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Drivers for Digital Transformation by Manufacturing Small and Medium Enterprises (SMEs) in Tanzania for Sustainable Supply Chains.

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a b s t r a c t

This study examines drivers of digital transformation (DT) among manufacturing small and medium enterprises (SMEs) in Tanzania, with a particular focus on how place-based conditions shape DT-enabled sustainable supply chains (SSC) across coastal and inland settings. A mixed-methods design combined a questionnaire survey (n = 103) and semi-structured interviews (n = 15) with procurement, production and transport stakeholders in Dar es Salaam, Pwani and Morogoro. Descriptive analysis identified commonly used DTs and their extent of implementation, while confirmatory factor analysis and structural equation modelling tested the drivers of adoption. The findings show that Internet of Things and cloud computing are the most widely used DTs, but overall implementation remains moderate. SEM results indicate that organizational readiness and financial capability are the strongest drivers, complemented by technological capability, external support and environmental pressures. Key barriers include limited infrastructure, unclear benefits and shortages of digital skills, which amplify perceived complexity and reduce trialability especially where supply-chain connectivity is weaker. The study contributes a geography-sensitive account of DT adoption in Tanzanian manufacturing SMEs and offers implications for corridor/cluster-oriented support that can accelerate DT for SSC.

1. Introduction

The concept of digital transformation has recently gained high research interests in the world due to potential impact of its novel technologies on the manufacturing processes, and Supply Chains Management (SCM) in achieving sustainability outcomes (Rice and Pearce, 2015; Tolstolesova *et al.*, 2021; Dixit *et al.*, 2024; Swain *et al.*, 2024). Digital transformation offers many opportunities in enhancing strategic, tactical and operational capabilities of manufacturing Small and Medium Enterprises (SMEs) to attain the Sustainable Development Goals (SDGs) specifically the SDG goal 12 which emphasize on ensuring the sustainable consumption and production patterns by reducing waste, resource efficiency and circular economy practices(Oubrahim and Sefiani, 2023). Digital transformation refers to how businesses use digital competencies to transform their business development models and ecosystems. Digital transformation is characterized by application of novel technologies in business processes, identification of new opportunities and improved system's integration of many organizations (i.e., established network of business entities in the supply chain) whereby the business environment changes at an ever-increasing rate (Bigliardi *et al.*, 2022). Typically, supply chain managers strive to increase market value by reducing costs and creating more adaptable, flexible, and interconnected systems in order to keep up with unpredictable markets, and fast changing consumer behaviors. By using the existing digital technologies, manufacturing SMEs may minimize time used in producing a product, become more flexible, encourage innovation, and boost their ability to compete in the digital age. Tavana *et al.* (2022) found that smart manufacturing activities are created in the countries manufacturing sector due to integrated production, reduced delivery and lead times, resource efficiency and prevention of information distortion brought by digital transformation. As a result, many manufacturing SME's, especially in the developed countries have adopted digital transformation for improved systems integration, logistic operations performance and smart business processes (Dadsena and Pant, 2023).

Geography matters for digital transformation (DT) adoption in Tanzania because manufacturing SMEs are unevenly distributed across coastal, port-based industrial clusters and inland production distribution corridors. Dar es Salaam and the adjacent coastal belt (Pwani) host the country's main port, dense markets and industrial estates, which can lower the perceived complexity of adopting digital tools by improving access to connectivity, suppliers, finance and technical support. In contrast, inland nodes such as Morogoro, although strategically located on the Dar es Salaam, central corridor, can face intermittent utilities and weaker ICT coverage, which raises adoption costs and slows diffusion. Therefore, beyond firm-level capabilities, place-based infrastructure and proximity to markets shape how SMEs perceive the relative advantage, compatibility and feasibility of DT for sustainable supply chains (Rogers, 2003).

The emergence of novel technologies under digital transformation such as internet of things (IoT), cyber-physical systems (CPS), big data analytics (BDA), machine learning (ML), cloud computing (CC), radio frequency identification (RFID), enterprise resource planning (ERP) and electronic data

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interchange (EDI), is precisely what is responsible for the significant transformation in the global SCM. Usually, by improving efficiency, transparency, and security, these technologies have the potential to fundamentally alter the way supply chain processes are carried out (Oubrahim and Sefiani, 2023; Ahmed Deif, 2023). These Digital Technologies (DTs) specifically, support supply chains by improving information accessibility, gathering real-time data, optimizing SCM procedures, lowering production and transaction costs, elimination of wastes (i.e., time, solid and liquid wastes), enhancing delivery time, and boosting efficiency and effectiveness of Supply Chain (SC) functions (Bigliardi *et al.,* 2022; Nayal *et al.,* 2022). Following the exponential growth rate of the current technologies, it is likely that digital transformations will continue to play a crucial role in determining the course of economic and social activities (Ardito *et al.,* 2019). Manufacturing SMEs, therefore, can increase logistics operational performance, achieve manufacturing sustainability, Sustainable Supply Chain (SSC) and reduce the bullwhip effect by employing DTs smarter internal processes (Queiroz *et al.,* 2019). According to Rodríguez-González *et al.* (2022), SSC intends to integrate the industrial sustainability issues into the SCM. The pursuit of sustainability in supply chains has been claimed to increase SSC performance including resource use efficiency, remanufacturing, substitution of materials, reusing, recycling, waste reduction at the source and reverse logistics (Gardas, Raut and Narkhede, 2019; De Gao, 2017). The SSC performance is a measure of how well the SME's supply chain practices are aligned with the environmental, social, and economic sustainability goals to effectively manage resources (i.e., materials, manpower, machines), capital and information flow in the value chain (e.g., procurement, production and distribution) to fulfill the stakeholder's requirements and industry's resilience (Dubey *et al.,* 2017).

These practices include reducing waste and pollution, supporting local communities (i.e., societal sustainability), guaranteeing fair labor practices, reduce energy consumption, and looking for a long-term operational and environmental feasibility which involves the combined effect of lower material consumption and fewer wastage of products which significantly lower pressure on the environment (Khan *et al.*, 2022). In other words, SSC have social-economic and environmental benefits that improves the SME's long-term financial performance via reduced operational costs, and increased productivity (Suhi *et al.,* 2019). Mangla *et al.,* (2020), documented that for SMEs to reach a well-balanced SSC performance level of managing flow of materials, capital, personnel, and information in the SC, the SMEs must cope with the present technology, be aware of developments on the digital transformation front, and place proper emphasis on the operational excellence. Hence, SMEs should concentrate on their customers, innovate, and make better use of their resources, capabilities, and productivity by integrating sustainability practices into their SC (Junaid, Zhang and Syed, 2022). In aggressive businesses, enhancing SC performance is primary objective of the SSC which corresponds to the global SDG goals. However, because of the complexity of decision-making processes, and the prevalence of trade-offs between indicators used for guiding decision-makers' choices, accomplishing such objectives is a challenge (Fu *et al.,* 2022).

Prior studies indicate that digital transformation in manufacturing is shaped by a combination of organizational capabilities and leadership, availability of enabling technologies, and the broader institutional and environmental context, including regulation and infrastructure (Vogelsang *et al.,* 2018; Steiber *et al.,* 2020). In addition, diffusion processes can differ across countries and regions because firms face different levels of connectivity, skills and market access, which affects how innovations spread and are adopted (Rogers, 2003; Rice and Pearce, 2015). However, evidence on how these drivers jointly influence DT in manufacturing SMEs for sustainable supply chains in Tanzania remains limited, motivating the current study.

