2021).

The present study examined the big data-driven supply chain as an independent variable, utilising a set of four items derived from a study (Del Giudice et al., 2021). Additionally, the same study provided the researcher with three items to assess circular economy HR management. It is worth noting that the adopted scale items for both variables demonstrated high reliability, as indicated by the original study. The mediator in this study was assessed using a set of scale items employed in a previous study that utilised three items to measure firm performance within the context of the circular economy supply chain (Del Giudice et al., 2021). The dependent variable of waste minimization was assessed using three items adapted from a recent study (Onubi et al., 2022). The researcher used the statistical software SPSS to derive and compute the results and significant findings of the study. The subsequent table provides a summary of the variables and their respective sources.

Variable name	Source of items
Big data analytics AI	(Benzidia et al., 2021)
Reverse logistics	(Bor, 2020)
Environmental process integration	(Benzidia et al., 2021)
Big data-driven supply chain	(Del Giudice et al., 2021)
Firm performance for circular economy supply chain	(Del Giudice et al., 2021)
Circular economy HR management	(Del Giudice et al., 2021; Onubi et al., 2022)
Waste minimization	

4. Analysis

4.1. Demographics

When conducting research, it is crucial to undertake an analysis of the demographics of the participants. The results of demographics are presented in Table 4.1. There were 200 participants in the present study, 101(50.5%%) male and 99(49.5%) female. Looking upon their age-group, 75(37.5%) were between 31-35, 65(32.6%) between 26-30, 33(16.5%) were above 35 and 27(13.5%) were less than 25 years. Moreover, 105(52.5%) had experience of 2-5 years, 65(32.5%) had 5-8, 23(11.5%) had less than 2 years and 7(3.5%) had more than 8 years.

Table 4.1: Demographic Profile

		Frequency	%
Gender			
	female	99	49.5
	male	101	50.5
Age			
	Less than 25Y	27	13.5
	26 to 30Y	65	32.5
	31 to 35Y	75	37.5
	More than 35Y	33	16.5
Experience			
	less than 2 years	23	11.5
	2-5	105	52.5
	5-8	65	32.5
	more than 8 years	7	3.5

4.2. Descriptive Statistics

The large and complex datasets were analysed using descriptive statistics in order to organise and summarise the data (MacFarland & Yates, 2021). Table 4.2 entails values of descriptive statistics against all observed constructs.

Table 4.2: Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation	Skewness
BDD	200	1.00	5.00	3.8313	.93874	-1.243
BDA	200	1.20	5.00	3.7980	.92209	-1.052
CEHR	200	1.33	5.00	3.7267	.93434	-.846
FP	200	1.00	5.00	3.7183	.93990	-.874
EPI	200	1.00	5.40	3.5340	.95950	-.385
RI	200	1.00	5.00	3.4892	1.02114	-.427
WM	200	1.00	5.00	3.6350	.88892	-.645
Valid N	200					

"BDA=Big data analytics AI, RI=Reverse logistics, EPI=Environmental process integration, BDD=Big data-driven supply chain, CEHR=Circular economy HR management, FP=Firm performance for circular economy supply chain, WM=Waste minimization."

4.3 Reliability Analysis

In order to assess the dependability of the dataset, the study has employed the Cronbach alpha reliability analysis. A value greater than 0.7 for α indicates that the dataset can be considered reliable (Hajjar, 2018). From Table 4.3, α for BDD, BDA, CEHR, FP, EPI, RL and WM are .939, .832, .750, .727, .862, .881 and .864, these values are greater than 0.7; dataset is reliable.

Table 4.3: Reliability

Variable	α
BDD	.939
BDA	.832
CEHR	.750
FP	.727
EPI	.862
RL	.881
WM	.864

"BDA=Big data analytics AI, RI=Reverse logistics, EPI=Environmental process integration, BDD=Big data-driven supply chain, CEHR=Circular economy HR management, FP=Firm performance for circular economy supply chain, WM=Waste minimization."

