

American Journal of Economics and Business Management

Vol. 9 Issue 10 | **pp.** 484-514 | **ISSN:** 2576-5973
Available online @ https://www.globalresearchnetwork.us/index.php/ajebm

Article

Digital Innovation as an Entry Point for Enhancing Operational Sustainability: The Intermediary Role of Reverse Logistics in a Textile and Knitting Factory in Wasit

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Abstract: The purpose of this study is to investigate the mediating effect of reverse logistics on the connection of digital innovation adoption with operational sustainability. The study consisted of three primary variables and their sub-dimensions. The independent variable (digital innovation) was measured in four dimensions: digital infrastructure, application of digital technologies and solutions, digital work environment and digital skills and capabilities. The mediating variable (reverse logistics) had four aspects, namely product acquisition, recycling, reuse and remanufacturing. The dependent variable (operational sustainability) consisted of three dimensions: energy efficiency, sustainable packaging and process automation. The study topic is the knowledge and application gap on how to use digital technologies and technology solutions to support operational sustainability mechanisms through reverse logistics practices in the studied facility. The population of the field study was determined from the administrative, supervisory and technical staff of the Wasit Textile and Knitting Factory, which amounted to (180). The statistically needed sample size of 123 respondents was calculated using Thompson's technique. The researcher sent out 140 questionnaires, of which 133 were returned. After the review, 5 questionnaires were discarded as invalid and the statistical analysis was performed on a total of 128 valid questionnaires, with a response rate of 91.4%. The data were analysed and the hypotheses were tested by a descriptive-analytic technique, using the statistical software SPSS version 26 and AMOS version 24. Advanced statistical procedures were used, namely: confirmatory factor analysis (CFA), normality test, Cronbach's alpha coefficient, structural equation modelling (SEM), path analysis and Sobel's test to validate the significance of the mediation effect. The study found that digital innovation plays a substantial and crucial role in improving operational sustainability indirectly through the mediation of reverse logistics. This mediation raised the explanation power of the structural model to 62 % . Based on these findings, the study recommended the management of the factory under investigation to incorporate modern digital technologies with recycling and manufacturing practices to recover resources, optimise energy consumption and automate processes to ensure the highest level of operational sustainability.

Keywords: Digital innovation, operational sustainability, reverse logistics, Wasit Textile and Knitting Factory.

Citation: Aujah A. M. Digital Innovation as an Entry Point for Enhancing Operational Sustainability: The Intermediary Role of Reverse Logistics in a Textile and Knitting Factory in Wasit. American Journal of Economics and Business Management 2026, 9(10), 484-514.

Received: 10th Jul 2026
Revised: 11th Aug 2026
Accepted: 11th Sep 2026
Published: 15th Oct 2026

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1. Introduction

The contemporary industrial and production environments have experienced profound modifications hastened by the digital revolution and the environmental issues resulting from operating activities. This has forced organisations to find new ways to survive and remain competitive. In this way, digital innovation is a key technique that

facilitates the development of technological capabilities and the use of networks and software for the improvement of institutional performance.

However, to achieve the desired outcomes of digital innovation, it still depends on how it is directed to improve resource efficiency and reduce waste. This is reflected in reverse logistics, through activities of product acquisition, recycling, reuse and production, which constitute the lifeblood of improving operational sustainability in its aspects of energy efficiency, sustainable packaging and process automation.

The problem of the research is based on a gap in knowledge and application exhibited in the limited use of existing digital technologies in the laboratory under study to assist pathways of reverse logistics. This has resulted in data fragmentation and a sluggish response to sustainability standards. Furthermore, the study vacuum is underscored by the lack of Arabic studies that have tackled the mediating function of reverse logistics between digital innovation and operational sustainability in the textile sector. The importance of the study is to throw light on how to fill this

gap and to provide a scientific and practical framework that helps the administrative leadership at the Wasit Textile and Weaving Factory to make proactive decisions. During the fieldwork, the researcher confronted problems with data accuracy and the retrieval time of questionnaires in a hectic operational environment.

To deal with these holistic characteristics, this research is organised within an integrated methodological framework with four key sections. The first section includes the scientific methodology of the study and previous studies. The second section includes the theoretical framework for the research variables. The third section includes the fieldwork, statistical analysis, and hypothesis testing. The fourth section includes the conclusions and recommendations.

2. Methodology of the Research

2.1. The Problem of Investigation

The epistemological problem of this study is the existence of a clear scientific and academic gap on the nature of the interactive relationships between digital innovation and operational sustainability in the industrial environment, especially in the analysis of the mediating role of reverse logistics practices. There is increasing literature on digital innovation and its role in improving organisational performance. However, there is limited and nascent Arab initiatives and research on how digital technologies, solutions and infrastructure can be transformed to reverse logistics mechanisms that directly contribute to energy conservation, sustainable packaging and process automation. Therefore, this study seeks to fill this knowledge gap by developing a complete conceptual model that explains the structural routes by which the characteristics of digital innovation via reverse logistics influence achieving operational sustainability.

The problem of the study is represented at the applied level by the operational and field challenges that the Wasit Textile and Weaving Factory faces, represented by the weak utilisation and application of digital applications and solutions in tracking and managing the movement of returned and damaged products and supplies from the market. The heavy dependence on conventional procedures for the management of industrial output and production waste has resulted in disjointed operational data and sluggish reactions to environmental protection and cost reduction demands. The limited recycling, reuse and remanufacturing mechanisms within the production lines also represent a practical problem, negatively impacting energy efficiency and the desired automation levels, and limiting the plant management's capacity to reach a sustainable operating performance and compete effectively against the growing local and industry competition.

This study is based on the following main question: "Does adopting digital innovation at the Wasit Textile and Weaving Factory contribute to enhancing operational sustainability through the mediating role of reverse logistics?"

This main question leads to the following sub-questions:

- What is the level of availability and importance of the dimensions of digital innovation, reverse logistics, and operational sustainability at the factory under study?
- Is there a significant direct impact of digital innovation on reverse logistics at the factory under study?
- Is there a significant direct impact of digital innovation on enhancing operational sustainability for the management and employees of the factory under study?
- Does reverse logistics play a significant mediating role in strengthening the relationship and impact between digital innovation and operational sustainability in the field of application?

2.2. Significance of the Study

The value of this study is that it adds to the academic and administrative library by giving a modern theoretical and conceptual framework that relates three important elements that have become prominent in the contemporary industrial environment. Its contribution to science is the emphasis on the mediating role of reverse logistics practices as a key link that transforms the effect of digital innovation and its structural and technological dimensions into operational sustainability that includes energy efficiency, sustainable packaging and automation. This provides a strong experimental model that fills the vacuum in study in the textile sector, contributing to the literature of Arabic management.

At the applied level, the value of the study is in providing a field vision and a practical road map for the leadership and management of the Wasit Textile and Knitting Factory on how to make best use of digital applications and software in developing operational processes. The study results serve to identify strengths and weaknesses in the processes of product recovery, recycling and manufacturing, enabling management to make proactive decisions that optimise energy and resource consumption, minimise industrial waste and improve the efficiency of production line automation. This ultimately makes the factory more competitive and helps it to accomplish its sustainable environmental and economic goals.

2.3. Study Objectives

The present research in its philosophical and field context aims at translating the theoretical concepts into practical outputs contributing to the development of the business environment. According to the research questions developed, these have been translated into precise primary and sub-objectives that the study wants to achieve:

- To determine the level of availability and importance of the dimensions of digital innovation, reverse logistics, and operational sustainability, as well as the philosophical orientation of the staff and employees at the factory under study in Wasit Governorate.
- To measure and test the significant direct impact of digital innovation on reverse logistics at the factory under study.
- To measure and test the significant direct impact of digital innovation on enhancing the dimensions of operational sustainability in the field of application.
- To reveal the nature and extent of the mediating role played by reverse logistics in transferring and activating the impact of digital innovation towards achieving operational sustainability at the factory under study.

2.4. Methodology of Research

In this research, the descriptive-analytical approach is used since it is appropriate and consistent with the nature of the research aims and testing of its field hypotheses. This approach aims to effectively describe and analyse the phenomenon under enquiry through field data collection on digital innovation, reverse logistics and operational sustainability. Data is identified and categorised. Advanced statistical procedures and analyses are used to arrive at exact scientific results. The field of application was the Wasit Textile and Weaving Factory, and the questionnaire was the main instrument for gathering data from the selected sample of administrative and supervisory leaders and technical staff. The approach was designed to interpret the nature of existing structural linkages and to test the direct and indirect influence of the proposed model.

2.5. Hypothesis of research and its hypotheses

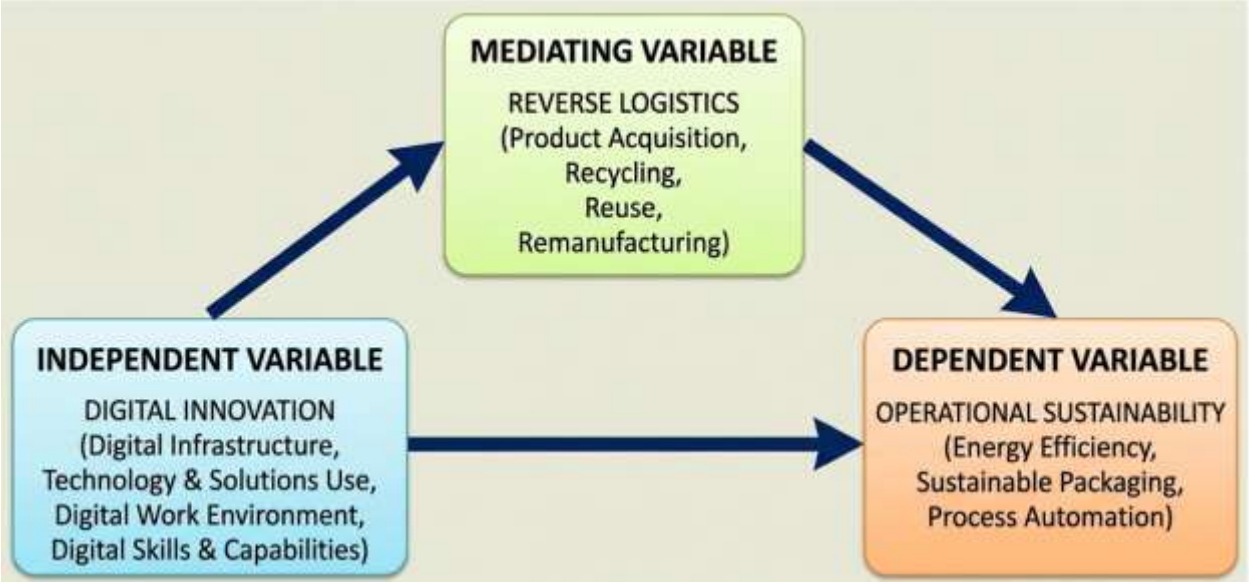


Figure 1. Hypothetical model for the research

Source prepared by the researcher.