Similarly, many studies have been conducted to explore digital transformation of industries in general (i.e., without consideration of the manufacturing and service industries) such that these industries may have differences in technology adoption needs and requirements. Moreover, studies have focused on barriers and enablers of digital transformation by industries in general without critical examination of the contribution margin of each factor towards adoption of DTs. and finally, studies were conducted about digital transformation of manufacturing industries and sustainable supply chains separately. Hence, this study has taken a new research direction by exploring drivers for digital transformation by Manufacturing SMEs in Tanzania for SSC with the following research questions:

RQ1: What are the commonly used DTs by manufacturing SMEs for SSC?

RQ2: What is the degree of DTs implementation by manufacturing SMEs for sustainable procurement, production and distribution?

RQ3: What are the main drivers for implementation of DTs by manufacturing SMEs for the SSC?

Uncovering the stated questions contributes to the existing global knowledge by providing critical information to the country's policy making instruments, business owners and community about cost and benefits of DTs adoption, DTs investment decisions, and motivating factors for manufacturing industry's digital transformation and make informed decisions. To explore the stated research questions, this study intended to:

1) Identify DTs implemented by manufacturing SMEs for SSC.
2) Determine the extent to which manufacturing SMEs implement DTs for sustainable procurement, production and distribution.
3) Establish the main drivers for implementation of DTs by manufacturing SMEs for SSC in Tanzania.

The rest of this article is organized as: Section 2 which provides review of relevant studies, research gaps and theoretical framework. Section 3 narrates the methodology used in the data collection and analysis. Section 4 presentation of the findings. Section 5 discussion of the results and finally section 6 presents the conclusion.

2. Review of Relevant Literature

2.1. Digital transformation by industries for sustainable supply chains

Digital transformation of the manufacturing sector in the majority developed and developing countries is now a reality due to its wide application towards sustainable manufacturing operations (Sharma *et al.,* 2023; Salman *et al.*, 2024; Swain *et al.,* 2024), smart product design (Srai and Lorentz, 2019; Qi, Xu and Rani, 2023), machine learning and automation (Hansen, Christiansen and Lassen, 2024), sustainable supply chains and circular economy(Deif, 2023; Quiroz-Flores *et al.,* 2024). The concept of digital transformation can be traced back to the introduction of computers and digitalization of industrial processes that attributed to emergence of Germany's industry 4.0 in 2011 (Omol, 2023; Swain *et al.,* 2024). Many social, economic and environmental benefits have been obtained from digital transformation by industries including improvement in productivity e.g., augmented reality and 3D printing, minimized machine downtime and production cost, efficient transportation and logistics operations, workers safety, as well as sustainable supply chains (SSC) e.g., reverse logistics (Albukhitan, 2020). To date, there are different definitions of the term "SSC" whereby Zailani *et al.* (2012) describes SSC as a strategic and transparent integration of sustainability aspects and supply chain management by an industry measured by the three dimensions of sustainability (i.e., social, economic and environmental performance). According to Mota *et al.* (2018), SSC refers to industrial efforts towards mainstreaming sustainability issues in the industry's value chain activities like supplier selection, product reuse and recovery, inventory planning, production as well as material and product flows in the supply chains (e.g., forward, reverse and closed-loop).

While Gao *et al.* (2017) documented SSC as the management of resources (i.e., machines, manpower and materials), flow of capital and information, and engagement of other actors along the supply chain with consideration of social, economic, and environmental aspects determined by the stakeholder needs e.g., customers, government, and community. The SSCM therefore, is not only very instrumental towards achievement of the global SDGs but also a solution to depletion of scarce natural resources and emission of greenhouse gases which threatens sustainability of many manufacturing industries specially in Africa such that adoption of Digital Technologies (DTs) is necessary. Table 1 presents different type of DTs applied in the procurement, production and distribution phases in the value chain of manufacturing SMEs as follows:

Table 1: Digital technologies applied in the value chain

Value chain stage	Technology applied	Sector	Reference(s)
Procurement/supplier acquisition	Internet of things (IoT), Block Chain (BC).	Health	(Neumark, 2023; Swain *et al.,* 2024)
	Big Data (BD), Cloud Computing (CC)	Agriculture, telecommunication	(Caldarola *et al.,* 2023; Dibbern, Romani and Massruhá, 2024)
	Machine Learning		
Production/manufacturing	IoT, BC, Cyber Physical Systems (CPS), Artificial Intelligence (AI).	Health, telecommunication	(Caldarola *et al.*, 2023; Neumark, 2023; Swain *et al.*, 2024)
	Sensor Technologies ST, BD, CC.	Agriculture	(Deif, 2023; Dibbern, Romani and Massruhá, 2024)
	Big Data and Artificial Intelligence and machine learning	Manufacturing	(Vimal *et al.*, 2023; Dixit *et al.*, 2024)
Distribution/transportation and logistics	Internet of things, artificial intelligence.	Health, manufacturing	(Deif, 2023; Neumark, 2023; Dixit *et al.*, 2024; Swain *et al.*, 2024)
	CT, BD, CC	Agriculture, telecommunication	(Caldarola *et al.*, 2023; Dibbern, Romani and Massruhá, 2024)

According to Arakpogun *et al.* (2020) and Mwananziche *et al.* (2023) digital transformation of the production sectors in Tanzania, Uganda, and Zimbabwe has been influenced by several factors including inadequate infrastructure to support information sharing as well as institutional environment like absence of policies and regulations that motivate digital transformation e.g., tax subsidy and other incentives offered on digital machines and equipment. The empirical evidence from a study which intended to establish the influence of DTs in the telecommunication sector in Rwanda showed lack of company investment capabilities in DTs, and skilled manpower "under the perception that adoption of DTs will favor skilled personnel leaving unskilled unemployed" to have hindered digital transformation in many developing countries however, the study findings provided different results whereby implementation of DTs have caused increase in employment (Caldarola *et al.*, 2023). Vimal *et al.* (2023) and Dibbern, Romani and Massruhá (2024) documented several barriers towards adoption of DTs such as unclear benefits of DTs, lack of efficient leadership, senior management support and knowledge expertise and awareness about DTs implementation, as well as security challenges and unclear government policies. Also, a study by Yüksel (2022) and Dibbern, Romani and Massruhá (2024) revealed different factors for adoption of DTs mainly industry 4.0 such as company size, products technology requirement, agility or flexibility of the technology, availability of competent labor, political security, education and economic challenges as well as management style e.g., focus on international market. A different perception was obtained by a study by Dixit *et al.* (2024) and Sharma *et al.* (2023) whereby the lack of proper industrial innovation strategy, the absence of urgency for DTs adoption, inadequate leadership that lead digitalization were found to significantly influence adoption of DTs.

2.2. The identified research gaps

In addition to the commonly discussed technological and organizational gaps, the DT-for-SSC literature contains a clear geographical gap. Much of the empirical evidence on DT drivers is drawn from developed economies or large emerging markets (Queiroz *et al.,* 2019; Ardito *et al.,* 2019), while place-based constraints typical of Sub-Saharan Africa such as uneven ICT coverage, reliability of utilities, and differing proximity to ports and industrial clusters are less frequently integrated into explanations of SME adoption (Arakpogun *et al.,* 2020; Mwananziche *et al.,* 2023). In Tanzania, spatial differences between coastal industrial zones and inland corridor nodes can shape both the opportunities for DT-enabled SSC (e.g., digital traceability and coordination) and the constraints that raise perceived complexity and reduce trialability (Rogers, 2003; Vimal *et al.,* 2023; Dibbern, Romani and Massruhà, 2024). Addressing this gap, this study examines DT drivers across Dar es Salaam, Pwani and Morogoro to capture geographically grounded adoption conditions.

