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# Performance Impact of Digitalization in the Food Supply Chain: Evidence from the Food Processing Complex in Ethiopia

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**Abstract**

*Background*: Although digitalization is recognized to improve the food supply chain, its effect pathways have not been thoroughly researched, especially in the context of developing countries. This study examines the association of three digitalization practices: digital internal practice (DIP), digital integration with suppliers (DIS), and digital integration with customers (DIC) with nine supply chain performance metrics: efficiency, flexibility, food safety/quality, reliability, traceability, food loss, and sustainability, mediated by operational efficiency, trust, and transparency, using food processing company case in Ethiopia. *Methods*: Using an explanatory approach, data from 153 respondents were analyzed through mediation-based structural equation modeling (SEM) in JASP (v.0.95.4.0). The analysis involved 27 direct and 81 indirect effect paths. *Results*: The results demonstrated a fundamental comprehension that while digital practices manifest direct positive (improvement) effects, a purely direct-impact assessment is insufficient. Statistically, more than half of the suggested direct paths were not significant. The total effects, on the other hand, were significant for all 27 paths tested with much stronger positive associations. *Conclusions*: The mediation-based examination of the relationship of digitalization practices on food supply chain performance offers essential insight, indicating that the impact of digitalization on supply chain performance is primarily indirect, functioning through the enhanced capabilities it fosters.

**Keywords:** supply chain digital integrations; food supply chain performance; sustainability; mediation analysis; resource-based view; Ethiopia

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## 1. Introduction

Food supply chains consist of a complex system of food producers, processors, distributors, and retailers, who need to be coordinated in a seamless manner for food product quality, safety, traceability, and on-time delivery [1]. However, many food supply chains, especially in developing countries, are challenged by fragmented information flows, coordination issues among different supply chain players, and a lack of end-to-end visibility [2]. One of the ways to improve the food supply chain right now, to overcome these challenges, is to digitalize it [1,2]. Digitalization has the potential to make the process more efficient, flexible, reliable, and sustainable, and to cut down on the amount of food waste. Studies indicated that technologies like blockchain (BCT), artificial intelligence (AI), machine learning (ML), big data analytics (BDA), and geographic information systems (GIS) can

improve traceability, demand forecasting, resource management, and route optimization in agri-food supply chains [1–7].

However, empirical research on the relationship between digitalization and food supply chains, especially in developing countries like Ethiopia, is scant [2]. The current body of studies regarding the applications and paper sources is mainly focused on Global North settings, indicating a rather big empirical gap with regard to particular benefits, barriers to adoption, or overall effectiveness within distinct environments of developing countries such as Ethiopia. Additionally, much current inquiry relies upon high-level conceptual models studies that fail to offer an empirical basis that warrants rigorous testing and validation. For instance, the systematic review of the digitalization of the food system [1] noted that "more than half of the papers were of a conceptual nature or did not investigate a specific country; of the remaining case-based papers, not a single paper focused on an African country, and the majority of the studies were conducted in Europe, Asia, and the USA, while only two studies were conducted in South America and none in Africa." Further, the studies examining the performance impacts of digitalization too often focus on direct relationships while neglecting the crucial mediating roles provided by the capabilities that digitalization augments [8]. These could result in the undervaluation of the potency of digital technology to transform performance in food supply chains.

This paper fills these gaps by studying the effects of digitalization on the performance of the food chain in Ethiopia with a case study on K.O.J.J. Food Complex. K.O.J.J. Food Processing Complex, which was purposefully selected due to its relatively established nature as an older, well-known food processing firm in Ethiopia, and because it had initiated a digital integration program with its suppliers and customers, even though the program was still in its early stages. The primary aim of this study is to investigate the association of digitalization with the supply chain performances of K.O.J. J. Food Processing Complex PLC in Addis Ababa, Ethiopia. The study aimed to provide answers to the following research questions: 1. How do digitalization practices (DIP, DIS, DIC) relate to fundamental supply chain performance (efficiency, flexibility, food safety/quality, reliability, traceability, food loss) both directly and indirectly via operational efficiency, trust, and transparency? 2. How do digitalization practices (DIP, DIS, DIC) relate to sustainability performance (environmental, economic, and social) both directly and indirectly via operational efficiency, trust, and transparency?

This paper proposes to study the direct effects on nine performance measures of the food chain, efficiency, flexibility, reliability, reduced loss of food, sustainability factors, along with indirect (mediated) effects of digital internal practices (DIP), digital integration with suppliers (DIS), digital integration with customers (DIC), on these measures with three mediational factors: operational efficiency (OE), trust (Tru), and transparency (Tra). The originality of this research work is in its in-depth analysis of nine different performance measures, along with comparing direct and indirect effects. Its assessment of the food industry in a developing country (Ethiopia) adds further originality by studying a previously less-explored area in research. Hence, through providing evidence-based insights for digitalization policy and management practices related to particular sectors and economic context, the study contributes to theory development and a practical guide in making appropriate use of digitalization to make food supply chains more competitive and resilient. The rest of the paper is organized as follows. Section 2 presents the theoretical model and research hypotheses; Section 3 describes the research design; Section 4 reports the data analysis and results; Section 5 discusses the findings; finally, in Section 6, the research concludes with a summary of the major contributions of the research.

## 2. Theoretical Model and Research Hypotheses

In order to develop the theoretical and empirical base for this study, as well as identify the research gaps, the authors undertook a comprehensive review of the supply chain management and digitalization literature. The process of conducting a comprehensive review is as follows: the authors conducted a comprehensive review by searching the Scopus, Web of Science, and Google Scholar databases with keyword combinations including "digitalization," "supply chain performance," "food supply chain," "sustainability," and "developing countries." The literature research did not strictly follow the process for conducting a systematic literature review, and the main purpose was to collect a good volume of peer-reviewed literature that would be useful for the development of the conceptual framework and research hypotheses. The research gaps identified through a critical analysis of the literature are presented in Section 2.3.

### *2.1. Brief on Historical Development of SCM and Digital Applications*

Military logistics, which goes back to ancient times, is where the idea of controlling the flow of goods and services comes from [9]. Supply chain management (SCM) was the term coined by Keith Oliver in 1982, and the idea was to "bust down the internal silos" created by the organization's functions [10]. Since then, there has been a major shift in the evolution of supply chain management. The initial phase covers, primarily, the implementation of manufacturing resource planning, MRPII, as a mechanism by which to change the organization through fits with the organization's structure and culture [11].

SCM gained fame during the 1990s, as it served the purpose of linking suppliers and customers externally to the company. The use of electronic data interchange (EDI) and web-based systems (Table 1, Mid-1990s–2000s) enabled the significant expansion of the concept of SCM to extend beyond the four walls of a company. It enabled fundamental business-to-business (B2B) connectivity. Today, a supply chain is viewed as consisting of a set of businesses interlinked, working together for product creation and distribution. Today, supply chain management uses mathematical modeling and various decision theories to improve decision-making across the entire chain, from material sourcing to the end customer. Technological and relational advancements in the supply chain will be realized through greater collaboration between individuals within the domain of control theory and individuals within the management of supply chains [12]. The digital functions are fundamental for implementing theoretical models in today's supply chains.

Recently, the attention has shifted to SCM 4.0, which consists of Logistics 4.0 as its key constituent. This involves a totally integrated and autonomous ecosystem of physical processes and digital data made feasible by the connectivity of cyber–physical systems [13]. Digitalization is not only an enabler; it is the key constituent of Supply Chain 4.0 [14]. The authors assert that the supply chain is transformed from a linear and physically controlled process to a dynamic and self-optimal network with physical processes controlled by digital intelligence. The supply chain management has shifted its focus from cost reduction to value-oriented and agile networks because of the innovative integration of different technologies such as big data, robotics, and the Internet of Things.

Despite these, there are significant business challenges and obstacles in adopting such state-of-the-art technology such as artificial intelligence/machine learning (AI/ML), Internet of Things (IoT), cloud computing (CU), and blockchain technology (BCT) (as identified in Table 1, 2010s–Present era) and understanding such challenges and obstacles is equally important [15,16]. The failure rate and slow rate of adoption of such technology make such an environment even worse. It has been seen that the reason for such slow adoption and improper implementation of digital supply chain management is mainly due to a set of key interrelated barriers, such as a lack of digital skills and industry-specific guidelines,

and costs [17,18]. This highlights the importance of understanding such factors that influence the failure of aligning supply chain management goals and business strategy due to external and internal uncertainties, complexities of managing activities, and a lack of standard frameworks and measures for such integration. Meanwhile, there exists an emphasis from organizations' customers regarding better services, better quality, and better prices; therefore, such integration has become more important than before. Table 1 provides a brief chronology of changes and the adoption of digitalization in supply chain management compiled from various authors for a better understanding of the dynamics of SCM. As can be seen from Table 1, the technology and process evolve from "Internal control" through "External integration" and then to AI-driven resilience and sustainability.

**Table 1.** Summary of the historical development of SCM and applications of digitalization.

| SCM Era (Approximate) | Terminology Core Focus | Major SC Challenge | Digital/Tech Evolution in That Era | Key Digital Application & Benefit | Few References |
|---|---|---|---|---|---|
| 1950s–1970s | Logistics & Physical Distribution<br>✓Inventory Control.<br>✓Cost reduction through internal efficiency. | Fragmented data; Inaccurate, static inventory counts; High paperwork burden. | Early Computing & Mainframe Systems. Development of basic inventory and accounting software. | MRP (Material Requirements Planning). Digital planning of raw material needs based on production schedules. | [19,20] |
| 1980s–Early 1990s | Materials Mgmt<br>MRP II.<br>✓Internal Integration (MRP II).<br>✓Coordinating major internal functions.<br>The term Supply Chain Management (SCM) was coined (1982) | Functional silos (e.g., manufacturing did not share data easily with finance); Inefficient resource utilization. | ERP (Enterprise Resource Planning) Systems. Large-scale software suite integrating internal data. | Seamless Internal Data Flow. Unified planning allows companies to see a holistic, digital view of the entire organization's resources. | [21–23] |
| Mid-1990s–2000s | Supply Chain Management (SCM) Adoption.<br>✓External Integration.<br>✓Extending efficiency to suppliers and customers. | Slow, manual communication with external partners; Lack of visibility beyond the company's four walls. | The Internet & VMI/E-Procurement. Commercialization of the web; Development of standardized communication protocols, Electronic Data Interchange (EDI). | B2B Connectivity. Enabled Vendor Managed Inventory (VMI) and e-commerce platforms for procurement, automating replenishment. | [24–27] |
| 2010s–Present | SCM 4.0.<br>✓Resilience.<br>✓Sustainability.<br>✓Managing volatile, complex global networks. | High risk of global disruption; Need for real-time tracking; Demand for hyper-customized products and rapid delivery. | AI/ML, IoT, Cloud Computing, & Blockchain. Maturation of real-time data and advanced analytics. | Real-time, Predictive SCM. Enabled end-to-end visibility via IoT, predictive analytics (AI for forecasting), and immutable trust (Blockchain for traceability). | [28–30] |

This historical review elucidates the transformative objectives and technological elements of digitalization, while also pinpointing substantial adoption obstacles. However, the literature regarding the causal mechanisms by which digital capabilities affect operational and strategic performance is comparatively less explored, particularly with regard to developing economies. There is a need to move beyond descriptive accounts of technology and barriers to empirically model and measure the direct and mediated effects of digitalization on key performance indicators. This study aims to address this gap by analyzing these direct and mediated relationships to provide an understanding of how digitalization generates major supply chain performance outcomes. The major supply chain performance metrics used in this study are briefly discussed in the following section.