The following hypotheses for this research are presented in the following figure:

- The first main hypothesis: Digital innovation has a significant impact on reverse logistics in the Wasit Textile and Knitting Factory (the application field).
- The second main hypothesis: Digital innovation has a significant impact on operational sustainability in the Wasit Textile and Knitting Factory (the application field).
- The third main hypothesis: This hypothesis relates to testing the mediating role of reverse logistics in the relationship between digital innovation and operational sustainability in the Wasit Textile and Knitting Factory (the application field).

2.6. Study Population, Sample and Area of Application

The Wasit Textile and Knitting Factory was chosen as the site for this study due to its rapid operational and environmental changes, and because it is an important industrial facility facing tangible challenges, such as the high volume of textile waste and the waste of energy and raw material consumption. The site was chosen because it possesses basic manufacturing infrastructure that requires the deployment of digital innovation strategies and process automation to boost production efficiency. Moreover, it needs to urgently adopt reverse logistics strategies such as recycling, recovery and remanufacturing to minimise its environmental footprint and strengthen its operational and financial viability.

To test its direct and intermediate hypotheses, and to ensure the relevance of the field to the study problem and objectives, the focus was on three primary departments within the factory, which are the knitting workshop, the weaving department, and the marketing department. These departments are the direct executive, marketing and operational drivers of the product lifecycle and reverse supply chains.

The target study population comprised of administrative and supervisory leaders and technical workers in three designated departments, totalling (180) individuals. The population was used to determine the sample size with Thompson's formula for sample size calculation at 95% confidence level and 5% margin of error. The statistically required sample size was 123 respondents. In an effort to assure this statistical quorum and to adjust for possible shortcomings or invalid questions, the researcher distributed 140 questionnaires in the field to the targeted group. 133 questionnaires were received. After field verification and elimination of missing data, 5 questionnaires were invalid for statistical analysis due to incomplete responses. The final number of valid questionnaires for statistical analysis was 128, a response rate of 91.4%, which is a very high percentage, above the statistically required sample size, providing accurate representation and robust results.

2.7. Demographic and Organisational Characteristics of the Sample Members

The field data of the study sample of (128) respondents is distributed in a balanced manner on four primary demographic and organisational factors (gender, age, organisational department, and administrative position), as shown in the following table:

Table 1. Demographic and Organisational Characteristics of Study Sample Participants

Variable	**Categories**	Number	(%)
Gender	Female	32	25.0%
	Male	96	75.0%
Age	Over 50 years old	28	21.8%
	40-50 years old	56	43.8%
	30-39 years old	34	26.6%
	Under 30 years old	10	7.8%
Organizational Department	Marketing Department	15	11.7%
	Textile Department	61	47.7%
	Knitting Workshop	52	40.6%
Managerial Position	Unit Manager	**80**	**62.5%**
	Division Manager	**45**	**35.2%**
	Department Head	**3**	**2.3%**
Total		**128**	**100.0%**

"Source: Compiled by the researcher based on the output of the SPSS program".

The following is a systematic analytical discussion of the statistical data shown in the table above, for each classificatory variable:

- **Gender:** As seen in the table above, the bulk of the respondents in the study sample were male (96 respondents, making up 75.0%) whilst the female sample composed of 32 respondents (25.0%). This result is consistent with the operational and industrial nature of the Wasit Textile and Weaving Factory, which requires a predominantly male workforce for most of its production and engineering tasks, while simultaneously indicating the active administrative and supervisory presence of women across support and organisational departments.
- **Age:** As per the statistics, the age group of 40-50 was the largest group of the sample with 56 respondents (43.8%), the second largest group was the age group of 30-39 with 34 respondents (26.6%) and finally the age group of over 50 with 28 respondents

(21.8%). The lowest frequency was in the under-30 age group with 10 responders (7.8%). These results confirm that the field of study is administered by staff with professional maturity and acquired field experience, which increases the sample's ability to understand the demands of digital innovation and reverse logistics.

- **Organisational sector** The textile sector obtained the first position with the biggest percentage of responses (61, 47.7%) followed by the knitting workshop with 52 respondents (40.6%). The marketing section got the final position with 15 respondents (11.7%). This is because of the higher operational weight and the larger capacity of the direct production sections (textiles and knitting) compared to marketing activities, which thus gives the study a thorough field coverage of the reverse supply chains and production lines.
- **Administrative Position:** The majority of respondents (80 respondents or 62.5%) were unit managers, followed by division managers (45 respondents or 35.2%) and department heads (3 respondents or 2.3%). This hierarchical distribution is characteristic of the correctness of the field representation of the structure of the factory organisation. The heads of departments are the senior leadership of the three primary departments defined while the divisions and supervisory units provide the operational and logistical flow.

3. The Conceptual Framework of the Research

3.1. Digital Innovation

3.1.1. The Idea of Digital Innovation

Digital innovation is depicted as a basic structural framework and integrated technical system that allows firms and institutions to fundamentally shift from linear consumption models based on resource depletion to complex ecosystems of circular supply chains [1]. It is also defined as the process of activation and implementation of advanced digital layers and technologies to improve the mechanisms of collaboration and integration among institutions, ensuring the expansion of sustainable methods and raising their operational efficiency along the entire value chain [2]. Digital innovation in management literature is defined as the intelligent application of solutions and applications of the Fourth Industrial Revolution technologies, such as RFID and real-time tracking systems, which allow organisations to have a detailed and comprehensive view during product collection and management processes, thus transforming reverse logistics into sustainable systems that are responsive to operational fluctuations [3]. Here, the notion is also articulated as the amount of technological maturity that enables the shift to a circular economy through the automation and simplification of processes for renewal of existing resources and reduction of waste, by improving the tracking and monitoring of materials [4]. In addition, digital innovation is described as the strategic and technology enabler to minimise waste and manage damaging emissions effectively and as a bridge between old operating practices and more sustainable circular operations [5].

3.1.2. The Importance of Digital Innovation

Digital maturity is a key strategic enabler to address the underlying systemic issues and barriers provided by the linear "extract, make and dispose" model. This is achieved by embedding and activating novel circular methods such as remanufacturing, full recycling and sharing of novel goods into the fundamental business model of firms [6, 7] . Thanks to real-time data streams from the Internet of Things (IoT) and advanced machine learning algorithms, organisations will be able to manage the return flow of returned products with pinpoint accuracy, as well as optimise regeneration and recycling cycles in an effort to ensure that the maximum possible residual value is maintained for product components and parts at the end of their life cycle [8, 9]. Moreover, by effectively leveraging these big data analysis capabilities, organisations can obtain deep and

actionable strategic insights that can directly support the improvement and evolution of circular business models and the efficient closing and slowing of resource flow cycles [10]. In this integrated organisational context, the adoption and activation of digital collaborative platforms allow companies to share best operational practices and advanced infrastructure, which is essential to overcome the organisational and logistical barriers of operating closed-loop systems with exceptional efficiency and long-term sustainability [11, 12].

3.1.3. Aspects of Digital Innovation

3.1.3.1. Digital Infrastructure

This vital layer consists of integrated physical and virtual assets such as flexible cloud computing architectures and high-speed sensor and connectivity networks that provide the necessary infrastructure and connectivity to support the efficient and secure exchange of real-time data across the reverse supply chain [13]. This infrastructure is the backbone on which the whole digital transformation relies, linking all operational centers and field logistics units to central databases to enable rapid decision-making [14]. The basic condition for the improvement of the advanced processes and functions is advanced infrastructure, which enables organisations and firms to efficiently synchronise the flows of material recovery with the demands of production and market, and adapt to changes in consumption standards [15]. [16] It also helps to reduce the expenses of operation due to technical failures, offering back-up communication networks and enhanced protection procedures that assure the continuity of data flow between suppliers and customers.

3.1.3.2. Technology and use of digital solutions

Such a higher classification requires the application and activation of advanced intelligent algorithmic frameworks such as artificial intelligence and machine learning systems to coordinate and manage complex circular business models that fully automate product recovery and resource lifecycle management processes [17]. The technologies offer complete analytical tools that may predict market trends and future recycling requirements and so reduce operational waste and optimise the use of available technological assets [18].

By means of these smart algorithmic solutions, companies and organisations can dynamically sense and seize opportunities, as well as reconfigure their internal and external processes in an effort to meet the fluctuating and unstable demand for secondary and recovered materials, thus putting high flexibility and agility at the core of circular supply chain operations [19]. Furthermore, digital technologies provide more accurate tracking and monitoring of returned picks and components, ensuring that the materials are processed to the highest standards of global production [20].

3.1.3.3. The digital work environment

This organisational dimension is mostly about the cultural and structural changes that are necessary to develop and grow digitally enabled capabilities across the entire workforce. This guarantees that the workers have the capabilities to handle the human-machine interface, which is critical for the effective circular operations [21]. This means re-evaluating previous practices and developing flexible leadership styles that encourage technology innovation and the strategic integration of various administrative units [22].

Firms can successfully implement circular economy ideas in their day-to-day operations and strategic decision-making processes by promoting multidisciplinary collaboration between technical specialists and engineers on one hand and operational people and management teams alternatively [23]. The digital work environment also helps promote a stimulating environment of work based on the interchange of digital knowledge and data-driven decision-making, boosting the overall performance of the firm [24].

3.1.3.4. Digital skills and capacity

This dimension concerns the construction and development of a set of advanced cognitive and technical competencies that allow individuals and organisations to analyse complex digital data and to use these data in an intelligent way in the management and guidance of activities related to the circular economy and sustainable supply chains [25]. Currently organisations are investing in continual training programs to enhance the capabilities of their personnel and to increase their capacity to deal with contemporary software and systems [26].

These competencies also highlight the need to promote innovation and fast adaptation to present-day digital technologies, thus ensuring the continuity of operational performance and the ability to deal effectively with new technical and environmental obstacles, and the future readiness of the organization [27]. New transformation solutions demand advanced digital skills that offer the basis for closing the knowledge gap between theoretical methods and practical application [28].