Beyond the geographic gap, the literature indicates further knowledge gaps that justify this study. Many DT studies discuss "industries" or "production systems" in aggregate, drawing broadly on Industry 4.0 narratives without separating manufacturing from service-sector adoption contexts (Omol, 2023; Swain *et al.,* 2024; Sharma *et al.,* 2023). This aggregation can mask manufacturing-specific requirements-such as asset-intensive processes, quality control, and traceability needs-that shape which DTs are prioritized and how quickly they diffuse among SMEs (Qi, Xu and Rani, 2023; Hansen, Christiansen and Lassen, 2024). Empirical studies also commonly catalogue drivers and barriers but less frequently estimate the relative contribution of each factor or examine how organizational, technological and institutional influences interact (Yüksel, 2022; Vimal *et al.,* 2023; Dibbern, Romani and Massruha, 2024; Dixit *et al.,* 2024). Consequently, the marginal influence of factors such as top management support, digital skills, affordability, and policy incentives remains uncertain, particularly in resource-constrained settings. Finally, DT adoption research and the SSC literature often progress in parallel: while SSC is conceptualized as integrating environmental, social and economic considerations into supply chain management (Zailani *et al.,* 2012; Gao *et al.,* 2017; Mota *et al.,* 2018) and DT is discussed as a mechanism for visibility and performance (Queiroz *et al.,* 2019), fewer studies explicitly connect SME DT adoption drivers to SSC functions across procurement, production and distribution.

Therefore, this study took a new research direction by exploring drivers to digital transformation by manufacturing SMEs in Tanzania for SSC. In addition, considering the rapid advancement of technologies in the world and the benefits (i.e., social, economic and environmental) to the global supply chains, it is the best option for each industry to implement DTs relevant to the nature and type of products transformed for manufacturing sustainability (i.e., manufacturing process proceed without affecting the well-being of the future generation. Policy making institutions, managers and business owners can take proper decisions towards DTs investment decision and successful adoption of novel technologies via critical analysis of the potential drivers and barriers. Moreover, with the stated enabling environment for implementation of DTs, this study parks a research hypothesis that "there are significant implementation of DTs by manufacturing SMEs in the value chain (i.e., procurement, production and distribution)" in the developing countries in which Tanzania is part.

2.3. Theoretical framework

The Innovation Diffusion Theory, as outlined by Rogers (2003), serves as the basis for this study as it describes how new technologies, and other developments spread throughout cultures and societies from introduction to widespread adoption. The theory aims to clarify the process by which novel concepts and methods are adopted, as well as reasons behind why adoption of novel concepts can occur incrementally over time. According to the theory, every potential adopter of an innovation must become aware of it, be convinced of its benefits, decide to adopt it, implement it, and confirm that is, affirm or reject (i.e., their decision to embrace it). The degree to which an innovation is perceived as being better than the prior idea is the most obvious attribute that adopters look for in a new technology. However, many population groups, and individuals typically perceive the same innovation differently due to certain characteristics like relative advantage, and the five steps of technology diffusion in digital transformation like desirability, feasibility, first trial, implementing, and sustaining have been documented. Depending on how adopters see their access to DTs, and their ability to digitally transform their businesses, different countries and adopters embrace differently digital platforms. Also, on a worldwide basis, different cultures and nations have diverse attitudes towards new products at the individual, and/or organizational levels. The rate of adoption varies from product to product, and occasionally geographically from country to country for the same product. This is attributable to the fact that not all markets are equally open to embrace a new product.

To operationalize Innovation Diffusion Theory in this study, the five driver constructs identified for DT implementation (organizational, technological, financial, environmental and external drivers) are linked to the core IDT mechanisms of relative advantage, compatibility, complexity, trialability and observability (Rogers, 2003). Technological and organizational drivers primarily influence perceived complexity and compatibility by shaping whether SMEs have the infrastructure, skills and routines needed to use digital tools effectively. Financial drivers affect relative advantage and trialability because affordability determines whether SMEs can pilot DT and realize benefits that justify continued adoption. Environmental drivers (market and sustainability pressures) increase observability and strengthen relative advantage by making performance outcomes visible to customers, regulators and peers. External drivers (policies, institutions and partners) work through diffusion channels and the wider social system by providing information, standards, incentives and inter-firm learning opportunities that accelerate the spread of DT practices.

In addition, there is a natural integration between the digital inequality and diffusion of innovations approaches, more macro level measures should be included, and diffusion adoption categories can provide additional conceptual, and empirical insight into the influences on DTs adoption and related inequalities (Rice and Pearce, 2015). Therefore, based on the current understanding of the innovation diffusion theory, I find it relevant for this study in the sense that it helps to explain different factors for the adoption of new technologies such as awareness, the benefits of adoption as well as perceptions of adopters. Henceforth, with the help of innovation diffusion theory, this study intended to establish the drivers for DTs implementation by manufacturing SMEs in Tanzania for SSC. The conceptual framework (Figure 1) elucidates the association between the implementation of DTs whereby different factors including organizational, external, environmental, financial and technological capabilities promote digital transformation of manufacturing SMEs for SSC.

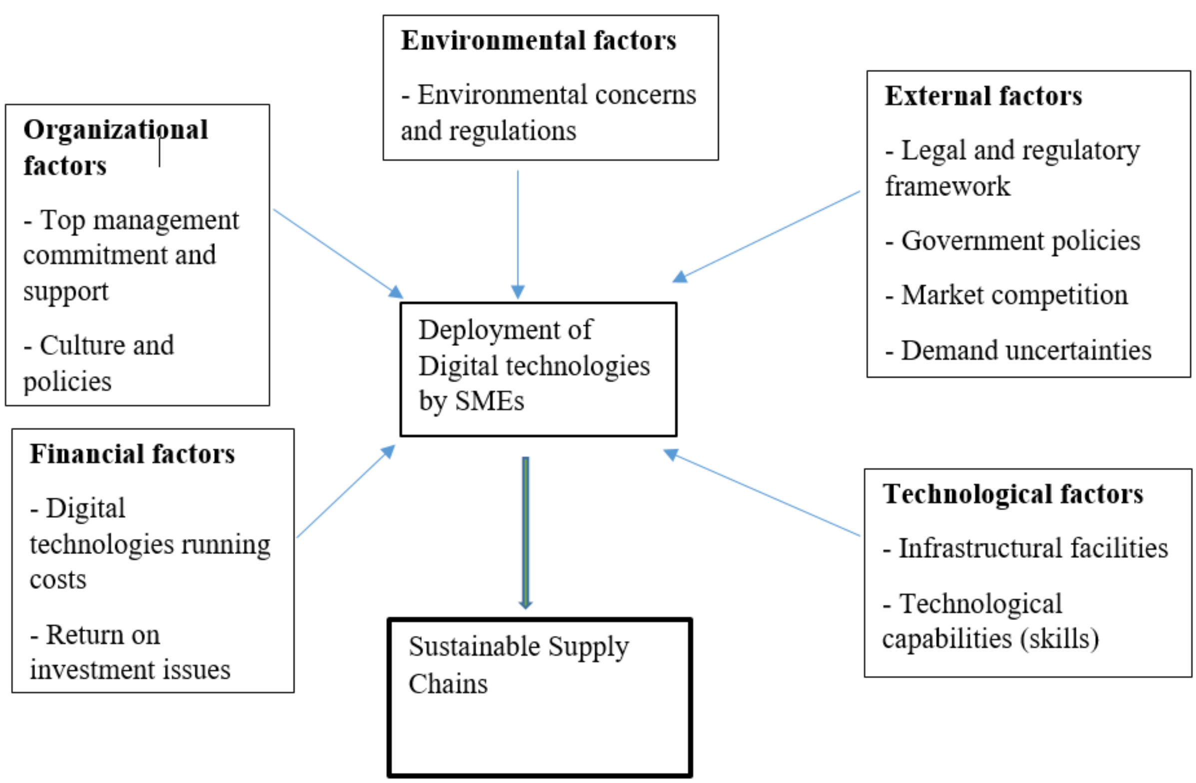

Figure 1: Conceptual framework: (Source: Author's construction, 2024)