### 2.2. Supply Chain Performance Indicators

Performance indicators of supply chain management need to be theoretically justified, as they translate strategic objectives into measurable terms and provide the foundation for evaluating supply chain effectiveness [31]. In the supply chain management literature, a number of theories are discussed, each with a specific focus on different aspects of performance indicators. For example, the lean supply chain perspective has been discussed with a central focus on cost efficiency, resource utilization, and waste reduction as core elements of the strategy [32]. On the other hand, agile supply chain perspectives have been discussed with a major focus on performance indicators such as flexibility, speed, and responsiveness to clients in the ever-changing market environment [33]. Due to increasing disruptions in the contemporary supply chains with diverse issues (e.g., pandemics like COVID-19), the resilient supply chain perspective has become another important strategy with performance indicators such as reliability, robustness, and recovery gaining significant attention [34]. Recently, sustainable and circular supply chain management has become a central focus of discussion both in academia and practice, with performance indicators such as environmental stewardship (including emissions reduction and energy efficiency), social responsibility (including ethical sourcing and worker safety), and economic viability [35]. There are other performance indicators, such as traceability and food quality and safety, which are crosscutting across different supply chain strategic perspectives, especially with agri-food supply chains [36].

In reality, supply chain strategic viewpoints are not mutually exclusive. For example, organizations that follow a lean supply chain perspective never completely abandon agility and other strategic priorities; they must balance agility, robustness, and sustainability in response to their competitive environment. Similarly, organizations with a focus on agile strategies never completely drop lean and other elements of supply chain performance indicators.

Therefore, this study adopts a multi-theoretical approach to the selection of supply chain performance indicators. The nine supply chain performance indicators selected for this research have been deliberately chosen from across these perspectives to assess the association of digital practices with supply chain performance indicators in a relatively holistic approach. Specifically, efficiency and food loss reduction have been primarily derived from the lean and sustainable/circular viewpoints. Similarly, flexibility has been derived from the agile viewpoint. While reliability and traceability have been derived from the resilient and sustainable/circular viewpoints, food safety and quality have been derived from all viewpoints as they are cross-cutting for supply chain performance, and the three dimensions of sustainability have been derived from the sustainable supply chain management viewpoints. In the following subsections, we describe each selected performance indicator in detail.

#### 2.2.1. Efficiency in Food Supply Chain Performance

Efficiency in food supply chains involves optimizing processes to minimize costs, time, and waste while maximizing resource utilization for the whole supply chain. Supply chain efficiency is one of the performance parameters in evaluating food supply chains [37–39]. Note that supply chain efficiency is distinct from a firm's operational efficiency. Supply chain efficiency is a core objective of supply chain management. It is achieved when all activities, operations, and processes—from source to consumer—reduce waste by cutting down on overproduction, getting rid of old stock, speeding up movement, and getting rid of delays [37]. Operational efficiency, on the other hand, looks at how well a specific organization is doing and how well it uses its resources and processes. Although different, these two types of efficiency should work well together in theory. This

study examines the impact of digitalization on supply chain efficiency, considering operational efficiency as a mediating variable. This methodology is predicated on existing literature that recognizes digitalization as a principal catalyst for enhancing supply chain efficiency [40–42].

#### 2.2.2. Flexibility in Food Supply Chain Performance

Flexibility refers to the ability of supply chains to adapt to changes in demand, disruptions, or varying customer preferences. Similar to efficiency, supply chain flexibility is a critical performance indicator for food supply chains. Many studies have argued that digitalization of the supply chains has a positive impact on enhancing supply chain flexibility for agri-food supply chains [1,43,44].

#### 2.2.3. Food Safety and Quality Performance in the Food Supply Chain

Ensuring food quality and safety is critical for maintaining consumer health, trust, and complying with regulations. Maintaining food safety and quality is a prime responsibility of modern supply chain managers, as failure to do so has both economic and legal consequences. Leveraging digital technology applications to achieve food safety and quality targets is another area of discussion, both in academia and practice alike [45–48].

#### 2.2.4. Reliability in Food Supply Chain Performance

Reliability refers to the consistent and timely delivery of products and services in the supply chain. Managing the reliability of supply chains is a challenging task, and failing to do so has a devastating impact on the supply chain's economic and resilience parameters. Managing supply chain reliability involves integrating reliability theory, operations research, and risk management into a unified mathematical model and assessing reliability dynamically with distributions suited to renewable systems [49]. Similar to other performance parameters, digital practices have the potential to leverage power to improve supply chain resilience and reliability [50,51].

#### 2.2.5. Tracking and Traceability in Food Supply Chain Performance

Tracking and traceability are important parts of modern supply chains, and they have a big effect on other parts of supply chain performance. For instance, this function helps with food safety and quality control, and it makes supply chains more reliable and flexible by letting goods and information flow freely. There is no substantial contention regarding the significance of digitalization in augmenting the tracking and traceability functions of supply chains. The sole inquiry pertains to the methods and types of digital practices that are most effective and efficient in enhancing supply chain tracking and traceability [1,52–54].

#### 2.2.6. Food Loss as an Aspect of Food Supply Chain Performance

Food loss severely undermines supply chain performance by reducing product availability and escalating costs. Research indicates that around 30% of food worldwide is lost prior to reaching consumers, with developing nations experiencing particularly significant losses during the production and transportation stages [55]. Food loss reduction is not often seen as a separate performance metric in mainstream supply chain literature, even though it has a big impact. It should, however, be officially recognized as a key performance indicator, and all participants in the food supply chain should have the goal of lowering it as a central goal. Research, such as ref. [56], upholds this point with conclusive evidence linking supply chain management practices and levels of lost food. Ethiopia is one of the countries with serious problems of food loss in terms of post-harvest losses due to poor storage, transport logistics practices, and climate fluc-

tuations [56–58]. To combat food loss, specific measures should be taken related to food tracking and logistics to fortify and enhance supply chain management practices; in this process, digitalization has a key role.

#### 2.2.7. Sustainability in Food Supply Chain Performance

Sustainability, drawing on the threefold basis of the bottom line, is now established as a major concept in contemporary supply chain management. Evidence for this is the increasing adoption and usage of management practices such as the sustainable supply chain management (SSCM), green supply chain management (GSCM), and circular supply chain management (CSCM), among many others, that have now taken their rightful place within it. The aim is to integrate the sustainability concept within the basic supply management processes of firms, so that the business can be sustainable in the long term and ethical value can be created. Empirical research has proved that its adoption has been augmenting its performance; for example, the study by ref. [59] provided that the initiation of green strategies can add to its environmental as well as economic outcomes. However, its adoption is yet to see the end of various structural concerns, like the lack of coordination, start-up costs, and lack of infrastructure.

The trend of digitalization is being increasingly acknowledged as one of the most important means of moving past all these and implementing sustainability agendas. The use of technologies such as the Internet of Things (IoT), blockchain, and big data analysis enables promoting visibility and traceability and provides all the analytic intelligence required to reduce waste, maximize value loops, and ensure sustainability [60]. The authors argue that digital competencies represent one of the key starting conditions to implement circular economy thinking in supply chain management practices. In the same way, ref. [61] assert that artificial intelligence and Internet of Things technologies play important roles in making supply chain operations and practices environmentally sustainable.

Table 2 summarizes key findings from the literature on the impact of digitalization on performance metrics of the food supply chains (FSC). It covers key performance indicators for the FSC, such as efficiency, flexibility, reliability, food safety and quality, reduced losses, tracking, tracing, and sustainable performance.

**Table 2.** Effect of digitalization on different aspects of food supply chain performance parameters.

| Food Supply Chain Performance Indicators | Key Remarks | A Few Exemplary References |
|---|---|---|
| Efficiency | Digitalization enhances resource utilization, reducing waste and operational costs. | [4,62] |
| Flexibility | Real-time data sharing allows for quicker adaptation to market changes. | [3,63] |
| Food Quality and Safety | Digital tools ensure better monitoring and compliance with safety standards. | [64,65] |
| Food Loss Reduction | Technologies such as IoT and AI optimize inventory management, minimizing waste. | [66,67] |
| Reliability | Improved traceability and transparency foster trust and dependability in supply chains. | [3,66] |
| Tracking and Traceability | Blockchain and digital tracking enhance the ability to trace products from farm to table. | [66,67] |
| Sustainability | Digitalization promotes sustainable practices through better resource management, reduced environmental impact, and achieving better societal and ethical concerns. | [68–72] |

To sum up, from this review of the literature, it is possible to identify three major observations. First, it is evident that the majority of the existing literature is concerned with developed nations, leaving a considerable void with regard to digitalization and its value creation potential in developing nations like Ethiopia. Second, it is evident that the majority of the existing literature has been concerned with exploring direct relationships of digitalization with performance, with minimal consideration of the underlying indirect (mediation) mechanisms that may be important. Finally, the existing literature has been predominantly concerned with exploring limited aspects of performance, with minimal consideration of the comprehensive range of outcomes that are now possible with regard to food supply chains. In the following section (Section 2.3), these observations are further elaborated and formally articulated as the research gaps that this study aims to address.