3.2. Reverse Logistics

3.2.1. What is Reverse Logistics?

Reverse logistics refers to the systematic, strategic management of the flow of products and materials from the point of consumption back to the manufacturer or a recovery and recycling facility, with the aim of recovering the inherent economic value or ensuring safe disposal [21]. The concept is sometimes called a comprehensive and systematic strategy, which requires the design and execution of highly efficient systems for the collecting, sorting and transportation of used materials in an effort to successfully close the whole cycle of production and consumption [22]. It is also defined as the logistical and strategic intermediary function that facilitates the complex classification processes of the strategic, tactical and operational operations necessary to reintegrate expired or consumed commodities into the direct supply chain pathway [23]. It is also proposed as a system integrated with sensors and unique digital identities to provide a complete automation of the classification and sorting of recovered materials, avoiding the inefficiencies and high costs associated with manual sorting [24]. It is also defined as a set of logistics capabilities and specialist operations which aim to detect, decompose and process recoverable and reusable materials ensuring the smooth integration of the reverse system with the full supply chain network [25].

3.2.2. The Significance of Reverse Logistics

Efficient and well-organised reverse logistics systems are the primary mechanism for extracting the intrinsic and lost value of expired things and converting post-consumer commodities into viable, high-quality raw materials for modern industrial production [26]. By embedding these ideas and circular practices into the heart of their retail, transport and shipping activities, firms may minimise their carbon emissions and also boost the overall efficiency and sustainability of their resource recovery networks [27]. Furthermore, operators and circular logistics companies hold a key and crucial role in managing these intricate and intertwined direct and reverse flows, ensuring an accurate and continuous synchronisation of material recovery processes with the broader environmental and economic sustainability objectives of the organization [28]. Such processes help in building strong firm reputation and increased consumer and regulatory confidence through compliance to high environmental requirements and reduction of dependency on virgin resource exploitation [29, 30].

3.2.3. Aspects of Reverse Logistics

3.2.3.1. Ownership of Products

This strategic dimension redefines and reconfigures manufacturer responsibilities by expanding legal and environmental accountability to reach beyond the first point of sale and delivery. Innovation in business models, such as “product as a service”, is often

necessary to guarantee corporations full ownership of physical assets along their life cycle [31]. This change will ensure the constant monitoring of the product and frequent maintenance services, which will extend the life of the product and prevent it from being prematurely discarded [32].

These upgraded and enlarged manufacturer responsibility schemes encourage firms to create products and items that are simple to take apart and fix, lowering the significant future financial and environmental expenses of final disposal [33]. This dimension also pushes organisations to reconsider the components utilised and choose materials that are more recoverable and maintainable, therefore saving resources and improving competitive value [34].

3.2.3.2. Recycling

These systematic industrial procedures transform end-of-life materials and copious garbage into valuable secondary raw materials, finishing the resource cycle and reducing the environmental degradation associated with conventional disposal techniques such as landfilling or incineration [31]. Such methods need to apply strict quality requirements to ensure that the recovered materials are in accordance with the relevant specifications and may be reused in manufacturing lines [32].

These different routes of recovery – reuse, repair and remanufacturing – assist in further decoupling economic growth from depletion of natural resources through the recovery of the inherent and residual value of consumer products [33]. Advanced recycling helps organisations cut operational costs and guarantees a steady supply of raw materials, especially during times of global market volatility [34].

3.2.3.3. Reuse

This operational practice prolongs the service life and utility of products and goods by restoring them to the market in their original state or after repairs and refurbishment, in this way avoiding the energy-intensive and environmentally polluting phases involved in the extraction of primary raw materials [35]. This procedure ensures that the manufacturing value of the product is maintained as it was produced with the least feasible further processing [36].

The adoption and acceptance of such reuse tactics require sophisticated consumer engagement initiatives and solid economic and social incentive systems to ensure the continued flow and frequent return of products to secondary market markets [37]. This mechanism encourages corporate social responsibility and gives the client the power to be a direct participant in environmental protection and the promotion of circular practices [38].

3.2.3.4. Remanufacturing

This multi-step, multi-process strategy transforms end-of-use goods and products through careful and extensive processes including recovery, inspection, disassembly, cleaning, repair and reassembly to achieve a “like-new” functional condition [37]. The complicated process of remanufacturing includes the use of current technology to bring back damaged parts to their efficient operating state [38].

By remanufacturing these things and products to match or surpass the criteria of the original equipment manufacturer, the excessive demand on natural resources can be greatly reduced and the wear and tear of long-term usage can be successfully mitigated [39]. Moreover, remanufacturing helps enterprises to produce high-quality products at reasonable rates, satisfying different client segments’ expectations [40].

3.3. Sustainable Operations

3.3.1. The Operational Sustainability Concept

Operational sustainability is the strategic and operational readjustment of industrial and production processes to achieve a decoupling of economic growth from the consumption of finite natural resources [41]. It is conceived as the operational framework for the long-term resilience of organisations to offset environmental and systemic disturbances and risks [42]. It is also defined as a process of continual improvement and control of the technical and biological loops in the supply chain to save resources and reduce waste and losses [43]. It is also known as the change in production patterns from the old linear ones leading to environmental deterioration to the regenerative and restorative ones based on the full recovery of resources [44]. Operational sustainability is the ability of operational processes to execute in an adaptive and closed-loop manner, supported and amplified by digital infrastructure technologies and a resilient organisational culture [45].

3.3.2. The Significance of Operational Sustainability

It is imperative to integrate and apply sustainable operating methods to strike a delicate balance between environmental responsibility and supervision on one hand and high economic competitiveness on the other. Such initiatives and policies often promote the efficient use of the resources while at the same time minimising waste and total operating expenses [46]. Moreover, the correct functioning of closed-loop supply chains fulfils the objectives of waste reduction and optimal use of the resources available through systematic recovery, regeneration and recycling of diverse materials [47]. The strategic integration ensures that organisations comply with global sustainable development imperatives and goals by improving the management of resources through the entire product life cycle, from the selection of raw materials to the disposal and recycling of products at the end of their life, thereby ensuring a strong and sustainable competitive advantage in the market [48]. In addition, the adoption of sophisticated digital innovation is both a catalyst and a significant driver for this strategic alignment, enabling real-time data visibility and monitoring across complicated supply chains to address the challenges and complexities of interconnected loops [49, 50].

3.3.3. Operational sustainability aspects

3.3.3.1. Energy Efficiency:

This dimension uses predictive analytics and smart sensing to appropriately monitor and assess the trends of energy usage. This enables dynamic and instantaneous changes to industrial loads, which in turn helps to minimise waste and lower the carbon intensity of activities and manufacturing processes [41]. This approach allows enterprises to have greater control over the pace of operating expenditure and to achieve tangible environmental effects [42].

The deployment of IoT-based monitoring systems combined with automated process control technologies can result in significant and accurately targeted savings in the overall energy consumption, which directly contribute to the decarbonisation of logistics and manufacturing operations [48]. This factor also fuels the commitment to rigid national and international environmental law on emissions constraints [49].

3.3.3.2. Sustainable Packaging

The adoption of green containment and packaging solutions minimises the total carbon footprint of an organization as it lowers material waste and damage and promotes the efficiency of transit and shipping volumes because of light weight designs that are re-used or recyclable [43]. These original designs directly contribute to the reduction of storage space needs and the enhancement of the transport fleet capacity [44].

In addition, by applying big data analysis and blockchain technology, these materials may be traced and monitored from end to end, to ensure the correct recovery and re-integration of the packaging elements in the supply chain [49]. Sustainable materials also help to eliminate the harm caused by single-use plastics [50].

3.3.3.3. Automate processes

High-end robotic systems and machine learning technologies can be utilised to carry out complex and hard disassembly and sorting tasks, allowing businesses to obtain higher levels of accuracy in clean material recovery with minimised labour and effort costs [46]. Automation increases the pace of operation and decreases human error in sorting of recovered components [47].

Moreover, the tracking tools in real-time applied on digital platforms allow the smooth coordination of reverse material flows, boosting the synchronisation between recovery centers and manufacturing sites to maximise the use of resources and reach sustainable productivity [48]. Automation also leads to lower occurrence of occupational injuries and improved industrial safety in general [50].

3.4. Relationships of the Study Variables

3.4.1. Influence of digital innovation on reverse logistics

Digital innovation with its different faces and better technology has a direct and obvious influence on the efficiency and efficacy of reverse logistics systems. The Internet of Things (IoT) and other current digital technologies such as big data analysis tools offer unprecedented transparency and real-time visibility. They enable you to precisely track weights, reasons for returns and the actual state of waste and returned products. This enables proactive waste reduction strategies and programd and efficient product dismantling [1], [2], [3], [21]. Its high capacity of high precision visibility enables multiple stakeholders and beneficiaries to accurately and seamlessly coordinate among complex remanufacturing and processing cycles, thus guaranteeing the reintegration of recovered components into new production lines with minimal time and operational delays [22]. Additionally, the broad implementation of radio frequency identification (RFID) technologies and flexible electronic devices makes it possible to track reusable packaging assets accurately and continually, turning traditional return channels into large, data-intensive and intelligent networks that deliver vital information to steer and improve systemic policies for waste limiting along the supply chain [23]. The integration of artificial intelligence also assists in the automatic routing of returned products to their respective repair, refurbishment or recycling locations, thus lowering operational costs and shortening the return cycle, increasing the ability of companies to react quickly to changes and the fast-moving consumer market [24]. Finally, the whole digital transformation of logistics systems results in the creation of better planning capabilities that enable precise forecasting of water and industrial return quantities and the coordination of logistics fleet movements with sustainability principles [25].

3.4.2. The impact of digital innovation on operational sustainability

In revolutionising industrial processes, advanced digital interventions and solutions like machine learning and blockchain technologies are vital in transforming enormous volumes of difficult environmental data into clear and actionable strategic insights. This adds to the acceleration of the green digitalisation and to the overall economic and environmental sustainability of supply chains [4], [5], [15], [39]. These innovative technologies help and promote smart waste management by solving the main operational difficulties related to economic value recovery and fast and efficient disposal and treatment operations [16]. In particular, AI-enabled screening and sorting devices and sophisticated algorithms optimise the routes and directions of reprocessing activities, maximising the extraction of available value and drastically lowering the volume of

materials heading to landfills and final disposal locations [17]. In addition, the integration of these digital layers and systems, from live data flows to sophisticated technologies such as collaborative robotics, leads to an all-encompassing and interconnected organisational and structural architecture that provides a needed prerequisite and precondition to back up green activities and practices throughout the whole supply chain [18]. Such interconnected digital systems may allow organisations to migrate successfully from traditional linear consumption business models to regenerative ecosystems that help in extending the life of products and enabling resource efficiency through smart manufacturing and extremely clever material reuse [19]. Continuous optimisation based on digital modelling and intelligent process simulation, direct reduction of industrial pollutants, reduction of operational resource usage further improve the system [20].