4.4 KMO and Bartlett's Test

In order to assess the factor loadings, it is crucial to ascertain the appropriateness of the data and the sufficiency of the sample. Hence, the Kaiser-Meyer-Olkin (KMO) measure and the Bartlett test were utilised Tabachnick and Fidell (2007). assert that a Kaiser-Meyer-Olkin (KMO) test value exceeding 0.9 holds substantial significance, while a Bartlett test value below 0.05 is deemed significant (Shrestha, 2021). Results shown in table 4.3 indicates that KMO and Bartlett's Test is significant.

Table 4.3: KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.949
Bartlett's Test of Sphericity	Approx. Chi-Square	4535.545
	Sig.	.000
	df	406

4.5 Factor Loadings

In order to evaluate the absence of non-cross-loadings and the absence of outliers in the dataset, an analysis of factor loadings was conducted. The results of this analysis are presented in Table 4.4, specifically in the form of a rotated component matrix. Only values above 0.4 are reported in this table. The analysis included the examination of items pertaining to BDD (4 items), CEHR (5 items), FP (3 items), EPI (3 items), RL (6 items), and WM (3 items).

Table 4.4: Rotated Component Matrix

	1	2	3	4	5	6	7
BDD1	.615						
BDD2	.729						
BDD3	.722						
BDD4	.706						
BDA1		.747					
BDA2		.709					
BDA3		.709					
BDA4		.629					
BDA5		.688					
CEHR1			.495				
CEHR2			.758				
CEHR3			.578				
FP1				.636			
FP2				.625			
FP3				.498			
EPI1					.638		
EPI2					.665		
EPI3					.787		
EPI4					.778		
EPI5					.795		
RL1						.569	
RL2						.683	
RL3						.716	
RL4						.698	
RL5						.744	
RL6						.671	
WM1							.641
WM2							.565
WM3							.518

“BDA=Big data analytics AI, RL=Reverse logistics, EPI=Environmental process integration, BDD=Big data-driven supply chain, CEHR=Circular economy HR management, FP=Firm performance for circular economy supply chain, WM=Waste minimization."

4.6 Correlation Analysis

Correlation is a statistical method that quantifies the degree of association between two variables (Aggarwal & Ranganathan, 2016). The correlation coefficient, which spans a range from -1 to +1, serves as an indicator of both the intensity and direction of the association between two variables. A value of -1 represents a perfect negative correlation, while a value of +1 represents a perfect positive correlation. Table 4.5 displays the entirety of the acquired values, all of which fall within the predetermined range.

Table 4.5: Correlation

	BDD	BDA	CEHR	FP	EPI	RI	WM
BDD	1						
BDA	.852**	1					
CEHR	.724**	.686**	1				
FP	.723**	.703**	.620**	1			
EPI	.668**	.651**	.694**	.567**	1		
RL	.741**	.664**	.566**	.723**	.584**	1	
WM	.717**	.691**	.689**	.630**	.842**	.683**	1

"BDA=Big data analytics AI, RL=Reverse logistics, EPI=Environmental process integration, BDD=Big data-driven supply chain, CEHR=Circular economy HR management, FP=Firm performance for circular economy supply chain, WM=Waste minimization."

4.7 R-Square

The R-square statistic is a statistical method used to evaluate the portion of variability in the dependent variable that can be accounted for by the independent variable. The R-square results are presented in Table 4.6. The obtained values for R-square and adjusted R-square are 0.627 and 0.620, respectively, indicating a 62% relationship between the variables.

Table 4.6: R-square

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.792[a]	.627	.620	.54820

4.8 ANOVA

ANOVA testing was done, results shown in table 4.7 shows that overall model is fit as depicted by significance of the f test.

Table 4.7: ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	98.643	4	24.661	82.060	.000[b]
	Residual	58.601	195	.301		
	Total	157.244	199			

4.9 Hypotheses Testing

In this study there was 4 direct hypotheses. The results of hypotheses testing are given in table 4.8. The relationship between BDD and WM was not supported (t=1.178, p=.240), association between BDA and WM was supported (t=2.080, p=.039), relationship between CEHR and WM was supported (t=4.813, p=.000), and relationship between RI and WM was also supported (t=4.633, p=.000).