### *2.3. Problem Statement and Research Gap*

The potential digitalization for supply chains' transformations is quite discussed in the existing literature; however, this understanding has largely emerged from and been established in the context of developed countries. The models of success and evidence of related technologies like blockchain and artificial intelligence take certain conditions of infrastructure and integration as given. Such conditions are often not met and examined in developing countries. Studies on applications and effects of digital practices in real-life situations in food supply chains in developing countries like Ethiopia are rare. These food supply chains are mostly inefficient, inflexible, non-dependable, and have difficulties in tracing and high post-harvest losses. Overall, there are three major issues with the current state of the literature that this paper seeks to address.

The first issue is that there is a lack of context-specific studies. Most studies on digitalizing supply chains are from developed regions and focus more on manufacturing companies' supply chains. This creates a substantive gap with respect to our comprehension of digital practices as they pertain to different business environments, such as that of Ethiopia. The current study helps to fill this particular gap as it is pertinent to a less-explored food sector of a developing country, Ethiopia.

Second, there is a gap in the methodological focus used in most previous assessments. Most previous assessments rely on a conceptual framework and have not been rigorously proven through empirical evidence from diverse sectors. Additionally, they mostly concentrate on studying the direct impacts of digitalization and do not examine the fundamental mediators used in digital practices to alter supply chain performance results.

Third, there is a gap regarding comprehensiveness. Most previous research has commonly included a narrow range of performance outcomes related to the supply chain. To our knowledge, there is no previous research that evaluated the impact of digitalization on a comprehensive list of supply chain performance metrics with sustainability indicators included. This study attempted to fill this gap by analyzing the impact of digital practices on nine core and sustainability performance indicators related to food systems, including efficiency, flexibility, reliability, food quality and safety, reduction in food loss, food traceability, and triple bottom-line sustainability outcomes.

Overall, the current study aims to bridge such gaps by conducting context-oriented, empirical research for understanding the direct and mediated relationships between digitalization and wider supply chain outcomes, extending beyond direct effects. It aims to investigate how digital food supply chain practices are influencing the core and sustainability outcomes of food supply chains, either directly and indirectly, through the mediation of operational efficiency, trust, and transparency.

By doing so, the research provides new insights into the digitalization of the food system process and the possible channels through which value is created. It shifts the empha-

sis away from viewing the connection between technology and performance and instead highlights the need to examine in depth the processes involved in capability development.

### *2.4. Conceptual Framework and Hypotheses*

Figure 1 shows the conceptual framework that this study is based on. It provides the details of the relationships that exist between the digitalization of the supply chain and the performance outcomes within the context of the K.O.J.J. Food Complex PLC.

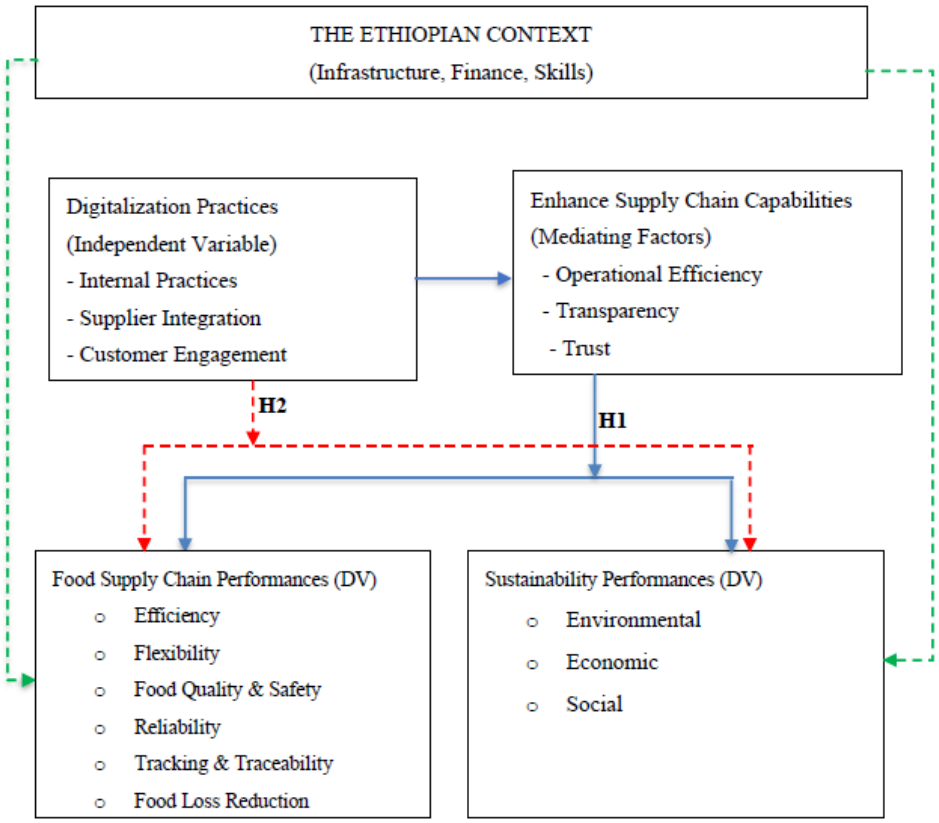


**Figure 1.** Conceptual framework of the study.

The framework proposes three types of digitalization practices, identified as the independent variable, namely digital internal practices (DIP), digital integration with suppliers (DIS), and digital integration with customers (DIC). The essential hypothesis that underpins this study states that there is an improvement in supply chain performance through the initial creation of supply chain capabilities, which are defined by three key mediators, namely, operational efficiency (OE), transparency (Tra), and trust (Tru). These improved abilities are then the main way that digital practices affect performance outcomes. The study presents this argument by making a comparative analysis of direct and indirect path analysis, which resulted in the development of two testable hypotheses:

**H1.** *Digitalization Practices (DIP, DIS, DIC) positively influence Core Supply Chain Performance and Sustainability Performance outcomes through the mediating effect of Enhanced Supply Chain Capabilities (OE, Tra, Tru).*

**H2.** *Digitalization Practices (DIP, DIS, DIC) have a direct positive impact on Core Supply Chain Performance and Sustainability Performance.*

In Figure 1, the blue solid line shows H1 or the mediated path, and the red dashed line shows H2 or the direct path. Additionally, the entire process occurs within the Ethiopian

context, where external factors such as digital infrastructure, access to finance, and technical skills (indicated by the green dashed lines) may affect the relationships. The examination of these particular contextual factors is out of the scope of this study and is recognized as a significant avenue for future research.

### 2.5. Theoretical Logic of the Framework and Hypotheses

The conceptual framework of the study is based on a blend of three interrelated theories: the resource-based view theory, the dynamic capabilities theory, and the sociotechnical systems theory. Taken altogether, these theories provide a strong foundation on which to generalize that supply chain performance is mainly enabled by digitalization through the development of critical organizational enablers like operational efficiency, transparency, and trust.

The resource-based view (RBV) asserts that enduring competitive advantage originates from valuable, scarce, and inimitable resources and capabilities [73]. In this case, digital technologies are at first resources. However, the RBV says that it is not the technologies themselves that give a company an edge; it is the capabilities the company develops with them. This study posits that, according to this theory, digitalization serves as a resource that enables firms to develop higher-order capabilities, specifically operational efficiency through the optimization of internal processes, and transparency and trust through the facilitation of information sharing through digital integrations with suppliers and customers.

The dynamic capabilities theory builds on the RBV by looking at how well a company can combine, build, and change its own and other people's skills to deal with environments that are changing quickly [74]. Digitalization is a common dynamic capability because it gives you the tools you need to notice changes in the market, take advantage of them, and change how you do business. According to this theory, digitalization allows a company to build "Trust" with partners in a dynamic way through reliable, data-driven interactions. It also enhances operational efficiency, which enables the firm to alter its processes in an efficient manner.

Lastly, the sociotechnical systems theory says that the best performance comes from optimizing both the social and technical parts of an organization [75]. In regard to this specific case, it means that the technical system (the digitalization) must be applied to assist and support the social system throughout the supply chain. This theory supports and justifies that the overall key mediators of this framework: digital tools—technical—make things more transparent; and by applying it consistently and consistently building trust—social—good collaboration leads to good performance throughout the chain. The essence of these theories shows that there is a more complex relationship between digitalization and supply chain performance. These theories combined set the basis for a core argument of this study, which states that there is a significant proportion of influence from digital practices that affects supply chain performances mediated through indirect channels. In other words, digitalization builds the premises that allow it to work and influence other factors such as operational efficiency, transparency, and trust. Then, the enabling factors become the real drivers of both core and sustainability supply chain performance outcomes.

## 3. Research Design

### 3.1. Data Source and Sampling Techniques

The research used primary data. The sample size of the respondents from the focal company and its external stakeholders (suppliers and customers) was determined by a multi-stage sampling.

For the focal company, K.O.J.J. Food Processing Complex PLC, sampling was conducted in two stages. First, we selected all important functional units with direct operational interfaces for digitalization.

These are procurement, inbound logistics, quality assurance, sales, distribution, outbound logistics, IT, and production planning and control. Then, within each of these selected units, a simple random sampling that was proportionate to the size of each unit was used. That is the number of staff selected at random from a unit that had to agree with the unit's total staff size compared to the total population of the units being targeted. This procedure ensured that the sample included important operational perspectives where digital tools are being applied. Random selection within units also aimed to reduce selection bias. Yamane's formula, as noted in Equation (1) [76], was used to determine the total sample size for the focal company. Then, the proportional allocation was used.

$$n = \frac{N}{(1 + N(e^2))} \quad (1)$$

*where n = sample size, N = total population in the selected units (180), e = margin of error (5%), n = (180)/(1 + 180 (0.05$^2$)) = (180)/(1 + 180 (0.0025)) = (180)/(1.45) = 124.14.*

Accordingly, the sample size among the internal staff was determined to be 125 individuals.

Purposive sampling was employed in selecting participants from among the external stakeholders based on their direct involvement and expertise in K.O.J.J. Food Processing Complex PLC's digitalized supply chain processes. That is, participants from selected firms (suppliers and customers of K.O.J.J. Food Processing Complex PLC) who had relevant positions and experiences relative to research objectives were selected. Suppliers were selected based on their active incorporation of technology in their business activities, such that electronic ordering and online invoicing had been employed. This made sure that the respondents had direct, practical experience. The same goes for the choice of customers, which included distributors, wholesale buyers, and retailers. These customers were chosen only if they were actively using the company's digital ordering or distribution channels and had digital communication systems with the focal company. The focal company provided information that helped identify supplier and customer organizations.