3.4.3. The Mediation of Reverse Logistics in the Relationship between Digital Innovation and Operational Sustainability

Reverse logistics is not only a key operational channel, but also an important intermediary, which transforms the high-level digital information and advanced technical capabilities into the practical and efficient resource recovery process. This is a wonderful contribution to the three pillars of an organisation's entire performance i.e. environmental, social and economic [25, 26, 27, 40]. This mediation mechanism uses state-of-the-art predictive analytics and smart sensing technologies to improve the accuracy of waste valorisation operations and the effective control of closed-loop flows. Finally, this gives a genuine benefit to the existing digital resources and capabilities in environmental responsibility and sustainability [28]. Fourth Industrial Revolution technologies substantially promote and enable green supply chain mandates and policies by coupling disruptive and sophisticated data capabilities with practical and successful implementation [29]. Therefore, organisations and businesses who are able to successfully combine dynamic digital capabilities with circular practices and reverse flow supply chains see substantial and concrete gains in their environmental sustainability performance indicators. Reverse flow infrastructure becomes an active and effective player in value creation, as opposed to traditional, post-consumer need [30]. The integration of circular economy notions into modern digital infrastructure and solutions can transform complex stakeholder networks into integrated ecosystems that balance high industrial efficiency with long-term environmental sustainability [31]. This synergistic and complementing link successfully helps to build high operational resilience and unique ability to cope with environmental and market instability as evidenced by recent statistics and practical research . This strengthens the sustainable competitive advantage of the organization and makes reverse flow logistics the immediate operational driver, without which the digital developments are only theoretical benefits, not tangible in the practical world [32].

4. The Implementation Framework

4.1. Coding and Reliability of Research Variables and Normal Distributions

Data coding is an important procedural step of converting qualitative and verbal data collected through questionnaires into particular numerical values that may be processed by advanced statistical tools. In this regard, a complete and rigorous coding process was undertaken by turning the answers on a five-point Likert scale into numerical values from (5) for strong agreement to (1) for strong disagreement.

Each primary variable and its sub-dimensions were assigned a separate organisational code. The independent variable (digital innovation) was represented by the symbol X and its four sub-dimensions (X1-X4), the mediating variable (reverse logistics) was represented by the symbol M and its four sub-dimensions (M1-M4), and the dependent variable (operational sustainability) was represented by the symbol Y and its three sub-dimensions (Y1-Y3). This coding approach helped to develop an organised and

non-interference database, which helped to conduct advanced testing and very accurate structural model testing of the adopted model.

Reliability is the degree to which the measurement device gives the same and steady results when it is used again for the same sample under the same field conditions. Cronbach's alpha coefficient was used to assess the internal consistency of the scale items and dimensions.

The alpha coefficient is greater than 0.70 (i.e. greater than 70%) which is the methodologically acceptable minimum (Hair et al., 2017) and so the measuring instrument is considered acceptable and very dependable methodologically.

Checking the normality of the data distribution is a necessary condition for selecting the proper statistical tests and for justifying the application of parametric tests and structural equation models . The normality of the distribution was evaluated in the field by calculating the standard values of Z-skewness and Z-curtosis for all variables and dimensions. Data are considered normally distributed if the standard estimated values are within the statistically acceptable range of ±1.96 at the significance level of $\alpha < 0.05$ according to the criteria of Hair et al. (2017). [51]

Table 2. Coding and Description of Research Variables and Dimensions Reliability

The variable		Dimensions	Cronbach's Alpha for Dimension	Number of paragraphs	Cronbach's alpha for the variable	Coding	**Z-SKEW**	**Z-K**
Digital innovation	X	Digital Infrastructure	0.834	5	0.862	X1	0.423	-0.512
		Use of Digital Technology and Solutions	0.871	5		X2	-0.318	0.284
		Digital Work Environment	0.853	5		X3	0.512	-0.193
		Digital Skills and Capabilities	0.889	5		X4	-0.247	0.631
Reverse logistics	M	Product Ownership	0.816	5	0.849	M1	0.381	-0.427
		Recycling	0.865	5		M2	-0.492	0.158
		Reuse	0.842	5		M3	0.174	-0.362
		Remanufacturing	0.873	5		M4	-0.289	0.541
Operational sustainability	Y	Energy Efficiency	0.827	5	0.858	Y1	0.312	-0.274
		Sustainable Packaging	0.861	5		Y2	-0.534	0.419
		Process Automation	0.886	5		Y3	-0.163	-0.388

"Source: Compiled by the researcher based on the output of the SPSS program".

As shown in Table (2) above, the data indicates that the measurement instrument has good internal consistency and reliability in all the dimensions and variables of the study. The independent variable (Digital Innovation X) has an overall reliability value of (0.862) with Cronbach's alpha coefficients ranging between (0.834) and (0.889). The mediating variable (Reverse Logistics M) showed overall reliability of (0.849) and its dimensions had reliability values between (0.816) and (0.873). The Dependent Variable (Operational Sustainability Y) got a reliability of (0.858) with the dimensions ranging from (0.827) to (0.886). These values are all above the minimum methodologically acceptable threshold (0.70) according to the criteria of Hair et al. (2017) which guaranties the accuracy of the instrument and the non-existence of random measurement errors in the data.

The findings of the verification of the normality of the data distribution as given in Table (2) above indicate full normality for all dimensions of the independent, mediating and dependent variables. The values of the standardised skewness (Z-SKEW) of the variables and dimensions were between -0.534 and 0.512, which showed stability. The values of the standardised kurtosis (Z-K) were between -0.512 and 0.631. According to the criteria of Hair et al. (2017), all these indicators are within the statistically acceptable range of ±1.96 at the significance level of $\alpha \leq 0.05$, which confirms the overall normality of the data distribution and justifies the confident use of parametric tests and structural modelling analyses.

4.2. Structural Validity of the Research Scale with its Variables, Dimensions and Items

The Structural Equation Modelling (SEM) will be used to field verify the structural validity of the study scales and to test the suitability of the hypothetical model to the obtained field data based on Confirmatory Factor Analysis (CFA) and using the advanced statistical software Amos V.24. In this confirmatory study the researcher would like to examine two basic procedural hypotheses:
Item Validity and Conceptual Loading: This stage deals with the confirmation of the sub-dimensions' capability to be a correct representation of the independent (X), mediating (M) and dependent (Y) variables, and the confirmation of the reliability and validity of the items of each dimension by assessing their level of factor loading. Methodologically, the minimum permissible value for an item to be included in the scale is a load value of 0.40 and the items below this value will be eliminated according to the guidelines of Hair et al . (2017) [51].

Matching the conceptual model with field data: Ensuring that the data obtained from the sample members correlate to a high and acceptable degree with the chosen hypothetical construct of measurement.
The model's efficiency and construct validity were assessed by a direct comparison with the acceptance criteria of the Goodness of Fit Indices, presented in Table (3) below:

Table 3. Statistically Acceptable Goodness of Fit Criteria for Confirmatory Factor Analysis (CFA) Model

Standardized chi-squared	chi^2 / df (CMIN/DF)	Less than 3.00 (and even less than 5.00 is acceptable)
Conformity quality index	GFI	≥ 0.90
Comparative conformity index	CFI	≥0.90
Tucker-Lewis index	TLI	≥0.90
Root mean squared rounding error	RMSEA	Less than 0.08 (preferably less than 0.05)

Source: Hair, J. F., Hult, G. T. M., Ringle, C. M., & Sarstedt, M. (2017) "A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM)", 2nd Ed. Thousand Oaks, CA: Sage, p.289.[51]

4.2.1. Confirmatory Factor Analysis for Digital Innovation

The findings of the confirmatory factor analysis, presented in the table and figure below, reveal the quality and validity of the measurement model for the variable (digital innovation). The saturations of all the items on its four dimensions were over the statistically acceptable threshold of (0.40) (Hair et al., 2017). The computed standard weights varied from a minimum of 0.412 for item X25 to a maximum of 0.849 for item X24 (significance level, $P < 0.001$). This structural acceptability is further supported by the structural fit of the model quality metrics presented in the image. The ratio of chi-squared to degrees of freedom (CMIN/DF) was 1.298 which is less than cut-off point (5). The goodness-of-fit index (GFI) was 0.939, the comparative fit index (CFI) was 0.976 and the Tucker-Lewis index (TLI) was significant too. 0.956, all above the acceptable limit (0.90), and the root mean squared error of rounding (RMSEA) was 0.071, below the standard (0.08), thus confirming the perfect fit between the field data and the assumed standard model, and demonstrating the construct validity and internal consistency of the items of the variable [51].

Table 4. Confirmatory Factor Analysis of Digital Innovation

item	Path	The dimension	Estimate	S.E.	C.R.	P
X11	<---	Digital Infrastructure	.589			
X12	<---		.448	.110	6.162	***
X13	<---		.687	.145	8.372	***
X14	<---		.518	.141	6.905	***
X15	<---		.678	.141	8.304	***
X21	<---	Use of Digital Technology and Solutions	.525			
X22	<---		.705	.177	8.162	***
X23	<---		.665	.186	7.910	***
X24	<---		.849	.196	8.836	***
X25	<---		.412	.180	5.733	***
X31	<---	Digital Work Environment	.675			
X32	<---		.587	.102	9.524	***
X33	<---		.577	.092	9.371	***
X34	<---		.546	.089	10.586	***
X35	<---		.658	.064	10.591	***
X41		Digital Skills and Capabilities	.757			
X42			.547	.083	8.728	***
X43			.459	.083	7.298	***
X44			.529	.071	8.426	***
X45			.661	.074	8.243	***