3. Methodology

The study employed a mixed-methods research design and hybrid research methodology, which involves collection and analysis of both quantitative and qualitative data from targeted stakeholders including procurement experts, engineers, food scientists, managers and others staff working in the procurement, production and transport departments in the manufacturing SMEs located in Morogoro, Pwani and Dar es Salaam regions in Tanzania. The study was conducted in three regions of Tanzania, focusing on drivers for digital transformation of manufacturing SMEs for the Sustainable Supply Chain (SSC) partly due to availability of many manufacturing SMEs compared to other regions as well as dominance of majority food and beverage; leather and textile; metal and aluminium products; wood and paper; electrical and electronics; hardware as well as industrial chemicals like detergents and sanitary products following the industrial profile of Tanzania (Ringo, Kazungu and Tegambwage, 2023). URT (2012) revealed that enterprises are classified into four (4) groups based on the number of employees, total investment, and sales turnover whereby in the context of this study SMEs are classified based on number of employees (Table 2).

The study sites were selected to capture spatial heterogeneity in infrastructure and supply-chain connectivity while remaining comparable in terms of manufacturing activity. Dar es Salaam represents the primary port and market hub with the highest concentration of logistics services and digital infrastructure; Pwani represents the coastal peri-urban/industrial expansion zone that interfaces with the port corridor and emerging industrial estates; and Morogoro represents a key inland corridor node linking the coast to central regions, where SMEs engage with national distribution networks, but may experience different levels of ICT coverage, power reliability and support services. This sampling logic allows the analysis of DT drivers in settings with different degrees of connectivity to national and international supply chains.

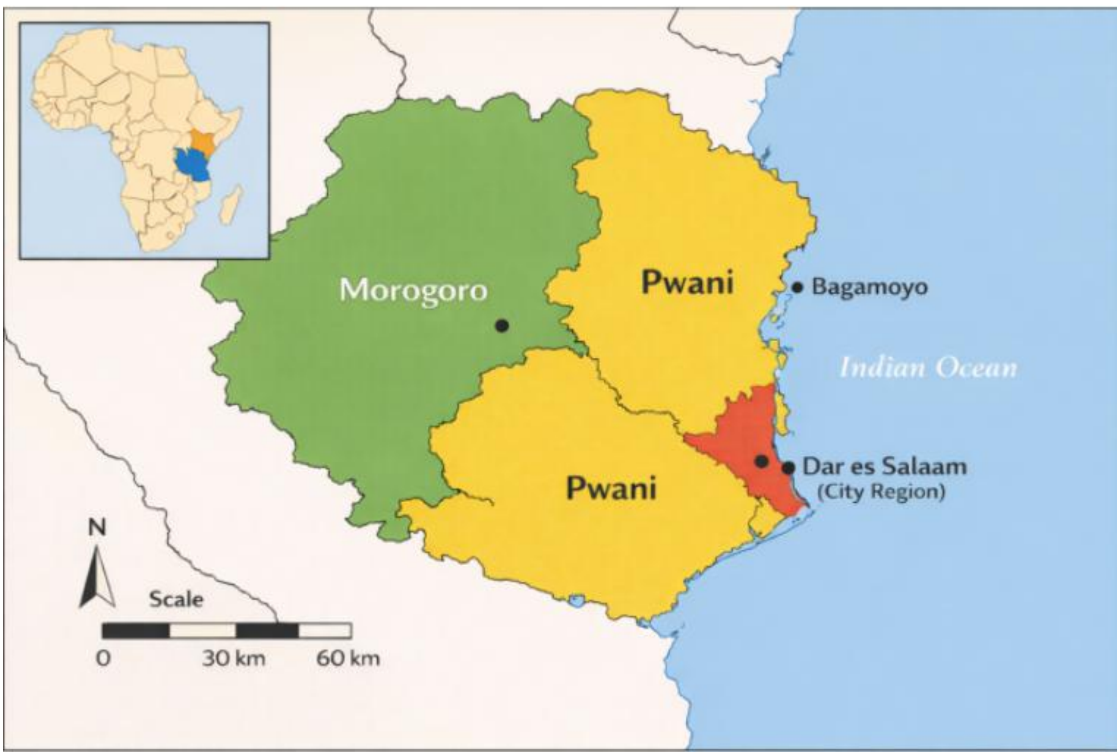

Figure 2: Study area map showing the three study regions (Dar es Salaam, Pwani and Morogoro) in Tanzania. (Source: Authors' compilation, 2026)

Table 2a: Spatial context of the study regions and expected DT adoption frictions/enablers (conceptual, based on study area selection logic and diffusion theory).

Region	Spatial/economic position	Connectivity & infrastructure implications for DT (examples)	Expected diffusion implications for SMEs (IDT lens)
Dar es Salaam	National market hub and main international gateway	Higher density of logistics services, ICT providers and access to customers/suppliers; relatively better broadband options and service markets	Lower perceived complexity and higher observability; stronger diffusion via peer networks and supplier/buyer requirements
Pwani	Coastal peri-urban/industrial expansion zone adjacent to the gateway corridor	Intermediate connectivity benefits from corridor proximity but may face uneven service availability depending on estate location	Moderate complexity; trialability depends on local support services and ecosystem maturity
Morogoro	Inland corridor node linking the coast to central regions and hinterland markets	Greater distance from port-based services; reliance on trunk-road distribution; potentially more exposure to power/ICT reliability constraints	Higher perceived complexity and risk; slower diffusion unless external support and demonstrable benefits are provided

Table 2: Categories of Micro, Small, Medium and Large Enterprises: Source: URT (2012)

Category	Employees	Capital investment in Machinery (TZS)
Micro enterprise	1 – 4	Up to 5 million
Small enterprise	5 – 49	Above 5 million to 200 million
Medium enterprise	50 – 99	Above 200 million to 800 million
Large enterprise	100+	Above 800 million

The primary data were collected through a structured questionnaire survey and semi-structured interviews. The questionnaire was administered to 103 respondents (engineers, procurement experts, managers, quality-control personnel and logistics staff) drawn from manufacturing SMEs in Dar es Salaam, Pwani and Morogoro. Respondents for the survey were selected using a random approach within participating firms where a sampling frame was available, while interviews (n = 15) were purposively conducted with key informants (operations/production managers, production engineers, procurement representatives and transport officers) to triangulate and validate the quantitative results on the degree of DT implementation.