Table 4.8: Direct Hypotheses testing

Model		Unstandardized-Coefficients		Standardized-Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.540	.178		3.035	.003
	BDD	.110	.093	.116	1.178	.240
	BDA	.171	.082	.177	2.080	.039
	CEHR	.296	.062	.311	4.813	.000
	RI	.264	.057	.303	4.633	.000

"BDA=Big data analytics AI, RI=Reverse logistics, BDD=Big data-driven supply chain, CEHR=Circular economy HR management."

4.10 Mediation Analysis

Using SPSS, mediation was analysed. In this study there are 4 hypotheses of mediation. Table 4.9 summarized the results of mediation analysis. It was found that FP does not significantly mediate the association between BDA and WM (as total-effect of BDA on WM is .66, direct-effect is 0.47, indirect-effect is .19, and t=13.45), FP was found to partially mediates the association between RL and WM (as total-effect of RL on WM is .59, direct-effect is 0.41, indirect-effect is .17, and t=13.16), however, FP does not significantly mediate the association between CEHR and WM (as total-effect of CEHR on WM is .65, direct-effect is 0.46, indirect-effect is .19, and t=13.36)., also FP do not significantly mediate the association between BDD and WM (as total-effect of BDD on WM is .67, direct-effect is 0.51, indirect-effect is .16, and t=14.48).

Table 4.9: Mediation Analysis

Relationship	Total-effect	Direct effect	Indirect effect	Confidence Interval		t-statistics	Conclusion
				Lower-bound	Upper-bound		
BDA→FP→WM	.6662	.4728	.1934	.5685	.7639	13.4535	Not supported
RL→FP→WM	.5948	.4154	.1794	.5058	.6839	13.1694	Partial Mediation
CEHR→FP→WM	.6552	.4605	.1947	.5585	.7519	13.3652	Not supported
BDD→FP→WM	.6791	.5190	.1602	.5867	.7716	14.4820	Not supported

"BDA=Big data analytics AI, RL=Reverse logistics, EPI=Environmental process integration, BDD=Big data-driven supply chain, CEHR=Circular economy HR management, FP=Firm performance for circular economy supply chain, WM=Waste minimization."

4.11 Moderation Analysis

The outcomes of the study moderation analysis are displayed in Table 4.10. The findings indicate that the impact of Environmental process integration is statistically significant, as evidenced by the significant interaction effect. Therefore, the hypothesis is supported.

Table 4.10: Moderation Analysis

	coeff	se	t	p	LLCI	ULCI
constant	-.6684	.3796	-1.7611	.0798	-1.4170	.0801
FP	.5501	.1094	5.0265	.0000	.3343	.7659
EPI	1.0691	.1288	8.2995	.0000	.8150	1.3231
Int_1	-.1114	.0336	-3.3177	.0011	-.1776	-.0452

"EPI=Environmental process integration, FP=Firm performance for circular economy supply chain."

5. Discussion

The main aim of this study was to analyse and investigate the effects of artificial intelligence-driven Reverse Logistics (RL) and Big Data Analytics (BD) on resource allocation and waste management within the manufacturing industry. The empirical evidence substantiates the considerable influence of big data analytics and artificial intelligence (AI) on waste reduction, thereby providing support for the initial hypothesis. The validation of the initial hypothesis underscores the significance of artificial intelligence and big data analytics within the realm of waste reduction. Therefore, the results of this study align with prior research (Mehrbakhsh, Abdullah M, & Rabab Ali, 2023) and highlight the potential of AI-driven technologies as avenues for enhancing waste reduction strategies in terms of efficiency and effectiveness.