Source: AMOS Outputs.V.24

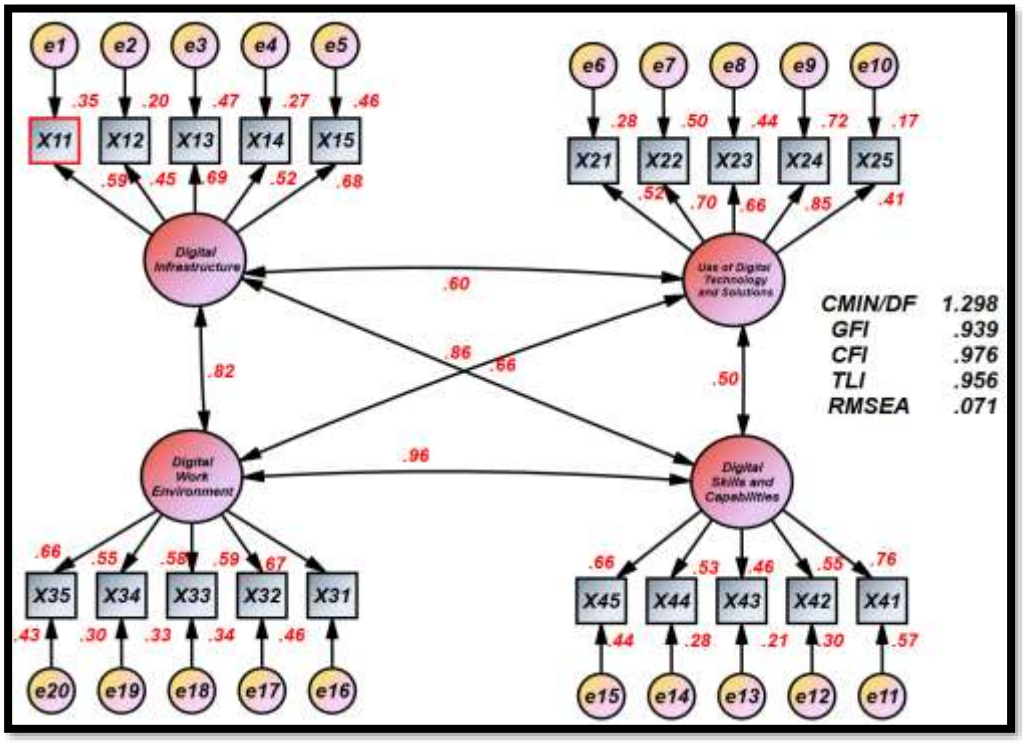


Figure 2. Confirmatory Factor Analysis of Digital Innovation

Source: AMOS Outputs.V.24

4.2.2. Inverse Logistics Confirmatory Factor Analysis

The quality and validity of the measurement model for the variable (inverse logistics) are confirmed by the findings of the confirmatory factor analysis, presented in the table and figure below. All items' saturations throughout its four dimensions were over the statistically acceptable cutoff of (0.40) (Hair et al., 2017). The computed standard weights varied from 0.461 (item M34) to 0.862 (item M32) and were very significant (P < 0.001). Further reinforced by the indices of the structural fit of the model quality as displayed in the figure this structural acceptability was supported. The ratio of the chi-squared to degrees of freedom (CMIN/DF) was 2.436 which is less than the criteria of (5). The goodness-of-fit index (GFI) was 0.943, the comparative fit index (CFI) was 0.997, and the Tucker-Lewis index was [Value missing] 0.946, all of which are above the acceptable limit (0.90), as well as the root mean squared error (RMSEA) which recorded 0.066, which is below the standard (0.08), confirming the perfect match between the field data and the assumed standard model and proving the construct validity and internal consistency of the variable items[51].(TLI)

Table 5. Confirmatory Factor Analysis and Inverse Logistics

Item	path	The dimension	Estimate	S.E.	C.R.	P
M11	<---		.629			
M12	<---		.646	.115	8.960	***
M13	<---	Product Ownership	.613	.132	8.597	***
M14	<---		.748	.131	9.955	***
M15	<---		.629	.117	8.774	***
M21	<---		.744			
M22	<---		.612	.061	9.987	***
M23	<---	Recycling	.755	.063	12.406	***
M24	<---		.695	.062	11.385	***
M25	<---		.569	.081	9.261	***
M31	<---		.829			
M32	<---		.862	.065	17.043	***
M33	<---	Reuse	.715	.068	13.300	***
M34	<---		.461	.082	7.871	***
M35	<---		.576	.059	10.150	***
M41	<---		.613			
M42	<---		.836	.115	10.761	***
M43	<---	Remanufacturing	.780	.114	10.321	***
M44	<---		.645	.101	9.016	***
M45	<---		.732	.103	9.884	***

Source: "AMOS.V.24 Outputs"

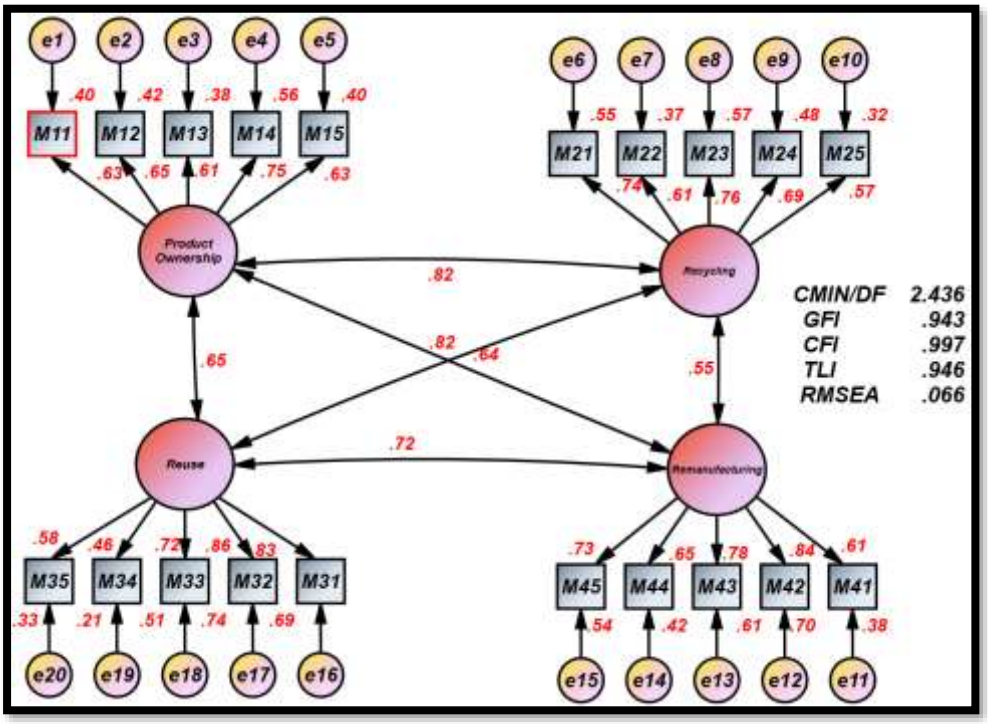


Figure 3. Confirmatory factor analysis of inverse logistic regression

Source: "AMOS.V.24 Outputs"

4.2.3. Confirmatory Factor Analysis of Operational Sustainability.

The findings of the confirmatory factor analysis depicted on the table and picture below indicates the quality and validity of the measurement model for the variable (operational sustainability). The saturations of all items in its three dimensions surpassed the statistically permissible level of 0.40 (Hair et al., 2017). The computed weights were statistically significant (P < 0.001) and ranged from 0.403 (lowest) for item Y12 to 1.000 (highest) for item Y21. The figure shows the structural model conformance indicators, which supported the structural acceptability. The chi-squared ratio of degrees of freedom (CMIN/DF) was 3.494, which is under the standard (5). The goodness-of-fit index (GFI) was 0.950, comparative-fit index (CFI) was 0.967, and Tucker-Lewis index (TLI) was 0.941, all of which were over the permissible level (0.90). In addition, the root mean squared rounding error (RMSEA) was 0.062, which is lower than the standard. (0.08) that verifies the construct validity and internal consistency of the items of the variable and confirms the perfect fit between the field data and the hypothesised standard model . [51]

Table 6. Confirmatory Factor Analysis Operational Sustainability

Item	Path	The dimension	Estimate	S.E.	C.R.	P
Y11	<---		.534			
Y12	<---		.403	.100	5.692	***
Y13	<---	Energy Efficiency	.685	.154	8.170	***
Y14	<---		.491	.108	6.603	***
Y15	<---		.592	.108	7.492	***
Y21	<---		1.000			
Y22	<---		.608	.087	9.576	***
Y23	<---	Sustainable Packaging	.580	.101	9.177	***
Y24	<---		.622	.093	9.770	***
Y25	<---		.626	.094	9.835	***
Y31	<---	Process Automation	.801			

Y32	<---	.696	.051	12.662	***
Y33	<---	.523	.054	9.049	***
Y34	<---	.555	.050	9.686	***
Y35	<---	.881	.059	17.179	***

Source: "AMOS.V.24 Outputs"

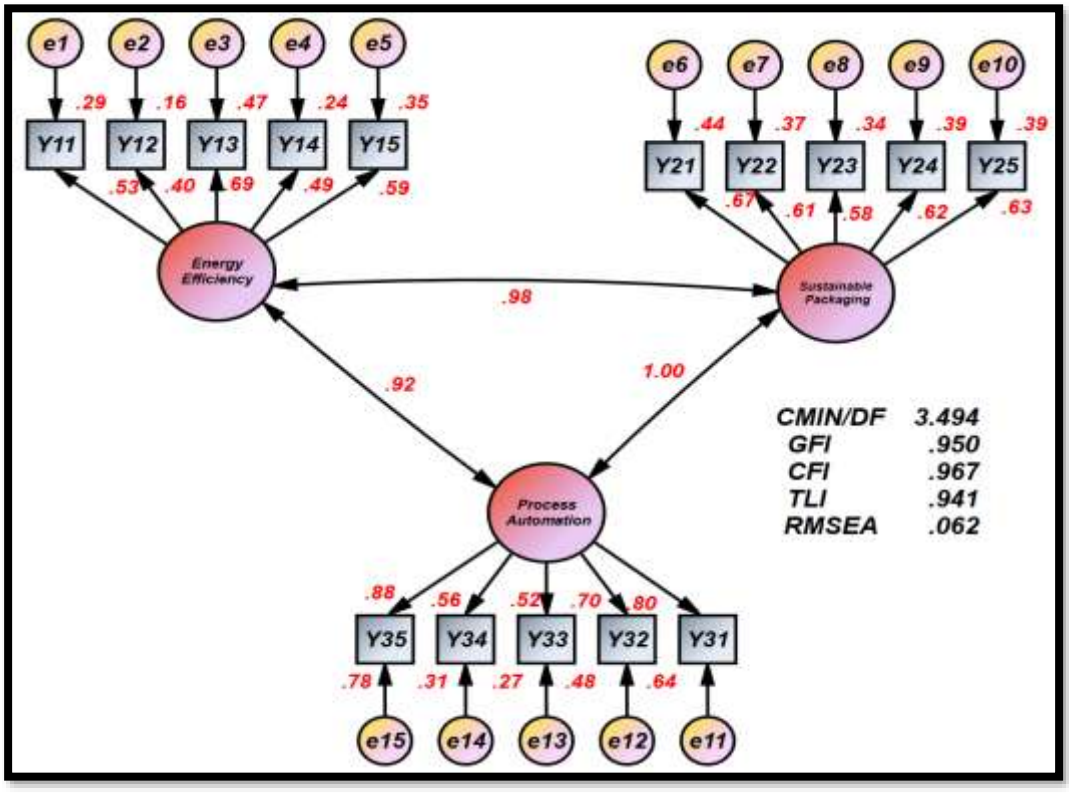


Figure 4. Confirmatory Factor Analysis of Operational Sustainability

Source: "AMOS.V.24 Outputs"

4.3. Interpretation and Description of the Research Sample Responses

This part offers the descriptive statistical analysis of the answers of the study sample related to the research variables and their sub-dimensions. Its purpose is to assess the amount of availability of these and the awareness of respondents on their practical implications. In an effort to attain the highest degree of statistical correctness, the evaluation and differentiation mechanism was established based on the Coefficient of Variation (CV), which is considered to be the most accurate and objective criterion for ranking. The lower its value, the better the degree of homogeneity and the less the dispersion of respondents' answers around the arithmetic mean. It is the main criterion for distinguishing among the dimensions. The descriptive analysis was based on the arithmetic mean, standard deviation and percentage agreement indices. Significance levels were interpreted directly based on the measurement categories used in Dewberry's (2004) classification as indicated in the following table.