The descriptive analysis was employed to identify DTs implemented by manufacturing SMEs and extent to which the manufacturing SMEs implement DTs for sustainable procurement, production and distribution, while an inferential statistical technique i.e., Structural Equation Modeling (SEM) through Confirmatory Factor Analysis (CFA) was used to establish drivers for the implementation of Digital Technologies (DTs) by manufacturing SMEs for SSC. Additionally, Analysis of Variance (ANOVA) was performed to test the research hypothesis that "There are significant implementation of DTs by manufacturing SMEs for sustainable procurement, production and distribution". The preliminary, descriptive and inferential statistical analysis were used in the analysis of the collected data about DTs implemented, and extent to which manufacturing SMEs implement DTs for procurement, production and distribution, and establish drivers for DTs implementation by manufacturing SMEs for SSC. The Stata software version 17 was employed in both descriptive and inferential analysis of the quantitative data while ATLAS.ti software version 7.0 was used for the qualitative data analysis. The preliminary analysis involved data quality check, and testing the assumptions of Exploratory Factors Analysis (EFA) such that all missing values were cross checked, and eliminated appropriately. The normality of data was also examined to establish whether the collected data are good for the SEM via CFA. Thereafter, descriptive and inferential analysis was carried out.

The descriptive analysis was conducted to different data groups mainly number of years in operations, number of employees, and extent of implementation of DTs by manufacturing SMEs for procurement, production and distribution. Usually, descriptive analysis intends to provide an insight of some findings, which may not necessarily be in the focus of the study's specific objectives to allow performance of the inferential analysis. The EFA was conducted in each construct (i.e., Organizational (ORG), Financial (FIN), Environmental (ENV), External (EXT), and Technological (TECH), and confirm variables in different constructs as the main factors driving manufacturing SME's implementation of DTs for SSC. The SEM has been widely applied in modeling drivers for adoption of manufacturing technologies and renewable power generation (Jabeen *et al.,* 2019; Hariyani and Mishra, 2023), barriers to sustainable construction and sweetened beverages consumption (Durdyev *et al.,* 2018; Wang and Chen, 2022), as well as the drivers for, and barriers to solar energy use by manufacturing MSMEs in Tanzania (Lyakurwa, 2023). The confirmed factors were then analyzed using the CFA so as to identify the relative importance of each towards implementation of DTs by manufacturing SMEs.

4. Analysis and Results

4.1. Results of the Study

4.1.1 Manufacturing SMEs profile

Table 3 presents the descriptive statistics of the manufacturing SMEs characteristics for the factors driving digital transformation by manufacturing SMEs in Tanzania for Sustainable Supply Chains (SSC).

Table 3: Manufacturing SMEs profile

Item	Variable measure	Frequency (N)	Percent (%)
SMEs category	Food and Beverage	13	12.6
	Textile and leather products	6	5.8
	Wood and paper products	18	17.5
	Metal, steel and aluminum products	18	17.5
	Foot wares	12	11.7
	Plastic products	18	17.5
	Electronic products	1	1.0
	Non-metallic mineral products	11	10.7
	Others (Industrial chemicals, Detergents, Jewelries and Sanitary products)	6	5.8
Total		**103**	**100%**
Number of employees	1-4	1	1
	5-49	44	43
	50-99	30	29
	100+	28	27
Total		**103**	**100%**
Years in operation	Less than 3 years	30	29.2
	3-5 years	15	14.6
	6-10 years	15	14.6
	11-15 years	14	13.5
	Over 15 years	29	28.1
Total		**103**	**100%**

The findings revealed that manufacturing enterprises can be grouped into nine (9) categories (Table 3). Out of 103 manufacturing enterprises, 18(17.5%) are dealing with transformation of metal, steel, and aluminum products; 13(12.6%) enterprises were food and beverage; 18(17.5%) enterprises were in the plastic product; 6(5.8%) enterprises were in the category of textile and leather processing; 18(17.5%) enterprises were in the wood and paper production; 12(11.7%) enterprises were in the foot wares; 1(1%) enterprise was in the electronic products;11(10.7%) enterprises were in non-metallic mineral products while 6(5.8%) enterprises were others i.e., enterprises dealing with production of industrial chemicals, detergents, jewelries and sanitary products. With regard to the number of employees, 44(43%) enterprises had 5 - 49 employees, indicating that they are small manufacturing enterprises, followed by 37(36%) enterprises with 50 - 99 employees indicating that they are medium manufacturing enterprises. Concerning the number of years in operation of the surveyed manufacturing enterprises, 30(29.2%) enterprises had less than 3 years in operation; 15(14.6%) enterprises had 3 - 5 years in operation; 15(14.6%) enterprises had 6 - 10 years in operation; 14(13.5%) enterprises had 11- 15 years in operation whereas 29(28.1%) enterprises had been in operation for more than 15 years.

4.1.2 DTs implemented by manufacturing SMEs for Sustainable Supply Chain (SSC)

Figure 3 presents the commonly used DTs by manufacturing SMEs in Tanzania for the SSC. The findings indicated significant difference in the implementation of DTs by manufacturing SMEs such that implementation of internet of things ranked number 1 with 64(62.1%) manufacturing SMEs use, the cloud computing ranked number 2 with 50(48.5%) of manufacturing SMEs usage, machine learning ranked 3 with 47(45.6%) usage, the enterprise resource planning ranked 4 with 44(42.7%) usage, big data analytics ranked 5 with 43(41.7%) SMEs usage, others ranked 6 with 40(38.8%) usage, cyber physical systems ranked 7 with 34(33%) usage, which radio frequency identification ranked 8 with about 32(31.1%) manufacturing SMEs usage and electronic data interchange ranked 9 with 23(22.3) usage.

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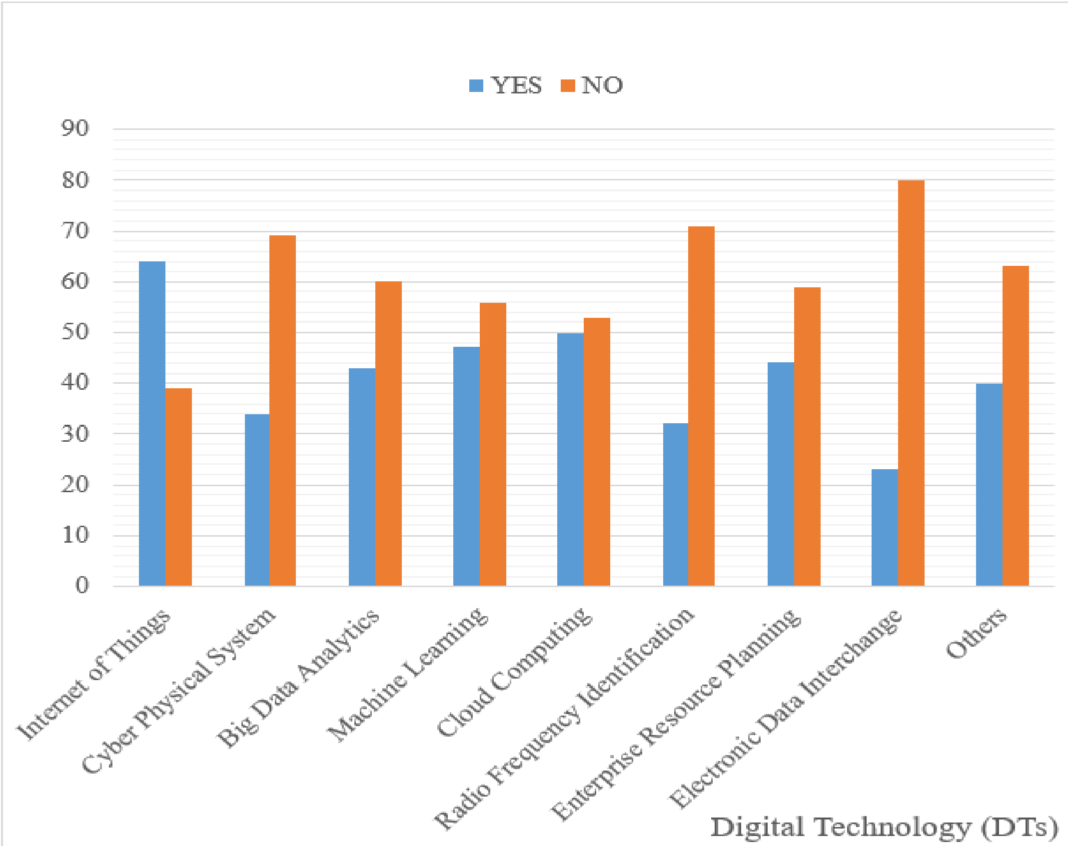

Figure 3: Digital Technologies implemented by manufacturing SMEs

4.1.3. Implementation of DTs by manufacturing SMEs for sustainable procurement, production and distribution

A one-way ANOVA was performed to test the null hypothesis that there is no significant difference in the level of DT implementation for sustainable procurement, production and distribution. Specifically, mean implementation scores were compared across enterprise size categories (micro, small, medium and large) defined by number of employees (Table 2). The ANOVA test results are presented in Table 4.