Because the company's digital integration programs were still new, the total number of digitally engaged external stakeholders was a small group. As a result, a census method was used on all the supplier and customer organizations that were found. There were 44 external respondents chosen from the recommended contacts in these organizations: 20 from five supplier organizations (four from each) and 24 from six customer organizations (four from each). All of them met the requirements for digital engagement and agreed to take part.

This process, along with the 125 internal staff members chosen earlier, resulted in 169 questionnaires being sent out to all groups of participants. After removing 13 surveys from internal staff and three from external participants that were either not returned or were not complete, only 153 completed responses were suitable for analysis.

### 3.2. Data Collection Instruments

A structured questionnaire (Appendix E) was used to collect the primary data. It was made to measure important supply chain performance metrics and important mediating factors. The questionnaire utilized a five-point Likert scale ranging from 1 = Strongly Disagree to 5 = Strongly Agree to obtain consistent and measurable answers. Preliminary interviews and discussions with company management have been used only in guiding the research process through the identification of relevant internal and external stakeholder groups for the survey. These discussions are not used as a formal data source for analysis.

### 3.3. Description of the Constructs and Measurement

This study analyzed the constructs outlined in the questionnaire (Appendix E), classified into three independent variables, three mediating variables, and nine dependent variables.

Independent Variables (Digital Integration Constructs):

Digital Internal Practices (DIP): This measures the effectiveness of using digital tools for integrating different operations within the organization through software, data flow, and process automation.

Digital Integration with Suppliers (DIS): This measure examines digital collaboration between the key organization and its suppliers with respect to sharing plans and forecasts digitally, automating ordering, previewing how suppliers function, and using teamwork environments.

Digital Integration with Customers (DIC): This assesses the ability of the focal firm to interact with its customers on digital platforms. The variables involved here are web ordering systems, real-time order status updates, web feedback systems, and web-based payments.

Mediating Variables:

Operational Efficiency (OE): This measures how digitalization has made things more effective and productive, such as shorter processing times, lower costs, better inventory management, and more output.

Transparency (Tra): It refers to the degree to which the digital practices make information visible throughout the supply chain, which includes internal operations, supplier or customer activities, and product traceability.

Trust (Tru): This would address how reliable and trustworthy the partners and systems have been established because of digital integration. It involves measures of data accuracy, platform security, confidence from transparency, and transaction dependability.

Dependent Variables (Core Supply Chain Performance Constructs):

Supply Chain Efficiency (SCE): It measures the extent to which the companies in the chain can improve upon the reduction in costs, management of supplies, acceleration of order processing, and use of capacity.

Supply Chain Flexibility (SCF): This measures an organization's adaptability regarding demand variability, disruptions, schedule variability, and a range of products and customers.

Supply Chain Food Safety and Quality (SSQ): This metric refers to the application of technology to determine improvements in safety documentation, product variability, defect detection speed, and compliance with regulatory matters related to safety and quality.

Supply Chain Reliability (SCR): This metric refers to the application of technology to determine improvements in delivery consistency, schedule adherence, lead time predictability, and the ability to maintain operational continuity despite disruptions.

Supply Chain Tracking and Traceability (STT): This is referred to as "how well can the items be traced?" indicating its ability to track items in real time and share information with trading partners in order to verify its accuracy.

Supply Chain Food Loss (SFL): This explores how digitalization impacts the effort put towards food loss reduction with respect to forecasting, managing inventory, transporting near-expired foods, and monitoring their status.

Supply Chain Sustainability Performance:

Environmental (SEn): This measures how digitalization affects efforts to protect the environment, such as reducing energy use, waste, and carbon footprint, and following environmental rules.

Economic (SEc): Looks at how digital projects can make a business more profitable, save money, create new sources of income, and give a good return on investment (ROI) throughout the supply chain.

Social (SSs): This measures how digitalization supports the social sustainability aspects. It looks at the effect of digitalization in making sure that workers are safe, improving their health and well-being, giving back to the community, and allowing for ethical sourcing.

### *3.4. Model Identification, Diagnosis, and Data Analysis*

#### 3.4.1. Model Identification: Structural Equation Modeling (SEM)

This research utilized a structural equation modeling (SEM) framework to perform an extensive mediation analysis. SEM was favored for its ability to model latent constructs, concurrently evaluate complex mediation pathways within a single analysis, and support models featuring multiple independent variables, mediators, and outcomes [77].

The framework was well-suited for evaluating the proposed theoretical model, which asserts that three digitalization constructs affect nine supply chain performance outcomes via three mediating variables. SEM makes it possible to estimate all of these relationships in one model that works together. This is a better and more statistically powerful test of the mediation hypotheses than running separate regression analyses because it takes into account the correlations between all endogenous variables and gives standardized estimates for all paths, making it possible to directly compare the strengths of effects across the model.

#### 3.4.2. Model Diagnosis

A multiple-step model diagnosis process was used before hypothesis testing in order to ensure the result of the SEM was robust and accurate.

Reliability of measurement evaluation: Cronbach's alpha was employed to determine the reliability of the multi-item scales. The metric extensively confirms whether items in a scale are correlated and therefore relate well to an overall similar latent construct [78]. The author states that in basic research, a standard of 0.80 or above alpha value is needed to confirm scale reliability.

Construct validity: Confirmatory factor analysis (CFA) was performed in order to test the construct validity of the measurement model. In line with the suggested values (factor loading value > 0.60; composite reliability (CR): >0.70 and average variance extracted (AVE): >0.50) of each measure [79]. For illustration, Appendix B shows the CFA result and a procedure for the calculations of CR and AVE for one of the constructs, i.e., digitalization of internal practices (DIP).

Evaluation of the overall model fit: To assess how well the structural model fit, a number of fit indices were employed. CFI, TLI, and RMSEA were used to check how well a structural model fits relative to a null model. These measures of fit for a structural model are expected to follow defined standards in structural models [80–82]. In order for a structural path estimate to be interpreted effectively, it requires an acceptable level of these measures according to these thresholds that are stated in the literature.

Robustness check: The mediation model's robustness is checked using bootstrap confidence intervals for the indirect effects. Following the suggestion of ref. [83], we used the bootstrap method with 1000 replications to compute the 95% confidence interval for each indirect effect using the bias-corrected percentile method. An indirect effect is statistically significant if its confidence interval does not contain zero.

Common method bias: Since all the data were gathered from single sources based on self-reported methods, common method bias (CMB) is a possible problem to consider [84]. In this regard, several procedural steps as recommended by the author were adhered to

address this concern in the research design. First, to address issues of evaluation apprehension and social desirability bias, anonymity and confidentiality of the respondents were ensured. Second, to address issues of item ambiguity and understanding, the questionnaire was designed to be clear and concise, and the items were unambiguous and easy to understand. Third, to address issues of priming effects and contextually induced mood states, the question order was counterbalanced.

Sampling adequacy and factorability assessment: In order to determine the appropriateness of the data for factor analysis, the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity were performed. The Kaiser–Meyer–Olkin measure of sampling adequacy is an index of the proportion of variance or covariance between variables that may be considered common variance. A value of 0.60 and above is considered appropriate for factor analysis [85]. Bartlett's test of sphericity tests the null hypothesis that the correlation matrix is an identity matrix, i.e., the variables are uncorrelated. The data is appropriate for factor analysis if the $p$-value is <0.05 [86].

#### 3.4.3. Data Analysis Procedure

JASP version 0.95.4.0 software was utilized for carrying out the mediation analysis using SEM. Maximum-likelihood analysis was adopted for estimating the parameters in the model. This procedure applies to continuous variables when they conform to normality requirements. This was done in the following manner. The full measurement and structural model were specified. The fitness of the model to the observed data was determined using a list of indices, which were defined in Section 3.4.2. Once the appropriate fit between the model and observed data was obtained, the model was run. The hypothesized direct and indirect effects were examined using the standardized estimates generated by the software and associated $p$-values. The results of the software are reorganized in Tables to observe the direct, indirect, and total effects of each supply chain practice on supply chain performance outcomes in a comparative manner.

## 4. Data Analysis and Results

### *4.1. Model Diagnostics*

Before testing the structural model, the reliability and validity of the measurement scales and the overall fit of the proposed model were assessed.

#### 4.1.1. Reliability and Validity Test Results

As stated under the methodology, the internal consistency of all multi-item constructs was evaluated using Cronbach's alpha. As presented in Table 3, all values ranged from 0.844 to 0.928, exceeding the recommended threshold of 0.80 for basic research [78]. This confirms that the measurement scales for digitalization practices (DIP, DIS, DIC), enhanced capabilities (OE, Tru, Tra), and all the performance outcomes demonstrated good to excellent reliability.

Likewise, confirmatory factor analysis (CFA) was employed to validate the proposed model. The results, depicted in the right three columns in Table 3, reveal the standardized values for the loading ranges, composite reliability (CR), and average variance extracted (AVE) for all the constructs employed in the study. The result shows that all the values for the loadings exceed the threshold value of 0.70, as recommended by ref. [79], with most values exceeding 0.80. Moreover, all the values for the loadings are statistically significant at $p < 0.001$. In addition, the values for the composite reliability (CR) range from 0.870 to 0.942, which is far above the acceptable benchmark value of 0.70 [79]. Similarly, the values for the average variance extracted (AVE) range from 0.628 to 0.803, which is above the acceptable benchmark value of 0.50 [79]. For the details of how the CR and AVE are

calculated, see the sample CFA and the computation procedure for one variable presented in Appendix B.