Table 7. Classification of Categories of Statistical Description

Level	Categories	Sequence
Very low	1-1.80	1
Low	1.81-2.60	2
Moderate	2.61-3.40	3
High	3.41-4.20	4
Very high	4.21-5.00	5

Source: Prepared by researchers based on literature review

Table 8**.** Descriptive analysis of the study variables (digital innovation, reverse logistics and operational sustainability)

	Dimensions of Digital Innovation	Mean	S.D	C.V	Agreement rate	Dimensional arrangement
1	Digital Infrastructure	3.443	0.668	19.4%	68.9%	3
2	Use of Digital Technology and Solutions	3.837	0.597	15.6%	76.7%	1
3	Digital Work Environment	2.789	0.844	30.3%	55.8%	4
4	Digital Skills and Capabilities	3.648	0.621	17.0%	73.0%	2
	Digital Innovation	3.429	0.683	19.9%	68.6%	
	Dimensions of reverse logistics	Mean	S.D	C.V	Agreement rate	Dimensional arrangement
1	Product Ownership	3.589	0.613	17.1%	71.8%	2
2	Recycling	3.414	0.706	20.7%	68.3%	3
3	Reuse	3.812	0.541	14.2%	76.2%	1
4	Remanufacturing	2.923	0.938	32.1%	58.5%	4
	reverse logistics	3.435	0.700	20.4%	68.7%	
	Dimensions of operational sustainability	Mean	S.D	C.V	Agreement rate	Dimensional arrangement
1	Energy Efficiency	3.333	0.891	26.7%	66.7%	3
2	Sustainable Packaging	3.543	0.533	15.0%	70.9%	1
3	Process Automation	3.428	0.799	23.3%	68.6%	2
	operational sustainability	3.435	0.741	21.6%	68.7%	

"Source: Compiled by the researcher based on the output of the SPSS program".

The statistical data in the above table show the results of the descriptive analysis of the study sample responses to the variables of the research and its sub-dimensions, as it includes the arithmetic mean, the standard deviation, the coefficient of variation (CV), the percentage of agreement and the relative ranking of the dimensions according to the highest degree of homogeneity (lowest coefficient of variation) .

4.3.1. The Independent Variable (Digital Innovation)

The overall arithmetic mean for the independent variable (Digital Innovation) was (3.429), with a standard deviation of (0.683), a coefficient of variation of (19.9%), and a percentage of agreement of (68.6%), which indicates a high level of agreement between the members of the sample, according to the criteria of Dewberry (2004). The four dimensions were ranked according to their coefficients of variation. The dimension "Use of Technology and Digital Solutions" was ranked highest, followed by the dimension "Digital Skills and Abilities", the dimension "Digital Infrastructure" and the dimension "Digital Work Environment" .

- Use of Technology and Digital Solutions: The mean score was 3.837 with a standard deviation of 0.597, a low coefficient of variation (15.6%) and an agreement rate of 76.7% indicating a good level of consistency and uniformity of response on the application of technology solutions. This indicates the organization's commitment towards the usage of latest technology and the use of software to automate day to day procedures and boost performance.
- Digital Skills and Capabilities: It received an average score of 3.648, a standard deviation of 0.621, a coefficient of variation of 17.0%, and an agreement rate of 73.0% with the second rank. The high score level of evaluation emphasises the digital empowerment of personnel. This means that the field workforce possesses higher digital expertise and more capacity to employ specialised technology programmes and apps efficiently.

- Digital Infrastructure: It is placed in the third position with an average of 3.443, a standard deviation of 0.668, a variation coefficient of 19.4% and a consensus rate of 68.9%, which shows the high degree of availability of the basic pillars of technology. This requires strong and durable communication networks and databases to facilitate digital transformation and meet the operational demands of the company.
- Work Environment: It is the last in the ranking with a mean of 2.789, a standard deviation of 0.844, the highest coefficient of variation of 30.3% and a consensus rate of 55.8% which indicates a modest degree of evaluation and a relative dispersion of opinions. This means that greater support and incentives are needed in the organisational climate in an effort to create a comprehensive digital culture and to overcome resistance to technological change.

4.3.2. The Mediating Variable (Reverse Logistics)

The mean of the mediating variable, reverse logistics, was (3.435) with a standard deviation of (0.700), a coefficient of variation of (20.4%) and an agreement percentage of (68.7%), which is at the high level of the approved assessment scale. The four dimensions differed in their rank on the field. The highest degree of homogeneity was the first place in the dimension of "Reuse". The dimension of "Product Ownership" came in the second rank, followed by the dimension of "Recycling" and the dimension of "Remanufacturing" in the third and fourth ranks, respectively.

- Reuse: It was ranked the first with arithmetic mean (3.812) and standard deviation (0.541). The lowest coefficient of variation was 14.2% and the percentage of agreement was 76.2%. This confirms the high level of conviction and the strong uniformity of the necessity of resource reuse. The trend indicates the organization's ability to best utilise assets and equipment that may be used continuously without sophisticated industrial process or additional expenditure.
- Product retrieval: this indicator was the second with an average of 3.589, a standard deviation of 0.613, a variation coefficient of 17.1% and an agreement rate of 71.8%. This demonstrates a great awareness of the techniques to retrieve products. This means the channels of collection and receiving of returned products from consumers and field outlets are well established and functional.
- Recycling: 3rd place, average 3.414, standard deviation 0.706, coefficient of variance 20.7% and agreement rate 68.3%. This is a case for the necessity of environmentally friendly recycling processes. This indicates a conscious effort to reduce waste and convert waste to usable contributions of economic value.
- Remanufacturing: It was in the last place with a mean of (2.923), a standard deviation of (0.938), the highest coefficient of variance (32.1%) and a high degree of agreement (58.5%), which shows a moderate evaluation and a greater dispersion among the respondents. This dispersion is due to the high technical and technological requirements for the restoration and refurbishment of products to the original state.

4.3.3. Dependent Variable (Operational Sustainability)

The mean score of the dependent variable (Operational Sustainability) was (3.435) with standard deviation of (0.741), coefficient of variance of (21.6%) and percentage of agreement of (68.7%) which places the sample responses in the high rating category. The relative ranking of its three dimensions was distributed according to their degree of homogeneity, being the dimension "Sustainable Packaging" the first, followed by the dimension "Process Automation" in second place and the dimension "Energy Efficiency" in third place.

- Sustainable Packaging: got the first place with an arithmetic mean of (3.543), a standard deviation of (0.533), the lowest coefficient of variation (15.0%) and percentage of agreement of (70.9%), showing the best degree of homogeneity among the dependent dimensions. This shows the company's dedication to use eco-friendly and biodegradable packaging solutions which can add to its brand image and environmental responsibility.
- Process Automation: Second in line with a mean of 3.428, standard deviation of 0.799, coefficient of variation of 23.3% and consensus of 68.6% showing a high level of agreement on automating tasks. This indicates the proper usage of smart systems in minimising human mistake and speeding up operational processes.
- Energy Efficiency: It was ranked lowest with an average of 3.333, standard deviation of 0.891, coefficient of variation of 26.7% and a consensus of 66.7%, indicating a moderate to high level of evaluation with considerable relative diversity in perception. The discrepancy is because the organisation has to upgrade some of its older equipment and replace it with more energy efficient technologies.

4.4. Testing the Hypotheses of Impact of the Research Variables

This part deals with the testing and assessment of the direct and indirect impact relations among the research variables, which are the independent variable (digital innovation), the mediating variable (reverse logistics) and the dependent variable (operational sustainability). This is to test the validity of the three key hypotheses. The explanatory power and impact strength of the variables were determined based on Structural Equation Modelling (SEM) and Advanced Path Analysis utilising the statistical programme AMOS V.24 estimating the structural parameters and quality of fit indicators of the conceptual model . The objective is to show the mediating effect of reverse logistics in transferring the influence of digital innovation for improving operational sustainability in the research laboratory.

4.4.1. The first main hypothesis is: "Digital innovation directly has a significant impact on reverse logistics in the research laboratory.

The first main hypothesis is accepted as we can see from the results of Figure and Table (9) below which states: "There is a direct significant effect of digital innovation on reverse logistics in research laboratory." The results of the path analysis indicate that the independent variable (digital innovation) contributes 38% to the change in the mediating variable (reverse logistics) based on the coefficient of determination (R2 = 0.38) and the remaining 62% is explained by other random variables outside the research model. The direct standardised effect coefficient (S.R.W = 0.604) was computed at the standard error (S.E. = 0.074), meaning that every one standard unit exerted on digital innovation would improve reverse logistics processes by 60.4%. This finding was supported by the critical ratio (C.R. = 5.521) which is larger than the statistical standard (1.96) and a significant significance level (P = 0.001) which is smaller than the accepted significance level (0.05). In addition, the quality of fit indices for structural model is obtained as given in attached figure (CMIN/DF = 2.543, GFI = 0.943, CFI = 0.973, TLI = 0.954, RMSEA = 0.067) which confirms the significance of the direct effect of the hypothesis. This is because the Wasit Textile and Knitting Factory depends on digital technologies, solutions and communications infrastructure that directly support the recycling, reuse and production of products and their recovery. The accurate digital data enables the monitoring and facilitating of the flow of returned materials and products leading to the improved efficiency of reverse logistics operations and better environmental and economic operational performance of the factory.