The ANOVA results (Table 4) suggest that there is a statistically significant difference between the means of all variables that measure SMEs implementation of DTs for sustainable procurement, production and distribution. The P_{value} and $F_{statistics}$ for the variables that measure implementation of DTs for procurement function were as follows: SMEs use DTs in sourcing, evaluation, and communicating with potential suppliers [P_{value}=0.000, $F_{\text{statistic}}$s=159.28]; SMEs use DTs in negotiation and purchasing of items [P_{value}=0.000, $F_{statistics}$=46.45]; DTs are employed in items inspection [P_{value}=0.000, $F_{statistics}$=23.21]; The records are stored in digital form for easy access [P_{value}=0.000; $F_{statistics}$=58.16]; Digital software used to track changes in inventory [P_{value}=0.000; $F_{statistics}$=41.08]; DTs are employed to optimize procurement process to minimize cost [P_{value}=0.000; $F_{statistics}$=69.33].. In regard to the manufacturing SMEs implementation of DTs for sustainable production, the P_{value}, and $F_{statistics}$ for the variables were as follows: DTs are employed to optimize the material utilization [P_{value}=0.000; $F_{statistics}$=70.32]; DTs are used in recycling and reusing to reduce production waste [P_{value}=0.000; $F_{statistics}$=66.12]; DTs are employed to minimize lead times for productivity improvement [P_{value}=0.000; $F_{statistics}$=68.90]; DTs are used in sharing data and information [P_{value}=0.000; $F_{statistics}$=74.72].The P_{value} and $F_{statistics}$ for the variables that measure implementation of digital technologies by manufacturing SMEs for sustainable distribution were presented as follows: The firm use DTs in sourcing and communication with potential customers [P_{value}=0.000; $F_{statistics}$=76.25]; DTs are used in receiving orders and keeping sales records [P_{value}=0.000; $F_{statistics}$=85.52]; DTs are used in tracking distribution of goods [P_{value}=0.000; $F_{statistics}$=111.59]; DTs are used to minimize inventory and distribution costs [P_{value}=0.000; $F_{statistics}$=90.34].

4.1.4. Drivers for implementation of DTs by manufacturing SMEs for SSC

The SEM results (Figure 4) of the drivers for implementation of DTs for SSC, revealed a strong correlation of all variables within the constructs, as well as many variables between constructs showed positive correlation whereas few variables had negative correlation (i.e., ORGANIZATIONAL(ORG), FINANCIAL(FIN), ENVIRONMENTAL (ENV), EXTERNAL (EXT), and TECHNOLOGICAL (TECH)). The SEM results showed strong correlation of the variables within the organizational factors i.e., top management commitment (= 1) and Organizational culture and policy (= 0.78). Financial factors revealed strong correlation of the variables within the construct including DTs running cost (= 1) and return on investment issues (= 0.53). All variables within the environmental construct showed a very strong correlation whereby waste reduction (= 1), emission reduction (= 0.98), and cleaner production (= 0.86). The external factors also revealed a strong correlation of the three variables within the constructs as legal and regulatory framework (= 1), government technology invention policy (= 0.33), and market competition (= 0.33). Also, all variables that measure correlation within the technological drivers were found to be strong such that infrastructural facilities (= 1) as well as technological capabilities (=0.38).

While some constructs were positively correlated and some were negatively correlated like Organizational and Financial λ =0.0015), Financial and Environmental λ =-0.03), Environmental and External (λ =0.039), External and Technological (λ =-0.98), Financial and Technological (λ =0.11), as well as Organizational and Technological (λ =0.017), the SEM model findings indicated that the variables within the constructs are strongly correlated, and positive weak correlation between constructs as well as negative correlation to some constructs, which is an indication of the factors driving manufacturing SMEs implementation of DTs for SSC in Tanzania that call for a need to carry out a SEM model fitting examination.

Table 4: ANOVA test results

Measure Variable		Sum of Squares	df	Mean Square	F	Sig.
Procurement						
The firm use DTs in sourcing, evaluation, and communicating with potential suppliers	Between Groups	135.6	3	45.2	159	0
	Within Groups	28.094	99	0.284		
	Total	163.69	102			
The firm use DTs in negotiation and purchasing of items	Between Groups	69.86	3	23.29	46.4	0
	Within Groups	49.635	99	0.501		
	Total	119.5	102			
DTs are employed in items inspection	Between Groups	42.084	3	14.03	23.2	0
	Within Groups	59.839	99	0.604		
	Total	101.92	102			
The records are stored in digital form for easy access.	Between Groups	94.099	3	31.37	58.2	0
	Within Groups	53.396	99	0.539		
	Total	147.5	102			
Digital software used to track changes in inventory.	Between Groups	68.352	3	22.78	41.1	0
	Within Groups	54.91	99	0.555		
	Total	123.26	102			
DTs are employed to optimize procurement process to minimize cost.	Between Groups	104.93	3	34.98	69.3	0
	Within Groups	49.947	99	0.505		
	Total	154.87	102			
Production						
DTs are employed to optimize the material utilization.	Between Groups	105.78	3	35.26	70.3	0
	Within Groups	49.638	99	0.501		
	Total	155.42	102			
DTs are used in recycling and reusing to reduce production waste.	Between Groups	123.44	3	41.15	66.1	0
	Within Groups	61.606	99	0.622		
	Total	185.05	102			
DTs are employed to minimize lead times for productivity improvement.	Between Groups	114.64	3	38.21	68.9	0
	Within Groups	54.912	99	0.555		
	Total	169.55	102			
DTs are used in sharing data and information.	Between Groups	135.58	3	45.19	74.7	0
	Within Groups	59.876	99	0.605		
	Total	195.46	102			
Distribution						
The firm use DTs in sourcing and communicating with potential customers.	Between Groups	126.56	3	42.19	76.2	0
	Within Groups	54.776	99	0.553		
	Total	181.34	102			
DTs are used in receiving orders and keeping sales records.	Between Groups	145.18	3	48.39	85.5	0
	Within Groups	56.022	99	0.566		
	Total	201.2	102			
DTs are used in tracking distribution of goods.	Between Groups	145.74	3	48.58	112	0
	Within Groups	43.099	99	0.435		
	Total	188.84	102			
DTs are used to minimize inventory and distribution costs.	Between Groups	148.54	3	49.51	90.4	0
	Within Groups	54.234	99	0.548		
	Total	202.78	102			