**Table 3.** Reliability and validity statistics.

| | Reliability Statistics (95% CI) | | | | * Validity Statistics | | |
|---|---|---|---|---|---|---|---|
| **Variables** | **Cronbach's Alpha** | **Number of Questions** | **Lower** | **Upper** | **Loadings Range** | **CR** | **AVE** |
| Digitalization of Internal Practices (DIP) | 0.893 | 4 | 0.865 | 0.920 | 0.714–0.853 | 0.870 | 0.628 |
| Digital Integration with Suppliers (DIS) | 0.901 | 4 | 0.878 | 0.924 | 0.881–0.910 | 0.942 | 0.803 |
| Digital Integration with Customers (DIC) | 0.928 | 4 | 0.909 | 0.946 | 0.826–0.944 | 0.938 | 0.792 |
| Internal Operational Efficiency (OE) | 0.900 | 4 | 0.877 | 0.924 | 0.817–0.969 | 0.941 | 0.799 |
| Supply Chain Trust (Tru) | 0.844 | 4 | 0.803 | 0.886 | 0.740–0.910 | 0.907 | 0.711 |
| Supply Chain Transparency (Tra) | 0.869 | 4 | 0.816 | 0.922 | 0.804–0.882 | 0.892 | 0.674 |
| Supply Chain Efficiency (SCE) | 0.852 | 4 | 0.806 | 0.898 | 0.777–0.857 | 0.892 | 0.674 |
| Supply Chain Flexibility (SCF) | 0.895 | 4 | 0.868 | 0.923 | 0.728–0.928 | 0.907 | 0.711 |
| Supply Chain Food Safety and Quality (SSQ) | 0.871 | 4 | 0.833 | 0.909 | 0.803–0.886 | 0.908 | 0.712 |
| Supply Chain Reliability (SCR) | 0.850 | 4 | 0.803 | 0.897 | 0.783–0.854 | 0.896 | 0.684 |
| Supply Chain Tracking and Traceability (STT) | 0.863 | 4 | 0.812 | 0.913 | 0.778–0.883 | 0.899 | 0.692 |
| Supply Chain Food Loss Reduction (SFL) | 0.918 | 4 | 0.896 | 0.939 | 0.730–0.892 | 0.905 | 0.706 |
| Supply Chain Environmental Sustainability (SEn) | 0.859 | 4 | 0.814 | 0.904 | 0.816–0.871 | 0.907 | 0.709 |
| Supply Chain Economic Sustainability (SEc) | 0.841 | 4 | 0.799 | 0.882 | 0.784–0.833 | 0.884 | 0.656 |
| Supply Chain Social Sustainability (SSs) | 0.880 | 4 | 0.846 | 0.915 | 0.812–0.912 | 0.918 | 0.737 |

* Note: All factor loadings are significant at $p < 0.001$. CR = composite reliability, AVE = average variance extracted.

#### 4.1.2. Model Fit Indices

The hypothesized structural equation model (SEM) was tested using maximum likelihood estimation. The key model fit indices, together with R-squared value results for all dependent variables, are summarized in Table 4. According to the result, all the indices' values indicate that the model fits well according to the recommended thresholds; details of the recommended threshold values for SEM fit indices are available in refs. [80–82]. Specifically, the final structural model yielded $\chi^2(15) = 32.08$, $p = 0.006$, $\chi^2/df = 2.14$, CFI = 0.996, TLI = 0.976, RMSEA = 0.086 (90% CI: 0.044, 0.128), and SRMR = 0.005. These values meet or exceed conventional benchmarks for good model fit (CFI > 0.95, TLI > 0.95, SRMR < 0.08, and RMSEA < 0.08 with confidence intervals encompassing acceptable values). Beyond

statistical fit measured through the fit indices, the model demonstrated a good explanatory power as measured through the R-squared values. As shown in Table 4, the combination of digitalization practices and enhanced capabilities (mediations) explained between 87% (social sustainability) and 95% (supply chain efficiency and supply chain reliability) of the variance in performance outcomes. Overall, the model fit indices and the R-squared value summarized in Table 4 show that the selected model surpasses the conventional benchmarks for good model fit, supporting the validity of the proposed structural model.

**Table 4.** Key model fit statistics and $R^2$.

| Key Model Fit and Model Summary Statistics | | | $R^2$ for All DVs | |
|---|---|---|---|---|
| **Category** | **Statistic** | **Value** | **DVs** | **$R^2$ Values** |
| | CFI | 0.996 | SCE | 0.952 |
| | TLI | 0.976 | SCF | 0.947 |
| | RMSEA | 0.086 (90% CI: 0.044, 0.128) | SSQ | 0.934 |
| | SRMR | 0.005 | SCR | 0.953 |
| | GFI | 1.000 | STT | 0.925 |
| | $\chi^2$ (df) | 32.08 (15) | SFL | 0.890 |
| | AIC | −579.862 | Sen | 0.922 |
| | BIC | −279.849 | Sec | 0.948 |
| | | | SSs | 0.870 |

Moreover, to check the robustness of the inference for the mediation effects, we complemented the maximum likelihood estimation with bootstrap confidence intervals. Specifically, we used 1000 bootstrap replications with the bias-corrected percentile method to obtain 95% confidence intervals for all indirect effects. The bootstrap results are presented in Appendix C. The results show that nearly all the significant indirect effects obtained in the mediation analysis remained significant, as their bootstrap confidence intervals did not include zero, indicating robustness of the findings [83]. Note: The complete set of fit indices values as produced by the analysis software is provided in Appendix A.

Sampling Adequacy and Factorability Assessment (KMO and Bartlett's Test Results): The Kaiser–Meyer–Olkin (KMO) sampling adequacy measure was found to be 0.954, which is well above the recommended level of 0.60. Bartlett's test of sphericity was found significant ($\chi^2$ = 10,480.487, df = 1770, $p < 0.001$). This shows that the correlation matrix is quite different from an identity matrix, which is necessary for performing the factor analysis. The results show the sampling adequacy and factorability of the correlation matrix, which is necessary for the subsequent analysis [85,86]. The detailed output, including individual item measures of sampling adequacy (MSAs), is presented in Appendix D.

### *4.2. Structural Equation Model Results*

The detailed results of the structural equation path analysis are presented in three sections. First, the results showing the direct and total effects of digitalization practices on the outcome variables are reported. Then, the effect breakdown of direct and mediation analysis for each independent variable. Finally, the results are summarized to test the hypotheses.

#### 4.2.1. Direct and Total Effects of Digitalization on Outcome Variables

Tables 5 and 6 summarize the direct and total effects, respectively, of digital internal practices (DIP), digital integration with suppliers (DIS), and digital integration with cus-

tomers (DIC) on the nine supply chain performance outcomes. A side-by-side look at these two results shows a key pattern that helps us understand how digital practices affect the performance of supply chains.

**Table 5.** Direct effects of digital practices on supply chain performances.

| | | | | | 95% CI | |
|---|---|---|---|---|---|---|
| | | | **Std. Estimate** | ***p*** | **Lower** | **Upper** |
| DIP | → | SCE | 0.133 | 0.011 | 0.031 | 0.236 |
| DIS | → | SCE | 0.089 | 0.061 | −0.004 | 0.183 |
| DIC | → | SCE | 0.162 | 0.019 | 0.026 | 0.298 |
| DIP | → | SEc | 0.087 | 0.116 | −0.021 | 0.195 |
| DIS | → | SEc | 0.067 | 0.181 | −0.031 | 0.165 |
| DIC | → | SEc | 0.570 | <0.001 | 0.428 | 0.712 |
| DIP | → | SSQ | 0.115 | 0.056 | −0.003 | 0.233 |
| DIS | → | SSQ | 0.068 | 0.213 | −0.039 | 0.175 |
| DIC | → | SSQ | 0.118 | 0.139 | −0.038 | 0.274 |
| DIP | → | SCR | 0.049 | 0.348 | −0.053 | 0.152 |
| DIS | → | SCR | 0.027 | 0.572 | −0.067 | 0.121 |
| DIC | → | SCR | 0.239 | <0.001 | 0.103 | 0.376 |
| DIP | → | STT | 0.070 | 0.293 | −0.060 | 0.200 |
| DIS | → | STT | 0.120 | 0.048 | 0.001 | 0.238 |
| DIC | → | STT | 0.260 | 0.003 | 0.088 | 0.432 |
| DIP | → | SFL | −0.201 | 0.012 | −0.358 | −0.044 |
| DIS | → | SFL | −0.127 | 0.082 | −0.270 | 0.016 |
| DIC | → | SFL | −0.242 | 0.022 | −0.450 | −0.034 |
| DIP | → | SEn | 0.046 | 0.501 | −0.087 | 0.179 |
| DIS | → | SEn | 0.011 | 0.859 | −0.110 | 0.132 |
| DIC | → | SEn | 0.405 | <0.001 | 0.229 | 0.581 |
| DIP | → | SCF | 0.294 | <0.001 | 0.186 | 0.403 |
| DIS | → | SCF | 0.100 | 0.047 | 0.001 | 0.199 |
| DIC | → | SCF | 0.158 | 0.032 | 0.014 | 0.301 |
| DIP | → | SSs | 0.085 | 0.323 | −0.084 | 0.255 |
| DIS | → | SSs | 0.092 | 0.242 | −0.062 | 0.247 |
| DIC | → | SSs | 0.068 | 0.552 | −0.156 | 0.293 |

Note: Estimator is ML; CI is 95% confidence interval.

The results in Table 5 show that digital practices have a statistically significant effect on certain supply chain outcomes. Specifically, digital integration with customers (DIC) emerges as the most directly influential, with significant positive effects on supply chain efficiency (SCE: $\beta = 0.162$, $p = 0.019$), economic sustainability performance (SEc: $\beta = 0.570$, $p < 0.001$), reliability (SCR: $\beta = 0.239$, $p < 0.001$), tracking and traceability (STT: $\beta = 0.260$, $p = 0.003$), and environmental sustainability performance (SEn: $\beta = 0.405$, $p < 0.001$). DIC also has a significant direct negative effect on food loss (SFL: $\beta = -0.242$, $p = 0.022$). In comparison, digital internal practices (DIP) show a focused direct effect, primarily enhancing supply chain flexibility (SCF: $\beta = 0.294$, $p < 0.001$) and reducing food loss (SFL: $\beta = -0.201$,

$p = 0.012$). Digital integration with supplier (DIS) exhibits the fewest direct effects, with significant links only to tracking and traceability (STT: β = 0.120, $p = 0.048$) and flexibility (SCF: β = 0.100, $p = 0.047$). While Table 5 shows direct effects of digital practices on certain supply chain performance outcomes, critically looking at Table 5 also shows that more than half of the 27 hypothesized direct paths (e.g., DIS to SCE; DIP to SEc; DIS to SSQ; DIC to SSQ; DIC to SCR) are statistically non-significant. This indicates that a purely direct-impact model is insufficient to explain digitalization's role in influencing supply chain performance.