Along with that, the results show that combining Reverse Logistics (RL) with Waste Management (WM) has a substantial effect, which supports Hypothesis 2 and is in line with previous research (Xu & Yang, 2022). The acceptance of hypothesis H2 carries substantial implications for comprehending the role of Reverse Logistics (RL) in attaining sustainability objectives within the context of the circular economy paradigm (CEP). The findings indicate that there is evidence to support the idea that implementation of efficient RL strategies facilitates a cyclical movement of materials, leading to a reduction in waste generation and an optimisation of resource utilisation. Moreover, the results of the investigation provide evidence for the substantial influence of human resource management practices centred around the circular economy on waste management, thereby confirming the third hypothesis (H3). The validation of the third hypothesis underscores the significance of incorporating sustainability principles and the concept of Corporate Environmental Performance (CEP) into human resource management (HRM) policies.

This finding suggests that HRM practices have the capacity to drive the sustainable growth of the manufacturing industry. This discovery aligns with prior research that highlights the significance of HRP in attaining objectives related to the circular economy (Dibia et al., 2020). However, the results of the research do not provide substantial evidence to support the notion that big data-driven supply chain strategies have a significant influence on WM. Consequently, this leads to the rejection of hypothesis H4. The null hypothesis H4 is rejected due to a lack of sufficient evidence supporting a clear and positive correlation between the implementation of supply chain strategies driven by big data and the outcomes of WM. Additionally, the current study also examined the mediating impact of firm performance. The study proposed that there is a mediating effect of firm performance on all four independent variables. The empirical evidence confirms that the mediating role of FP is supported in the relationship between RL and WM, thereby providing validation for Hypothesis 6.

Therefore, the findings suggest that there is partial mediation. The inclusion of H6 suggests that the role of FP is essential in facilitating the translation of RL practices into measurable WM outcomes. This suggests that the implementation of RL practises has a positive impact on the functioning of the frontal cortex, leading to improved working memory outcomes. Furthermore, the present study also examines the moderating effect of environmental process integration on the relationship between WM and FP. The results of the study provide support for the moderating role, thereby confirming the hypothesis H9. The acceptance of hypothesis H9 suggests that the influence of firm performance (FP) on Waste Minimization (WM) is contingent upon the degree of integration of environmental processes.

6. Conclusion

The Kingdom of Saudi Arabia (KSA) has experienced significant expansion in its manufacturing industry in recent decades, highlighting the necessity of adopting the Circular Economy Paradigm (CEP) to attain efficient resource utilisation and waste management. This study investigated the influence of multiple factors on waste management (WM) and explored the interconnectedness between sustainability, waste management (WM), and the circular economy principles (CEP) within the ever-changing context of the manufacturing industry in Saudi Arabia. The study's findings demonstrate the utilisation of circular economy principles as a foundational framework for the execution of sustainable supply chain management practices within the Saudi Arabian context. Furthermore, the study provided evidence for the substantial influence of artificial intelligence-driven reinforcement learning and big data analytics on improving working memory outcomes in terms of supply chain management. The exploration of the notable influence of human resource management (HRM) practices on corporate environmental performance (CEP) underscores the importance of cultivating a sustainable culture to motivate employees to actively participate in waste management (WM) initiatives. Additionally, the research also suggests that the Firm Performance (FP) plays a pivotal role in determining the extent to which Reverse Logistics (RL) practices affect waste minimization (WM).

6.1 Research Implications

6.1.1. Theoretical Implications

The current investigation carries substantial theoretical implications within the context of circular economy practises, a burgeoning paradigm that advocates for sustainable practises (CEP) (Patwa et al., 2021). This study enhances the current literature on the circular economy by incorporating it within the framework of AI-enabled reverse logistics and big data analytics. Therefore, this study enriches the existing body of literature pertaining to strategies for attaining a circular economy, thereby enhancing comprehension of the fundamental principles underlying circular economy concepts. Additionally, this study serves to bridge the theoretical divide between technology adoption and CEP by showcasing the integration of AI and big data within the CEP framework. Furthermore, this study throws a lights on the available literature on waste reduction and sustainability by demonstrating the potential of artificial intelligence (AI) to offer distinct possibilities for waste reduction.