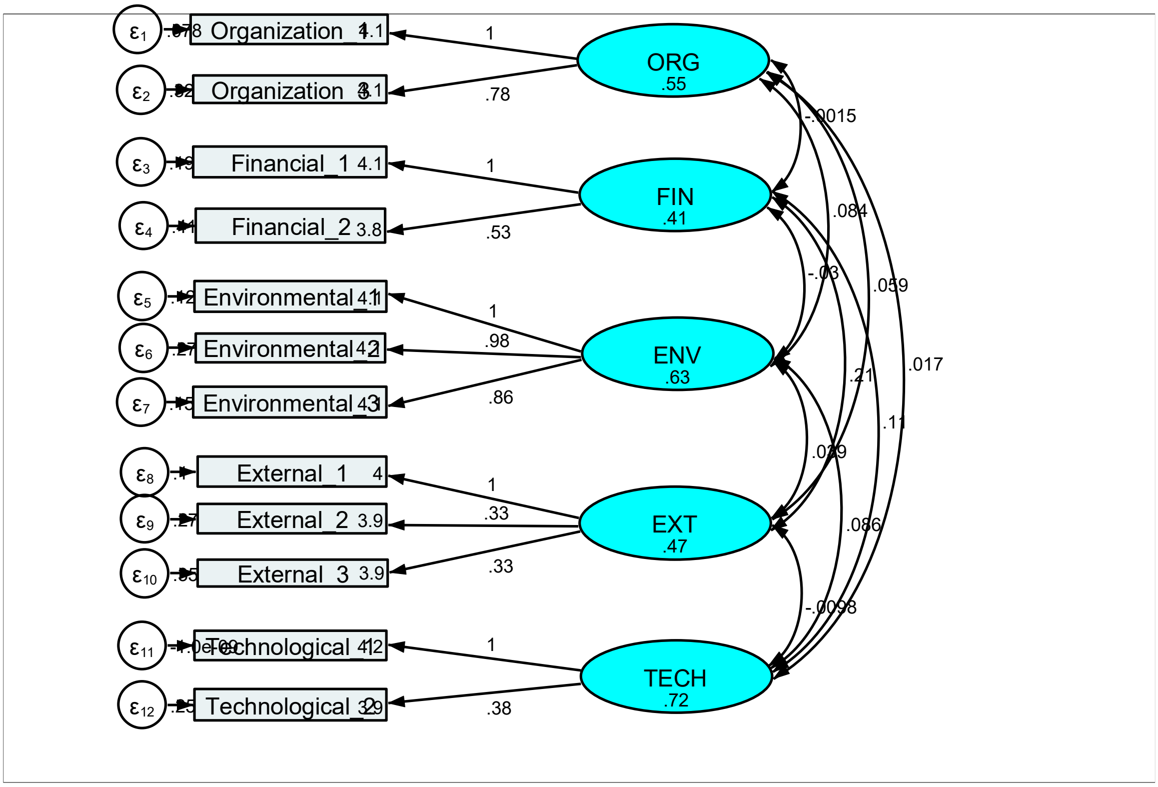

Figure 4: SEM model of the drivers for manufacturing SMEs use of DTs for SSC

Table 5: SEM model fitting results

Fit statistic	Value	Description
Likelihood ratio		
chi2_ms(.)	.	model vs. saturated
p > chi2	.	
chi2_bs (66)	1020.3	baseline vs. saturated
p > chi2	0	
Population error		
RMSEA	.	Root mean squared error of approximation
90% CI, lower bound	0	
upper bound	.	
pclose	.	Probability RMSEA <= 0.05
Information criteria		
AIC	2491.69	Akaike's information criterion
BIC	2581.27	Bayesian information criterion
Baseline comparison		
CFI	1	Comparative fit index
TLI	.	Tucker-Lewis's index
Size of residuals		
SRMR	0.298	Standardized root mean squared residual
CD	1	Coefficient of determination

4.1.4.1. Fitting the CFA model

The Model fit of Sahoo (2019); Shi, Lee and Maydeu-Olivares (2019) was assessed using commonly reported SEM goodness-of-fit statistics, including CFI, TLI, RMSEA and SRMR, which should be interpreted jointly rather than in isolation (Shi, Lee and Maydeu-Olivares, 2019; Sahoo, 2019). In the current analysis, some global fit statistics are not fully informative because the model is close to being just-identified in the software output (hence missing values for certain chi-square/RMSEA/TLI entries), and the SRMR value suggests non-trivial residuals. Therefore, the CFA evidence is interpreted primarily through the statistical significance and magnitude of factor loadings (Table 6), supported by the theoretical consistency of the measurement model, rather than relying on a single fit index.

4.1.4.2. CFA model estimation and interpretation

Table 6 revealed that there are 5 observations with missing values excluded in the model because the default estimation method i.e., maximum likelihood uses list wise deletion whereby all observations which do not have response value for all variables are dropped because the model interest of the researcher lies in the composite scale score (Chen, Savalei and Rhemtulla, 2020). All observed factors from Organizational (ORG) to Technological (TECH) in the model are all endogenous variables i.e., these measurement variables depend on the latent variables i.e., the top management commitment (Organizational_1), digital technologies running cost (Financial_1), waste reduction (Environmental_1), legal and regulatory framework (Extenal_1), and infrastructural facilities (Technological_1) that were all fixed at 1.0. The maximum likelihood estimator maximizes the log-likelihood function whereby with the list wise deletion method, only 50 observations were available with no missing values. The results explain the “Measurement” and a “Variance”. Usually, the measurement provides estimates of unstandardized measurement coefficients particularly factor loadings, standard errors, as well as the z-test for each estimate along loadings. To identify the variance of the latent variables, the software fixes the loading of the first indicator at 1.0, which is named a reference indicator such that all unstandardized estimates will change only if there is a change in the reference indicator.

Table 6: CFA Model estimation and interpretation

Structural Estimations	**Number of observations = 103**					
		OIM				
	Coef.	Std. Err.	z	P>z	[95% Conf.	Interval]
Measurement						
Organization_1 <-						
ORG	1	(constrained)				
_cons	4.145631	0.077844	53.26	0	3.99306	4.298203
Organization_3 <-						
ORG	0.7785971	.	.	.	.	.
_cons	4.097087	0.0796148	51.46	0	3.941045	4.253129
Financial_1 <-						
FIN	1	(constrained)				
_cons	4.087379	0.0763919	53.51	0	3.937653	4.237104
Financial_2 <-						
FIN	0.5316521	0.1363185	3.9	0	0.2644727	0.7988314
_cons	3.796117	0.0716933	52.95	0	3.6556	3.936633
Environmental_1 <-						
ENV	1	(constrained)				
_cons	4.116505	0.0852193	48.3	0	3.949478	4.283532
Environmental_2 <-						
ENV	0.9808453	0.0834227	11.76	0	0.8173398	1.144351
_cons	4.058252	0.0921446	44.04	0	3.877652	4.238853
Environmental_3 <-						
ENV	0.8645369	0.0667817	12.95	0	0.7336473	0.9954265
_cons	4.087379	0.0779064	52.47	0	3.934685	4.240072
External_1 <-						
EXT	1	(constrained)				
_cons	4.038835	0.0745642	54.17	0	3.892692	4.184978
External_2 <-						
EXT	0.334915	0.1038556	3.22	0.001	0.1313618	0.5384681
_cons	3.902913	0.0560632	69.62	0	3.793031	4.012795
External_3 <-						
EXT	0.3252122	0.1221621	2.66	0.008	0.0857789	0.5646456
_cons	3.854369	0.0623136	61.85	0	3.732237	3.976501
Technological_1 <-						
TECH	1	(constrained)				
_cons	4.174757	0.0835446	49.97	0	4.011013	4.338502
Technological_2 <-						
TECH	0.3817659	0.0578412	6.6	0	0.2683992	0.4951326
_cons	3.932039	0.0590856	66.55	0	3.816233	4.047845