**Table 6.** Total effects of digital practices on supply chain performances.

| | | | | | 95% CI | |
|---|---|---|---|---|---|---|
| | | | **Std. Estimate** | ***p*** | **Lower** | **Upper** |
| DIP | → | SCE | 0.288 | <0.001 | 0.167 | 0.410 |
| DIS | → | SCE | 0.250 | <0.001 | 0.140 | 0.361 |
| DIC | → | SCE | 0.451 | <0.001 | 0.310 | 0.592 |
| DIP | → | SEc | 0.155 | 0.005 | 0.048 | 0.262 |
| DIS | → | SEc | 0.144 | 0.004 | 0.047 | 0.242 |
| DIC | → | SEc | 0.690 | <0.001 | 0.567 | 0.813 |
| DIP | → | SSQ | 0.293 | <0.001 | 0.157 | 0.428 |
| DIS | → | SSQ | 0.225 | <0.001 | 0.102 | 0.349 |
| DIC | → | SSQ | 0.461 | <0.001 | 0.303 | 0.619 |
| DIP | → | SCR | 0.194 | 0.002 | 0.071 | 0.317 |
| DIS | → | SCR | 0.173 | 0.002 | 0.061 | 0.285 |
| DIC | → | SCR | 0.616 | <0.001 | 0.474 | 0.757 |
| DIP | → | STT | 0.180 | 0.010 | 0.044 | 0.317 |
| DIS | → | STT | 0.228 | <0.001 | 0.104 | 0.352 |
| DIC | → | STT | 0.567 | <0.001 | 0.410 | 0.725 |
| DIP | → | SFL | −0.323 | <0.001 | −0.479 | −0.168 |
| DIS | → | SFL | −0.224 | 0.002 | −0.366 | −0.083 |
| DIC | → | SFL | −0.416 | <0.001 | −0.597 | −0.235 |
| DIP | → | SEn | 0.133 | 0.061 | −0.006 | 0.272 |
| DIS | → | SEn | 0.135 | 0.036 | 0.009 | 0.262 |
| DIC | → | SEn | 0.699 | <0.001 | 0.540 | 0.858 |
| DIP | → | SCF | 0.378 | <0.001 | 0.264 | 0.492 |
| DIS | → | SCF | 0.210 | <0.001 | 0.106 | 0.314 |
| DIC | → | SCF | 0.406 | <0.001 | 0.273 | 0.539 |
| DIP | → | SSs | 0.277 | 0.003 | 0.096 | 0.459 |
| DIS | → | SSs | 0.280 | <0.001 | 0.116 | 0.445 |
| DIC | → | SSs | 0.383 | <0.001 | 0.172 | 0.594 |

A stark contrast with the results in Table 6 demonstrates that the total effects—which encompass both direct and indirect (mediated) pathways—are universally significant and substantially stronger for every single path. For instance, the total effect of DIP on SCE (β = 0.288) is more than double its direct effect. The transformation is particularly remarkable for paths where the direct effect was non-significant. Section 4.2.2 discusses the direct,

indirect (mediated), and total effects of digital practices on each performance outcome. At this point, it is important to point out that comparing the results in Tables 5 and 6 shows that primarily digitalization builds intermediate capabilities that have a greater effect on core and sustainability supply chain performance outcomes than its direct effect.

#### 4.2.2. Effect Breakdown by Performance Outcome

Effect on Supply Chain Efficiency (SCE):

Table 7 summarizes the direct, indirect, and total effects of the digital practices on supply chain efficiency (SCE). It presents a decomposition of effects on supply chain efficiency (SCE), offering detailed insight into the specific pathways through which each digital practice influences this outcome. The previous section gave a general comparison of direct and total effects on all dependent variables (Tables 5 and 6). The results in Table 7, on the other hand, show how three mediating variables: operational efficiency (OE), trust (Tru), and transparency (Tra), work as separate channels for digitalization's effect on SCE.

**Table 7.** Direct, indirect, and total effect of digital practices on supply chain efficiency (SCE).

| | | | | | | | | 95% CI | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | **Std. Estimate** | ***P*** | **Lower** | **Upper** |
| **Direct effect paths of independent variables on SCE** | | | DIP | → | SCE | 0.133 | 0.011 | 0.031 | 0.236 |
| | | | DIS | → | SCE | 0.089 | 0.061 | −0.004 | 0.183 |
| | | | DIC | → | SCE | 0.162 | 0.019 | 0.026 | 0.298 |
| **Indirect effect paths on SCE through each mediation variable** | DIP | → | OE | → | SCE | 0.096 | <0.001 | 0.040 | 0.152 |
| | DIP | → | Tru | → | SCE | 0.031 | 0.110 | −0.007 | 0.070 |
| | DIP | → | Tra | → | SCE | 0.028 | 0.078 | −0.003 | 0.059 |
| | DIS | → | OE | → | SCE | 0.065 | 0.006 | 0.019 | 0.112 |
| | DIS | → | Tru | → | SCE | 0.067 | 0.004 | 0.021 | 0.113 |
| | DIS | → | Tra | → | SCE | 0.029 | 0.064 | −0.002 | 0.059 |
| | DIC | → | OE | → | SCE | 0.084 | 0.006 | 0.024 | 0.143 |
| | DIC | → | Tru | → | SCE | 0.106 | 0.002 | 0.040 | 0.172 |
| | DIC | → | Tra | → | SCE | 0.099 | 0.025 | 0.012 | 0.186 |
| **Total indirect effect of each independent variable on SCE** | | | DIP | → | SCE | 0.155 | <0.001 | 0.073 | 0.237 |
| | | | DIS | → | SCE | 0.161 | <0.001 | 0.086 | 0.236 |
| | | | DIC | → | SCE | 0.289 | <0.001 | 0.174 | 0.404 |
| **Total effect of each independent variable on SCE** | | | DIP | → | SCE | 0.288 | <0.001 | 0.167 | 0.410 |
| | | | DIS | → | SCE | 0.250 | <0.001 | 0.140 | 0.361 |
| | | | DIC | → | SCE | 0.451 | <0.001 | 0.310 | 0.592 |

As previously discussed, the direct effects on SCE exist but are small in scale comparatively. Digital integration with customers (DIC) has the most direct effect (β = 0.162, $p = 0.019$), followed by digital internal practices (DIP; β = 0.133, $p = 0.011$). Digital integration with supplier (DIS) has a direct path that is positive but not statistically significant (β = 0.089, $p = 0.061$).

The findings in Table 7 (indirect effect section) indicate that each digital practice improves SCE via a distinct set of mediators. Digital internal practices (DIP) exert their influence primarily via operational efficiency (OE). The path from DIP to OE to SCE is strong and important (β = 0.096, $p < 0.001$), but the paths through trust (β = 0.031, $p = 0.110$) and

transparency (β = 0.028, $p$ = 0.078) are not significant. This implies that the effects of internal digitization on SCE are mainly positive when it comes to improving processes through increased efficiencies and better use of resources.

Digital integration with supplier (DIS) operates through two channels on SCE, that is, there are strong indirect effects through trust (DIS → Tru → SCE: β = 0.067, $p$ = 0.004) and operational efficiency (DIS → OE → SCE: β = 0.065, $p$ = 0.006). The transparency pathway is not statistically significant (β = 0.029, $p$ = 0.064). This pattern indicates that collaboration with suppliers increases SCE through improved reliability of collaboration and smooth operation of joint activities.

Digital integration with customers (DIC) demonstrates an effective mediation, which means using all three mediation channels effectively. The strongest indirect influence comes from trust (DIC → Tru → SCE: β = 0.106, $p$ = 0.002), followed by transparency (β = 0.099, $p$ = 0.025) and operational efficiency (β = 0.084, $p$ = 0.006). This three-way mediation shows that working with customers improves SCE by building stronger relationships, making information clearer, and aligning processes. Trust is the most important mediator for digital integration with customers (DIC) to supply chain efficiency (SCE).

The total indirect effect for each practice is the sum of all the specific indirect pathways. This grouping shows that mediated influence is the most powerful. DIC has the strongest total indirect effect (β = 0.289), which is 78% higher than its direct effect. DIS has a total indirect effect of β = 0.161, which is 81% higher than its direct effect. The total indirect effect of DIP is β = 0.155, which is 17% higher than its direct effect. For DIS, the total indirect effect is not only increased, but it is also become statistically significant compared to the direct effect. This means that a direct link that is not significant becomes a strong, statistically significant total influence.)

The total effect, which is the sum of the direct and all indirect pathways, is the best way to measure how each practice affects SCE. DIC has the most significant overall effect (β = 0.451), and 64% of that effect is mediated. DIP has a total effect of β = 0.288, and 54% of that effect is mediated. The total effect of DIS is β = 0.250, and 64% of that effect is mediated.

Analysis of some of these paths shows how every type of digitalization improves efficiencies. The result in Table 7 shows that DIP functions as a catalyst in terms of operational efficiency. Its value lies in digitalizing processes, i.e., operational efficiency (OE) is its primary mediator with regard to supply chain efficiency. DIS is more of an enabler to integrate relationships and operations. Its value lies in both being trustworthy to suppliers and making things run more efficiently. DIC, which applies all the mediation variables and has a large role in terms of building trust, comes out to be termed as a complete integrator for supply chain efficiencies. Thus, the study result shows that digital enablers with consumers are most useful for creating value through superior partnerships, information, and operational synergies.

In summary, digitalization is strongly associated with supply chain efficiency, but the pathways differ by practice. DIP operates primarily through operational efficiency, while DIS and DIC exert their influence through trust and transparency. Practically, this means that managers should align digital investments with their desired outcome: in order to realize overall supply chain efficiency gains, internal digitalization practices should focus on process optimization (operational efficiency), whereas customer and supplier integrations should prioritize building trust and transparency. Notably, DIC shows the strongest total effect (β = 0.451), with 64% mediated, indicating that customer-facing digital initiatives offer the highest efficiency returns when they successfully build relational capital.

Effect on Supply Chain Flexibility (SCF):

Table 8 shows how the digital practices affect supply chain flexibility (SCF) in three different ways: directly, indirectly, and in total. The result notes that there is a different way of mediating for flexibility than for efficiency.