Additionally, it highlights the role of big data in monitoring and managing resources, thereby enhancing sustainability within the manufacturing sector. The study's theoretical implications extend to the enrichment of existing research on the environmental impact of different practises within the manufacturing sector. This study contributes to the existing body of knowledge by providing insights into the effects of different operational decisions made by the manufacturing sector on the environment. This aligns with the central principle of the Circular Economy Paradigm (CEP). Additionally, this study addresses a notable research deficiency in the field of CEP studies specifically pertaining to the Saudi Arabian context. This study makes a valuable contribution to the understanding of the implementation of the concept of Corporate Environmental Performance (CEP) within the manufacturing sector of Saudi Arabia. It showcases how CEP can be effectively tailored to align with the distinct economic, cultural, and environmental characteristics of the Kingdom of Saudi Arabia (KSA).

6.1.2. Practical Implications

The present study offers valuable practical implications by furnishing actionable insights and recommendations for a diverse set of stakeholders, encompassing policymakers and leaders within the manufacturing industry. The practical implications outlined have the potential to stimulate advancements in waste and resource management practices within the manufacturing sector of Saudi Arabia. The results of this study provide valuable insights for manufacturing industries seeking to implement artificial intelligence (AI) and big data technologies in order to optimise their resource management practices. By doing so, these industries can achieve several benefits, including waste reduction, decreased production costs, and improved overall resource efficiency within the sector. This study advocates for the utilisation of reverse logistics processes as a means to achieve cost savings. The integration of artificial intelligence (AI) is proposed as a solution to reduce production costs and minimise downtime in the manufacturing industry, ultimately leading to increased profitability.

This study provides recommendations for the manufacturing industry to adopt AI-driven predictive maintenance and data analytics as a means to mitigate waste generation, thereby promoting sustainable waste reduction practices. Furthermore, the study's findings provide valuable insights for companies seeking to enhance their competitive edge in waste and resource management through the implementation of artificial intelligence (AI) and big data technologies, thereby demonstrating their dedication to the Circular Economy Principles (CEP). Within the framework of Saudi Arabia, the outcomes of the current investigation are consistent with the sustainability objectives of the Kingdom of Saudi Arabia (KSA), as outlined in Vision 2030. The insights from this study can be utilised by the manufacturing sector to align their practices with the sustainability goals of the country, thereby ensuring compliance with the country's sustainability policies.

6.2 Research Limitations and Future Directions

The current investigation possesses a number of limitations that warrant consideration in subsequent research endeavours within this field. One of the limitations inherent in this study pertains to its narrow industry scope, specifically targeting the manufacturing sector within the context of Saudi Arabia. While the study's emphasis on the specific context of Saudi Arabia's manufacturing sector offers valuable insights into the Circular Economy Principles (CEP), it is important to note that the findings may have limited applicability to other industries or sectors in different demographic settings. Future research endeavours should strive to examine the incorporation of artificial intelligence (AI)-enabled reverse logistics and big data within the realm of waste and resource management, specifically within an alternative industrial setting. The current study is grounded in an empirical examination of artificial intelligence-enabled reinforcement learning and big data analytics, utilising a quantitative survey as the primary research method.

In order to enhance the comprehensiveness of future studies, it is recommended that a qualitative analysis be integrated to effectively capture valuable insights from industry experts. This approach will contribute to the acquisition of a more holistic dataset. Furthermore, the concepts of Reverse Logistics (RL) and Big Data (BD) analytics are complex and encompass various dimensions. Consequently, it is unfeasible to comprehensively analyse all the pertinent variables within a single study. The current investigation may have failed to consider certain variables that could potentially impact resource and waste management. Hence, it is imperative for future research endeavours to thoroughly examine the influence of additional variables, such as organisational culture, employee capabilities, and regulatory compliance, on the efficacy of artificial intelligence (AI) and big data (BD) analytics.

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