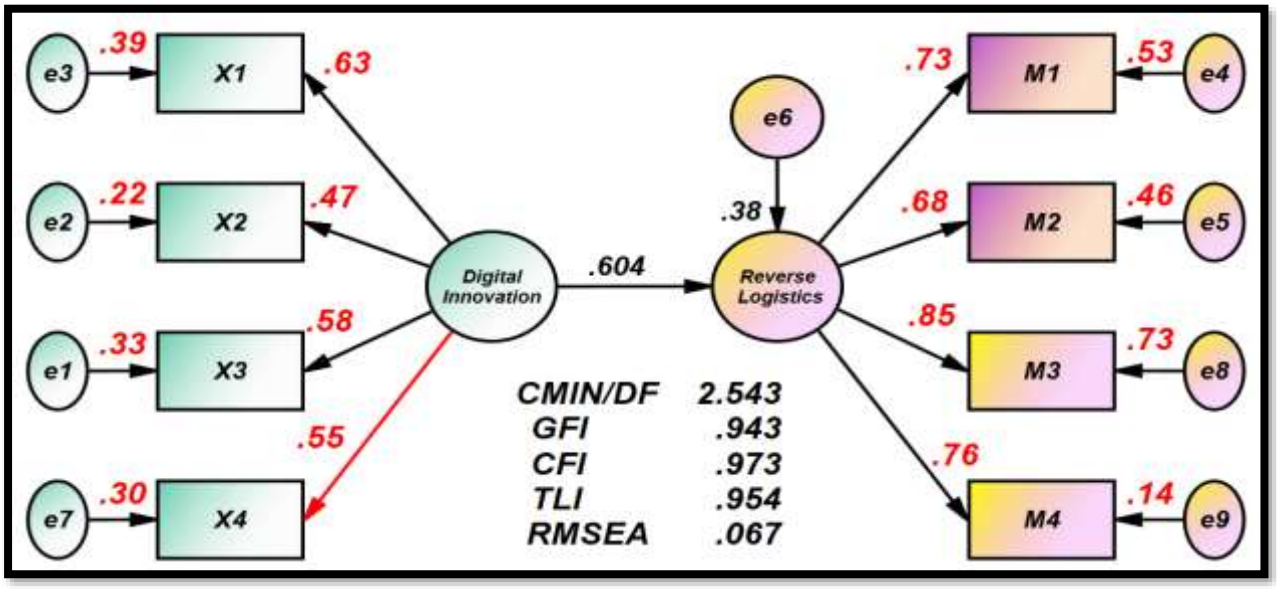


Figure 5. shows the Heike model of the impact of digital innovation on reverse logistics.

Source: "AMOS.V.24 Outputs"

Table 9. shows the significance of the impact values according to the P-value and the critical ratio (C.R.), which were significant, thus accepting the first main impact hypothesis.

Table 9. / Impact Values of Digital Innovation on Reverse Logistics

Med. Variable	Path	Indep. Variable	S.R.W	S.E.	C.R.	R2	P
Reverse Logistics	←	Digital Innovation	0.604	0.074	5.521	.38	0.001

"Source: Compiled by the researcher based on the output of the AMOS program".

4.4.2. The second primary hypothesis is "Digital innovation has a significant direct influence on operational sustainability in the laboratory under study."

The second primary hypothesis is accepted: "Digital innovation has a significant direct impact on operational sustainability in the laboratory under study" as shown in Figure and Table (10) below. The path analysis results showed that the independent variable (digital innovation) contributed 13% of the changes of the dependent variable (operational sustainability) based on the coefficient of determination ($R^2 = 0.13$) while the remaining 87% was due to other random variables outside of the research model. The direct standardised impact factor (S.R.W = 0.284) was calculated with a standard error (S.E. = 0.119) of 28.4% of a standard unit applied to digital innovation, hence improving operational sustainability. This finding was supported by the critical ratio (C.R. = 3.235) more than the statistical standard (1.96) and the significance level (P = 0.042) less than the accepted significance level (0.05). The structural model conformance quality indicators displayed in the attached figure were obtained (CMIN/DF = 4.765, GFI = 0.915, CFI = 0.912, TLI = 0.932, RMSEA = 0.078) confirming the hypothesis direct impact significance and its statistical support. The result is explained by the fact that the adoption of digital infrastructure and modern applications by Wasit Textile and Weaving Factory, in addition to training employees in digital skills, constitutes a fundamental pillar for improving energy efficiency, moving towards sustainable packaging and automating production processes, which results in reducing waste, operational errors and increasing the general level of operational sustainability in the factory.

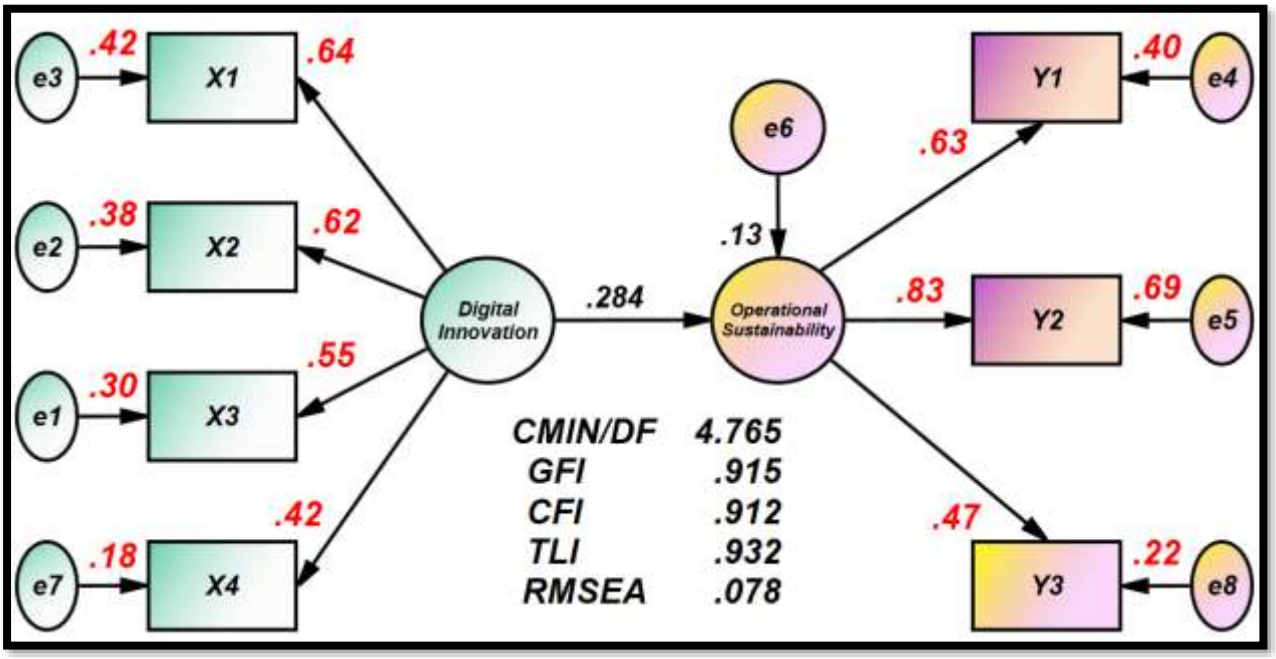


Figure 6. Structural model of the impact of digital innovation on operational sustainability

Source: "AMOS.V.24 Outputs"

Table (10) shows the significance of the impact values according to the P-value and the critical ratio (C.R.), which were significant, meaning the second main impact hypothesis was rejected.

Table 10. Impact Values of Digital Innovation on Operational Sustainability

Med. Variable	Path	Indep. Variable	S.R.W	S.E.	C.R.	R2	P
Operational Sustainability	←	Digital Innovation	0.284	0.119	3.235	.13	0.042

"Source: Compiled by the researcher based on the output of the AMOS program".

4.4.3. The third main hypothesis "Digital innovation has a significant indirect effect on operational sustainability through reverse logistics as a mediating variable in the laboratory under study".

In terms of the direct and indirect impact sizes and construct mediation tests, the data shown in the Figure and Table (11) above support the third primary hypothesis. Path analysis and structural equation modelling using AMOS software results showed high quality and acceptability of the conceptual model presented in the figure with statistical indices of model conformity reaching (CMIN/DF = 3.494, GFI = 0.950, CFI = 0.967, TLI = 0.941, RMSEA = 0.062). The direct standardised effect weight between digital innovation and the mediating variable reverse logistics (S.R.W = 0.604) was 0.604 with a standard error of 0.074, a critical ratio (C.R. = 5.521), a significance level of 0.001 and explanatory power of 0.38. The direct effect of Reverse logistics on operational sustainability was 0.565 with a standard error of 0.069, critical ratio (C.R. = 5.343), significance level 0.004, and explanatory power of 0.36. The total direct effect between the independent and dependent variables before the inclusion of the mediating path had an effect coefficient of (S.R.W = 0.284) with a standard error of (S.E. = 0.119), a critical ratio of (C.R. = 3.235), a significance of (P = 0.042) and an explanatory power of (R^2 = 0.13).