4.2. Validation of Results

In this part of the study, the drivers for the adoption of DTs were further validated with the help of experts of the surveyed manufacturing industries like engineers, production and operations managers as well as procurement and distribution officers. Interviews with different experts were used to validate the research findings. In regard to this, the interviewed experts said that, "*……following their vast experience in the manufacturing sector, usually nature of manufacturing enterprise i.e., type of manufacturing activities are the main driver for the use of DTs by a manufacturing SME, in which majority textile and footwear industries have not undergone digital transformation due to the nature of their production processes*". This was also evidenced by the fact that analysis of the surveyed manufacturing SMEs showed high levels of digital transformation in the beverage, and cement industries compared to others. These results align with studies conducted by Chituc (2022); Pal and Jayarathne (2022) which revealed that in textile and foot wares sectors, there are technological gaps which hinder the replacement of complex manual processes like sampling and manufacturing of clothes and foot wares with high heterogeneity and customization. Also, due to safety issues the digitization and automation are found to be essential in beverage and cement industries (Chatterjee *et al.,* 2022; Hollender *et al.,* 2018). Overall, this phase helped to further validate and refine the identified drivers and provided a deeper understanding of the relationships among them.

5. Discussion and Implications of the findings

5.1 Discussion of the findings

The findings of this study hold substantial significance in the context of the manufacturing organizations specifically SMEs in Tanzania. As DTs have transformed manufacturing, the adoption of its practices can revolutionize the industry's operations. However, understanding the drivers to DTs adoption and their implications is essential for fostering this transformative change. This study provides the light on the elements obstructing DT implementation and analyzes their impact on the industry's journey towards SSC. Regarding the profile of the explored manufacturing SMEs, this study was conducted across the majority classes of the manufacturing industries in the exploration of the factors for digital transformation by manufacturing SMEs and about 81% of the enterprises met the study's focus of being manufacturing SMEs. In addition, the study involved enterprises with a vast experience in operation and thus adequate knowledge/history about digital transformation of industrial operations.

Interpreting these findings through the lenses of the Innovation Diffusion Theory suggests that adoption decisions are strongly shaped by SMEs' perceptions of complexity, relative advantage and the ability to trial and observe benefits (Rogers, 2003). Where leadership commitment, skills and process readiness are stronger, SMEs can convert DT tools into observable SSC outcomes (e.g., improved coordination, reduced waste and better traceability), which reinforces diffusion through demonstration effects. Conversely, in settings where connectivity and support services are weaker, perceived complexity increases and trialability decreases, slowing diffusion even when the underlying technologies are available. Although the current dataset does not support a fully stratified comparison of regional effects, the inclusion of both coastal (Dar es Salaam/Pwani) and inland (Morogoro) contexts implies that place-based infrastructure and logistics access likely moderate DT diffusion. I recommend that future studies should use region-stratified designs and multilevel/spatial modelling to quantify such heterogeneity.

Concerning the extent of digital transformation by manufacturing SMEs for SSC, the findings revealed the implementation is rather low since its implementation is at 40.6%, which is below an average of 50%. This might have resulted from the high investment cost of DTs that might have influenced significantly the manufacturing SMEs decision to implement DTs as explained by majority SMEs use of the internet of things, and cloud computing technologies for SSC. Considering the social-economic, and environmental benefits of digital transformation by manufacturing SMEs, it is the right time for the government to intervene, and promote implementation of DTs (preferable through Public Private Partnerships or introduction of policies that requires digital transformation) since the majority manufacturing SMEs belongs to the private sector. The ANOVA results indicate that there is significant implementation of DTs for the sustainable procurement since all $P_{values} < 0.005$. Interview results indicated that, in Tanzania, the procurement policy which requires use of e procurement especially public tender advertisement by then through Tanzania e-Procurement System (TANePS), and now via National e-Procurement System of Tanzania (NeST), has contributed significantly to the digital transformation for the SSC. In addition, the ANOVA results revealed that there is a significant implementation of digital technologies for sustainable production since all variables have P_{value} <0.005. Despite the appreciation of implementation of DTs for SSC, the interview results gave a different result whereby to some extent, the employment policy of Tanzania was perceived to influence digital transformation because adoption of DTs in the production line such as robotics may cause unemployment to the society which is against the government policy. Furthermore, the ANOVA results revealed that there is significant implementation of DTs for sustainable distribution since all variables have P_{value} <0.005. These results fall into line with the study conducted by Junge and Straube (2020) on sustainable supply chains of manufacturing enterprises, which found that new technologies are vital for sustainable logistics and SCM in general.

With regard to drivers for implementation of DTs for SSC, the CFA results (Table 5) indicated that, all factor loadings in the five constructs (i.e., Organizational (pvalue=0.000), Financial (pvalue=0.000), Environmental (pvalue=0.000), External (pvalue=0.008) and Technological (pvalue=0.000)) are statistically significant since all pvalue < 0.050. This is construed to mean that such the indicator variables mainly Organizational (ORG), Financial (FIN), Environmental (ENV), External (EXT) and Technological (TECH) are all significantly related to their respective factors, and hence confirmed to be the main drivers for the manufacturing SMEs implementation of DTs for the SSC. The results are in-line with the study by, which explored drivers for DTs deployment by manufacturing industries such that the financial, technological, environmental, organizational and external factors were found to be the main determinant for DTs implementation. However, because the global fit indices reported by the software include missing entries and an elevated SRMR, the overall model fit should be interpreted cautiously; future work should consider additional indicators per construct, robust handling of missing data (e.g., FIML/MLMV) and alternative model specifications to further strengthen measurement validity.

The implications are threefold. Theoretically, positioning the five driver constructs within Innovation Diffusion Theory clarifies the mechanisms through which DT spreads in manufacturing SMEs and highlights the role of perceived complexity, relative advantage and diffusion channels. Practically, SME managers should prioritize capability-building (digital skills, process standardization and change management) alongside phased investments that enable low-risk trials and quick wins, thereby making benefits observable and accelerating internal buy-in. For policymakers and support institutions, the results point to targeted interventions especially affordable finance, SME-focused advisory services, and corridor/cluster-oriented infrastructure upgrades to reduce adoption friction and accelerate DT for sustainable supply chains.

6. Conclusion

This study examined the drivers of Digital Transformation (DT) among manufacturing SMEs in Tanzania in the context of Sustainable Supply Chains (SSC). Using questionnaire and interview evidence and SEM-based validation, the results show that organizational readiness and financial capability are the most influential drivers, supported by technological availability, environmental pressures and external support. Interpreted through Innovation Diffusion Theory, these drivers operate by shaping perceived relative advantage, compatibility, complexity, trialability and observability of DT-enabled SSC practices (Rogers, 2003).

Although the sample covered Dar es Salaam, Pwani and Morogoro, the study did not estimate region-specific effects. Nonetheless, the findings imply that corridor/cluster connectivity and infrastructure conditions (connectivity, logistics access and reliability of services) are likely to moderate DT diffusion and for that matter should be explicitly tested in future work. In terms of actionable recommendations embedded in these conclusions, the DT acceleration requires (i) capacity-building and change management for SME staff, (ii) affordable finance and phased investment models that enable piloting, and (iii) targeted upgrades to digital infrastructure and power reliability in the manufacturing clusters and along major corridors, complemented by advisory programs and partnerships that make successful DT outcomes visible and replicable.

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