**Table 8.** Direct, indirect, and total effect of digital practices on supply chain flexibility (SCF).

| | | | | | | | | | 95% CI | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Std. Estimate | *p* | Lower | Upper |
| **Direct effect paths of independent variables on SCF** | | | DIP | → | SCF | | 0.294 | <0.001 | 0.186 | 0.403 |
| | | | DIS | → | SCF | | 0.100 | 0.047 | 0.001 | 0.199 |
| | | | DIC | → | SCF | | 0.158 | 0.032 | 0.014 | 0.301 |
| **Indirect effect paths on SCF through each mediation variable** | DIP | → | OE | → | SCF | | 0.017 | 0.392 | −0.022 | 0.056 |
| | DIP | → | Tru | → | SCF | | 0.026 | 0.128 | −0.007 | 0.059 |
| | DIP | → | Tra | → | SCF | | 0.041 | 0.038 | 0.002 | 0.080 |
| | DIS | → | OE | → | SCF | | 0.012 | 0.399 | −0.015 | 0.038 |
| | DIS | → | Tru | → | SCF | | 0.055 | 0.012 | 0.012 | 0.099 |
| | DIS | → | Tra | → | SCF | | 0.042 | 0.026 | 0.005 | 0.079 |
| | DIC | → | OE | → | SCF | | 0.015 | 0.399 | −0.020 | 0.049 |
| | DIC | → | Tru | → | SCF | | 0.088 | 0.007 | 0.024 | 0.152 |
| | DIC | → | Tra | → | SCF | | 0.146 | 0.003 | 0.051 | 0.241 |
| **Total indirect effect of each independent variable on SCF** | | | DIP | → | SCF | | 0.084 | 0.011 | 0.019 | 0.148 |
| | | | DIS | → | SCF | | 0.109 | <0.001 | 0.050 | 0.169 |
| | | | DIC | → | SCF | | 0.249 | <0.001 | 0.147 | 0.350 |
| **Total effect of each independent variable on SCF** | | | DIP | → | SCF | | 0.378 | <0.001 | 0.264 | 0.492 |
| | | | DIS | → | SCF | | 0.210 | <0.001 | 0.106 | 0.314 |
| | | | DIC | → | SCF | | 0.406 | <0.001 | 0.273 | 0.539 |

All three digital practices have a significant effect on flexibility right away, but digital internal practices (DIP) have the biggest effect (β = 0.294, $p < 0.001$). Digital integration with customers (DIC; β = 0.158, $p = 0.032$) and digital integration with suppliers (DIS; β = 0.100, $p = 0.047$) also have direct effects. This means that digitalization can directly make supply chains more responsive and adaptable across both internal and external boundaries. This makes the supply chains more flexible. The indirect effects reveal that SCF is enhanced primarily through relational and informational mediators, contrasting with the operational focus seen for SCE. Digital internal practices (DIP) improve SCF significantly only through increased transparency (Tra → SCF: β = 0.041, $p = 0.038$). Paths through operational efficiency (β = 0.017, $p = 0.392$) and trust (β = 0.026, $p = 0.128$) are not significant. Digital integration with suppliers (DIS) enhances SCF through both trust (DIS → Tru → SCF: β = 0.055, $p = 0.012$) and transparency (β = 0.042, $p = 0.026$). The path through operational efficiency is not significant. This implies that supplier integration increases the flexibility of businesses because of the establishment of robust relationships and transparent communication, which increases the pliability of businesses to adapt to changed conditions.

Digital integration with customers (DIC) has a significant influence on these two mediators, with a robust result through transparency (β = 0.146, $p = 0.003$) and trust (β = 0.088, $p = 0.007$). This indicates that digital integration with customers increases the flexibility of the supply chain because it communicates clear signals for cooperation in order for the supply chain to be able to react quickly to required changes.

On observing the combination of the indirect effects, it is found that mediation has been a major amplifier, particularly in the context of practices that are strongly connected with the external groups. The total indirect effect for DIC is the largest (β = 0.249), which explains 61% of the total effect of DIC that is mediated in SCF. The total indirect effect of DIS is also significant (β = 0.109), which represents 52% of the total effect. DIP has a smaller total indirect effect (β = 0.084), but it is still statistically significant. Mediation makes up 22% of its total effect. The outcome in Table 7 substantiates that supply chain flexibility is primarily regulated by distinct principles compared to supply chain efficiency. Although digitalization directly improves supply chain flexibility (SCF), managers must recognize the particular relational and informational mediators that their selected digital practice most effectively engages. The results of this study show that investments in digital integrations with customers and suppliers should be looked at for their ability to build trust and transparency, since these are the vital ways to make a supply chain more flexible.

To sum up, digital practices are linked to making the supply chain more flexible in both direct and indirect ways, with the indirect paths being mostly relational. In other words, DIP has a small indirect effect through transparency (β = 0.041), while DIS and DIC have indirect effects through trust and transparency. DIC has the strongest total indirect effect (β = 0.249), which is 61% of its total effect. In practice, this means that managers who want their supply chains to be more flexible should focus on digitally integrating with customers and suppliers. These create the trust and transparency that are needed to quickly respond to changes in the market. Therefore, digital practices by themselves do not make the supply chain more flexible unless they contribute to transparency and trust building.

Effect on Supply Chain Food Safety and Quality (SSQ):

Table 9 summarizes the direct, indirect, and total effects of the digital practices on food safety and quality along the supply chain (SSQ).

The results in Table 9 show the breakdown of how the effects of digital practices enhance supply chain food safety and quality (SSQ). Unlike the previous outcomes, improvements in SSQ are achieved exclusively through indirect, mediated channels, with operational efficiency and transparency emerging as the critical conduits. The results show that there is no direct statistically significant ($p < 0.05$) effect of the three types of digital practices on SSQ.

However, through the indirect paths, all three digital practices demonstrated a statistically significant effect on SSQ. The aggregation of effects confirms that, in the case of food safety and quality (SSQ), mediation is not just important but is the only route to improving SSQ.

As can be seen from the results in Table 9, DIC has the strongest total indirect effect (β = 0.343), meaning a substantial 74% of its total impact on SSQ is mediated. Similarly, DIP (total indirect β = 0.178) and DIS (total indirect β = 0.157) also show significant mediated contributions, accounting for 61% and 70% of their respective total effects.

Consequently, the total effects—that are all highly significant—are entirely composed of these indirect pathways (DIC → SSQ: β = 0.461, $p < 0.001$; DIP → SSQ: β = 0.293, $p < 0.001$; DIS → SSQ: β = 0.225, $p < 0.001$).

In sum, the link between digital practices and improvements in food safety and quality operates through indirect channels, with operational efficiency and transparency serving as the primary mediators. DIC is very much linked to the improvement of food safety and quality (β = 0.461), where 74% of its influence is mediated, followed by DIP (β = 0.293) and DIS (β = 0.225). In practical terms, the finding means that the worth of investment in digital integrations in terms of the improvement of food safety and quality is in the improvement of operational efficiency and transparency, which makes it possible to control the process

better and make information more visible. Therefore, digital integrations in terms of food safety and quality requirements should be evaluated in terms of their practical and potential capabilities in improving the streamlining of operations and providing relevant stakeholders with transparent access to information along the supply chain, which are the real drivers of the improvement of safety and quality.

**Table 9.** Direct, indirect and total effect of digital practices on food safety and quality (SSQ).

| | | | | | | | | 95% CI | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Std. Estimate | *p* | Lower | Upper |
| **Direct effect paths of independent variables on SSQ** | | | DIP | → | SSQ | 0.115 | 0.056 | −0.003 | 0.233 |
| | | | DIS | → | SSQ | 0.068 | 0.213 | −0.039 | 0.175 |
| | | | DIC | → | SSQ | 0.118 | 0.139 | −0.038 | 0.274 |
| **Indirect effect paths through each mediation variable** | DIP | → | OE | → | SSQ | 0.107 | <0.001 | 0.044 | 0.171 |
| | DIP | → | Tru | → | SSQ | 0.010 | 0.346 | −0.011 | 0.031 |
| | DIP | → | Tra | → | SSQ | 0.061 | 0.021 | 0.009 | 0.112 |
| | DIS | → | OE | → | SSQ | 0.073 | 0.006 | 0.021 | 0.125 |
| | DIS | → | Tru | → | SSQ | 0.021 | 0.280 | −0.017 | 0.060 |
| | DIS | → | Tra | → | SSQ | 0.062 | 0.012 | 0.014 | 0.111 |
| | DIC | → | OE | → | SSQ | 0.093 | 0.006 | 0.027 | 0.160 |
| | DIC | → | Tru | → | SSQ | 0.034 | 0.274 | −0.027 | 0.094 |
| | DIC | → | Tra | → | SSQ | 0.216 | <0.001 | 0.108 | 0.325 |
| **Total indirect effect of each independent variable on SSQ** | | | DIP | → | SSQ | 0.178 | <0.001 | 0.088 | 0.267 |
| | | | DIS | → | SSQ | 0.157 | <0.001 | 0.075 | 0.239 |
| | | | DIC | → | SSQ | 0.343 | <0.001 | 0.216 | 0.471 |
| **Total effect of each independent variable on SSQ** | | | DIP | → | SSQ | 0.293 | <0.001 | 0.157 | 0.428 |
| | | | DIS | → | SSQ | 0.225 | <0.001 | 0.102 | 0.349 |
| | | | DIC | → | SSQ | 0.461 | <0.001 | 0.303 | 0.619 |

Effect on Supply Chain Reliability (SCR):

Table 10 shows how digital practices affect the reliability of the supply chain (SCR). The results show that digital internal practices (DIP) and digital integration with suppliers (DIS) do not have statistically significant direct effects on SCR. However, for digital integration with customers (DIC), the result is statistically significant and has a strong positive effect ($\beta = 0.239$, $p < 0.001$). This shows that digital integrations to customers directly help make the supply chain more reliable by making sure that the signals are more accurate and work together. When we look at the indirect effects, we see that the reliability construct mostly grows through improved capabilities. Transparency (Tra) is the most important mediator in all types of digital practices related to supply chain reliability (SCR).

The total effect is high only when all the indirect effects are added up. This is especially remarkable for paths that do not have a strong, statistically significant direct effect. The total indirect effect for DIC is the biggest ($\beta = 0.376$), and mediation is responsible for 61% of its total effect on SCR. Mediation accounts for a substantial 84% of DIS (total indirect $\beta = 0.146$) and 75% of DIP (total indirect $\beta = 0.145$). This is very impressive for DIP and DIS because their non-significant direct effects are made to become significant through high indirect effects.