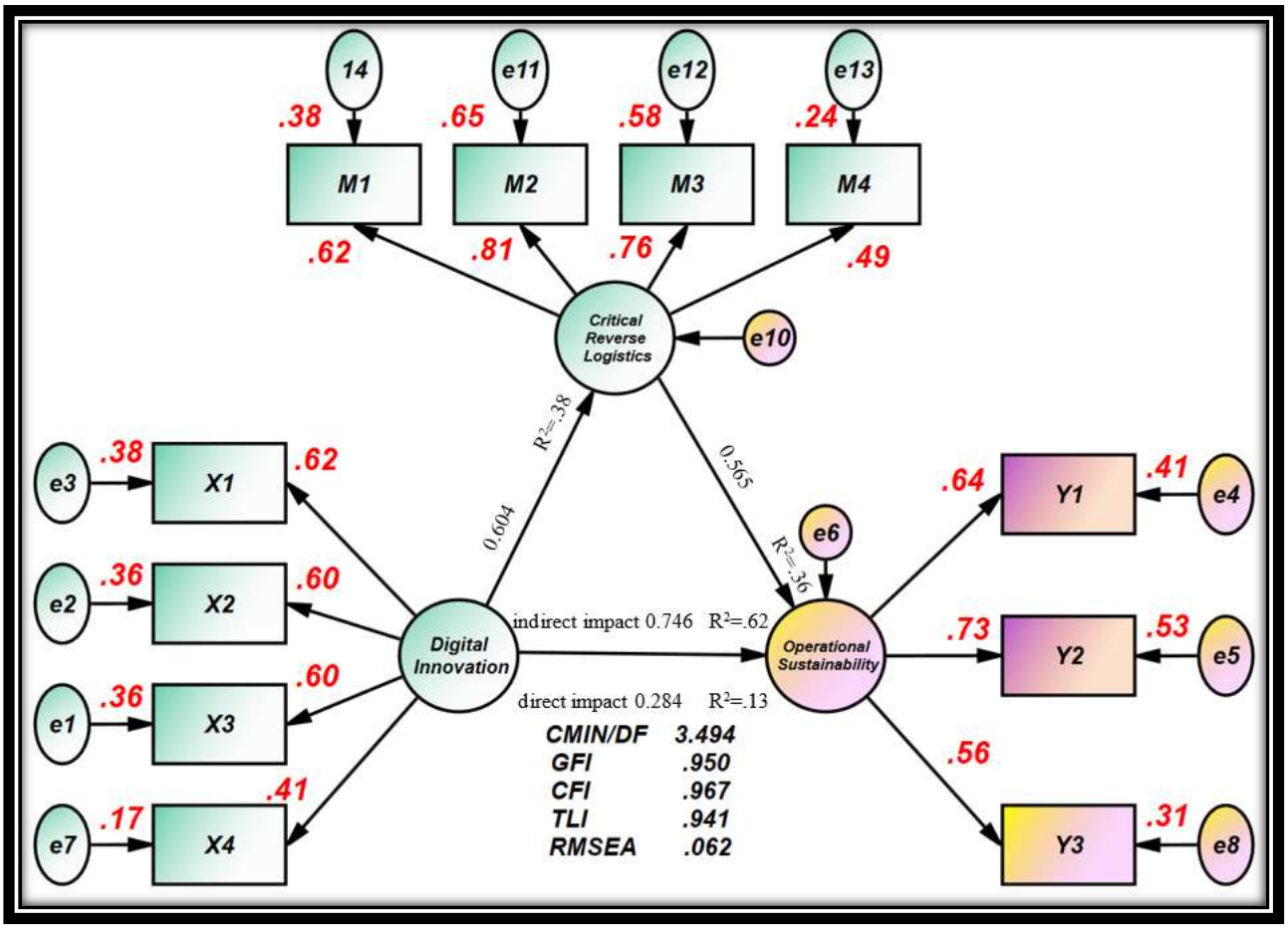


Figure 7. The intermediate structural model

Source: "AMOS.V.24 Outputs"

When the indirect impact was tested in the presence of the mediating variable, the results demonstrated a significant and direct increase in the overall explanatory power of the model. The typical indirect effect of digital innovation on operational sustainability through reverse logistics was (0.746) with a standard error of (0.052), high critical ratio of (8.876) and statistical significance level of (P = 0.000). This was associated with a large increase in the cumulative explanatory power up to (R^2 = 0.62). The importance of this mediation was validated by the sobel test for indirect effects, where the statistical value of the test was more than the acknowledged critical value of (1.96) with a significant significance level of (P < 0.05). The findings reveal that reverse logistics mediates the impact of digital innovation on operational sustainability at the statistically significant level. The finding also showed that the inclusion of mediating variable significantly increased the explanatory power of the model (0.462). The standard error was (0.067) and the critical ratio was (5.641). This raised the additional explained variance in operational sustainability by (0.49). Thus, the inclusion of reverse logistics as a mediating variable doubled the model's ability to explain and forecast operational sustainability behaviour.

This integrated structural formulation indicates that the implementation of digital innovation applications and current technologies does not reach comprehensive operational sustainability in their own or in isolation with the Wasit Textile and Weaving Factory. Rather, it implies the implementation of reverse logistics procedures, such as the collection of returned products, recycling, reuse and remanufacturing. Digital solutions are a catalyst and enabler for growing efficiency and simplifying of reverse logistics procedures. This, in turn, enables process automation, energy conservation and the promotion of sustainable packaging. In the end, it reaches the highest levels of operational sustainability and environmental and economic readiness for the factory.

Table 11. Paths and Parameters of the Selection of the Third Main Hypothesis

Variables	PATH	Variables	S.R.W Indirect Effect	S.R.W direct Effect	S.E.	C.R.	R^2	P
Reverse Logistics	←	Digital Innovation		0.604	0.074	5.521	.38	0.001
Operational Sustainability	←	Reverse Logistics		0.565	0.069	5.343	.36	0.004
Operational Sustainability	←	Digital Innovation		0.284	0.119	3.235	.13	0.042
Operational Sustainability	**Reverse Logistics →**	Digital Innovation →	0.746		0.052	8.876	.62	0.000
The amount of improvement in the presence of the mediating variable								
Operational Sustainability	**Reverse Logistics →**	Digital Innovation →	0.462		0.067	5.641	0.49	-

"Source: Compiled by the researcher based on the output of the AMOS program".

When performing the Sobel news operation in the table below:جدول () نتائج اختبار سوبل (Sobel Test)

Source: Sobel outputs

As indicated in the table, the results of the Sobel test indicate that the indirect effect of the mediating variable is highly statistically significant. The Z-value was 8.876 and the significance level was significant (P=0.000) and less than 0.05. This demonstrates that reverse logistics plays a major and comprehensive mediating function in translating the influence of digital innovation to improve operational sustainability in the factory under consideration.

5. Conclusions and Recommendations

5.1. Findings

- From the answers of the respondents we can deduce that there is a distinct difference on the preparedness of communication networks and the systems implemented within the factory. This means the organisation in question has not yet achieved the target level of technical advancement and cloud connectivity. This is because of the partial dependence on data processing solutions without a complete integration with operations, limiting the needed speed in the exchange of administrative data.
- The descriptive study shows the laboratory has problems in an efficient deployment of the smart apps and software in the production chain. Clearly, the organisation studied has not yet attained the requisite level in the use of these technical tools to enhance communication and facilitate the flow of information. This limits its ability to respond to developments and underscores the need to expand its digital programmes.
- The answers of the respondents show that the organisational environment still needs an integrated digital environment that promotes engagement and safeguards data properly. The level of providing the essential digital security measures and the level of building a culture of institutional innovation have not yet achieved the required level, which severely affects the flexibility of the daily operational performance.
- The descriptive analysis shows that there are no training courses to develop advanced digital skills for technical and administrative professionals. This demonstrates that the organisation under consideration has not reached the necessary level of investment in the competence of its personnel and in the

development of their technological abilities. This inhibits the ability to use contemporary equipment and to analyse complex data efficiently .

- According to the respondents' answers, we conclude that there are deficiencies in the channels assigned for the collection and receipt of returned or used products from the market. This is clear from the fact that the organisation under study has not yet attained the needed level in the organisation of product collection programmes from consumers and intermediaries, which inhibits the factory from reusing resources and reducing waste.
- The descriptive analysis shows that the techniques of treating damaged items and the utilisation of production waste are still carried out in a traditional way, which does not lead to full advantage. Clearly, the organisation under investigation has not yet achieved the level of dependence on recycled materials as a key source of raw materials, which results in the increased costs of operating supplies.
- Respondents allow us to deduce that the processes of shifting supplies and resources to new manufacturing pathways are not implemented systematically. This means that the organisation under examination has not attained the necessary level of decreasing industrial waste that leads to the depletion of available resources instead of their efficient use continually.
- The descriptive analysis shows there are weak areas in the technologies and programmes used to refurbish and repair returned products so that they can be used for longer. Clearly, the organisation under consideration has not achieved the needed level of development of technological means for reworking defective parts and improving their quality for reuse.
- Based on the replies of the respondents, we deduce that the plant is facing high energy and fuel consumption rates in its production departments. The investigation reveals that the organisation has not reached the level of adoption of energy-efficient equipment and technology, which leads to higher financial burden and uncompetitive environmental impacts.
- The descriptive study suggests that the manufacturer is falling behind in the use of biodegradable / environmental friendly materials for packaging of its textile products. Clearly, the organisation under review does not attain the necessary level of green packaging standards that fulfil modern environmental regulations and the needs of ecologically concerned consumers.
- The respondents' responses indicate that manual labour is still employed in many production and administrative lines, which suggests that the organisation under study has not yet reached the required level of comprehensive automation to ensure a reduction of operational errors and an increase of the speed and accuracy of outputs.
- The inferential statistics shows that digital innovation has a strong and direct favourable effect on supporting reverse logistics methods. Structural equation modelling identified digitalisation as the key to efficiency in reverse logistics chains. Digital infrastructure and technological solutions enhanced the laboratory's capacity to handle collection, recycling and manufacturing with high precision.
- The effect linkages reveal that digital innovation has a direct and essential impact on the operational sustainability of the laboratory under study. Statistical tests reveal that investment in technology and data automation has a favourable effect on energy efficiency, the use of environmentally friendly packaging materials and higher efficiency in the automation of manufacturing lines, which reduces errors and costs.
- The inferential statistics based on the Sobel test allow us to infer a significant and crucial mediating role of reverse logistics in enhancing the relationship between digital innovation and operational sustainability, as digital innovation does not

achieve the highest levels of operational sustainability by itself, but rather requires the existence of flexible and systematic reverse mechanisms that handle and recycle resources to translate the technological tools into a sustainable operational performance.

5.2. Recommendations

- Improve the digital infrastructure of the factory with linear and cloud connectivity and build secure databases to ensure quick information interchange and remove difficulties in administrative and production correspondence.
- To increase the adoption of current software and technology applications and to establish an integrated data flow system linking plant departments with suppliers and customers to enable product tracing.
- Create a safe digital working environment based on advanced industrial safety standards and provide incentives to employees for the generation and implementation of creative digital ideas on production lines.
- Conduct specific and frequent training courses for the industrial workforce to upgrade their technological skills and capacities in using new equipment and analysing large data efficiently.
- Establish incentive and cooperation programmes for consumers and intermediaries to promote returned product collection, and create organised and particular channels and processes for the return of worn or damaged products from the market.
- Introduce new technologies in the area of sorting and recycling industry waste, to use it as alternative raw materials, reduce the purchase costs and protect the environment.
- Total programme of reuse of reusable resources and supplies without expensive changes, permitting reduction of industrial waste and rationalisation of operational costs.
- Creation of dedicated repair and refurbishing units, which use breakthrough technologies to remanufacture damaged goods and parts, prolonging their lifespan and enhancing their quality.
- Installation of contemporary energy efficient systems and equipment in all weaving and knitting lines to cut waste and minimise the environmental and economic cost of operations.
- Switching to sustainable, eco-friendly, recyclable packaging materials for finished products, improving the factory's environmental responsibility and fulfilling consumer requirements.
- Fully automate operational and administrative operations to minimise human intervention hence minimising errors and improving the pace and quality of manufacturing output.
- Leverage existing digital solutions and technologies to facilitate and support reverse logistics activities, such as product collection, tracking and reprocessing.
- Drive digital innovations and accumulated competencies towards the strategic goals of operational sustainability – reduce manufacturing cost and safeguard the environment.
- Integrating reverse logistics activities into the factory's digital operating model, to ensure the effective transfer of the benefit of digital innovation to all elements of operational sustainability.

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