**Table 10.** Direct, indirect, and total effect of digital practices on supply chain reliability (SCR).

| | | | | | | | 95% CI | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Std. Estimate | *p* | Lower | Upper |
| **Direct effect paths of independent variables on SCR** | | | DIP | → SCR | 0.049 | 0.348 | −0.053 | 0.152 |
| | | | DIS | → SCR | 0.027 | 0.572 | −0.067 | 0.121 |
| | | | DIC | → SCR | 0.239 | <0.001 | 0.103 | 0.376 |
| **Indirect effect paths on SCR through each mediation variable** | DIP | → OE | → | SCR | 0.052 | 0.018 | 0.009 | 0.094 |
| | DIP | → Tru | → | SCR | 0.013 | 0.229 | −0.008 | 0.034 |
| | DIP | → Tra | → | SCR | 0.081 | 0.012 | 0.018 | 0.143 |
| | DIS | → OE | → | SCR | 0.035 | 0.033 | 0.003 | 0.068 |
| | DIS | → Tru | → | SCR | 0.028 | 0.123 | −0.007 | 0.063 |
| | DIS | → Tra | → | SCR | 0.083 | 0.005 | 0.025 | 0.141 |
| | DIC | → OE | → | SCR | 0.045 | 0.034 | 0.004 | 0.086 |
| | DIC | → Tru | → | SCR | 0.044 | 0.113 | −0.010 | 0.098 |
| | DIC | → Tra | → | SCR | 0.288 | <0.001 | 0.180 | 0.395 |
| **Total indirect effect of each independent variable on SCR** | | | DIP | → SCR | 0.145 | <0.001 | 0.061 | 0.229 |
| | | | DIS | → SCR | 0.146 | <0.001 | 0.069 | 0.223 |
| | | | DIC | → SCR | 0.376 | <0.001 | 0.260 | 0.493 |
| **Total effect of each independent variable on SCR** | | | DIP | → SCR | 0.194 | 0.002 | 0.071 | 0.317 |
| | | | DIS | → SCR | 0.173 | 0.002 | 0.061 | 0.285 |
| | | | DIC | → SCR | 0.616 | <0.001 | 0.474 | 0.757 |

To recapitulate this section, digital integrations are linked to enhancing supply chain reliability primarily through transparency, which serves as the key mediator across all digital practices. DIC has a strong direct effect (β = 0.239) as well as a strong indirect effect through transparency (β = 0.288), which accounts for 61% of its total effect. For both DIP and DIS, where direct effects are non-significant, transparency accounts for 75% and 84% of total effects for both variables, respectively, making non-significant direct relationships significant for total relationships. The implications are that supply chain reliability can be achieved through digital integrations if the digital integrations serve companies in enhancing information transparency. Therefore, managers must evaluate digital investments in terms of their capacity to enhance transparency within processes to realize supply chain reliability, which is essentially achieved through delivery timeliness.

Effect on Supply Chain Tracking and Traceability (STT):

Table 11 shows the direct and indirect effects of the three digital practices on the performance of supply chain tracking and traceability (STT). The findings demonstrate that mediated effects significantly enhance and fundamentally facilitate the overall influence of digitalization on STT performance.

Digital customer integration (DIC) has a strong and significant direct effect on STT (β = 0.260, $p$ = 0.003). Digital supplier integration (DIS) demonstrates a modest yet significant direct effect (β = 0.120, $p$ = 0.048). Conversely, the direct effect of digital internal practices (DIP) on STT is not statistically significant (β = 0.070, $p$ = 0.293).

The analysis of indirect effects highlights that the improvement of STT is primarily facilitated by a singular, potent mediator: transparency (Tra). Operational efficiency (OE) and trust (Tru) do not serve as statistically significant mediators for any of the three types of digital practice examined in this study.

**Table 11.** Direct, indirect and total effect of digital practices on supply chain tracking and traceability (STT).

| | | | | | | | 95% CI | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Std. Estimate | *p* | Lower | Upper |
| **Direct effect paths of independent variables on STT** | | | DIP | → STT | 0.070 | 0.293 | −0.060 | 0.200 |
| | | | DIS | → STT | 0.120 | 0.048 | 0.001 | 0.238 |
| | | | DIC | → STT | 0.260 | 0.003 | 0.088 | 0.432 |
| **Indirect effect paths on STT through each mediation variable** | DIP | → OE | → | STT | 0.032 | 0.192 | −0.016 | 0.080 |
| | DIP | → Tru | → | STT | 0.005 | 0.641 | −0.015 | 0.025 |
| | DIP | → Tra | → | STT | 0.074 | 0.018 | 0.013 | 0.135 |
| | DIS | → OE | → | STT | 0.022 | 0.207 | −0.012 | 0.055 |
| | DIS | → Tru | → | STT | 0.010 | 0.631 | −0.031 | 0.052 |
| | DIS | → Tra | → | STT | 0.076 | 0.009 | 0.019 | 0.134 |
| | DIC | → OE | → | STT | 0.028 | 0.207 | −0.015 | 0.071 |
| | DIC | → Tru | → | STT | 0.016 | 0.630 | −0.049 | 0.082 |
| | DIC | → Tra | → | STT | 0.264 | <0.001 | 0.141 | 0.386 |
| **Total indirect effect of each independent variable on STT** | | | DIP | → STT | 0.110 | 0.005 | 0.034 | 0.187 |
| | | | DIS | → STT | 0.108 | 0.003 | 0.038 | 0.179 |
| | | | DIC | → STT | 0.308 | <0.001 | 0.187 | 0.428 |
| **Total effect of each independent variable on STT** | | | DIP | → STT | 0.180 | 0.010 | 0.044 | 0.317 |
| | | | DIS | → STT | 0.228 | <0.001 | 0.104 | 0.352 |
| | | | DIC | → STT | 0.567 | <0.001 | 0.410 | 0.725 |

The combination of indirect effects shows how important they are in making a big overall impact, especially for practices with weak direct links. All practices have a significant total indirect effect. For DIC, it is substantial (β = 0.308), accounting for 54% of its total effect. For DIP (β = 0.110) and DIS (β = 0.108), the total indirect effects are highly significant ($p$ = 0.005 and $p$ = 0.003, respectively) and constitute 61% and 47% of their respective total effects. DIP's impact is transformed from a non-significant direct effect (β = 0.070, $p$ = 0.293) to a significant total effect (β = 0.180, $p$ = 0.010). In the same way, DIS's effect goes from a small, significant direct effect to a stronger, very significant total effect (β = 0.228, $p < 0.001$). DIC's already strong direct effect becomes the strongest total effect (β = 0.567, $p < 0.001$). Thus, this study demonstrates that supply chain tracking and traceability fundamentally result from improved information transparency, which serves as the primary mediator. The change from small or unimportant direct effects to large total effects is completely due to the mediated pathway through transparency.

To summarize, again, transparency is the major mediator by which digital practices are associated with supply chain tracking and traceability functions. This is actually inherent in the nature of tracking and traceability performance, which literally cannot be performed without information transparency. The DIC reveals a stronger total effect (β = 0.567), with 54% mediated, than DIS (β = 0.228, 47% mediated) and DIP (β = 0.180, 61% mediated). With DIP, indirect effects create a significant total relationship, where the direct relationship is non-significant. The practical implications are that managers who want to improve traceability, which is a key aspect of food safety and thus part of regulatory compliance, should focus on those digital integrations to enable improved transparency within the supply chain.

Effect on Supply Chain Food Loss (SFL):

Table 12 shows the direct, indirect, and total effects of digital practices on reducing food loss (SFL). It shows a clear and operationally focused way to reduce food losses in the supply chain. The results show that some digitalizing practices do reduce losses directly, but the biggest effect comes from the mediating effect of improving operational efficiency.

**Table 12.** Direct, indirect, and total effects of digital practices on reducing food losses (SFL).

| | | | | | | | | 95% CI | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Std. Estimate | *p* | Lower | Upper |
| **Direct effect paths of independent variables on SFL** | | | DIP | → | SFL | −0.201 | 0.012 | −0.358 | −0.044 |
| | | | DIS | → | SFL | −0.127 | 0.082 | −0.270 | 0.016 |
| | | | DIC | → | SFL | −0.242 | 0.022 | −0.450 | −0.034 |
| **Indirect effect paths on SFL through each mediation variable** | DIP | → | OE | → | SFL | −0.097 | 0.007 | −0.168 | −0.027 |
| | DIP | → | Tru | → | SFL | −0.005 | 0.705 | −0.028 | 0.019 |
| | DIP | → | Tra | → | SFL | −0.021 | 0.300 | −0.059 | 0.018 |
| | DIS | → | OE | → | SFL | −0.066 | 0.017 | −0.121 | −0.012 |
| | DIS | → | Tru | → | SFL | −0.010 | 0.699 | −0.060 | 0.040 |
| | DIS | → | Tra | → | SFL | −0.021 | 0.292 | −0.061 | 0.018 |
| | DIC | → | OE | → | SFL | −0.085 | 0.018 | −0.155 | −0.015 |
| | DIC | → | Tru | → | SFL | −0.016 | 0.699 | −0.095 | 0.063 |
| | DIC | → | Tra | → | SFL | −0.073 | 0.266 | −0.203 | 0.056 |
| **Total indirect effect of each independent variable on SFL** | | | DIP | → | SFL | −0.122 | 0.001 | −0.198 | −0.047 |
| | | | DIS | → | SFL | −0.097 | 0.006 | −0.167 | −0.027 |
| | | | DIC | → | SFL | −0.174 | 0.010 | −0.306 | −0.041 |
| **Total effect of each independent variable on SFL** | | | DIP | → | SFL | −0.323 | <0.001 | −0.479 | −0.168 |
| | | | DIS | → | SFL | −0.224 | 0.002 | −0.366 | −0.083 |
| | | | DIC | → | SFL | −0.416 | <0.001 | −0.597 | −0.235 |

The analysis reveals that digital customer integration (DIC) exhibits the strongest direct effect on reducing food loss (β = −0.242, $p$ = 0.022), followed by digital internal practices (DIP: β = −0.201, $p$ = 0.012). The direct path for digital supplier integration (DIS: β = −0.127, $p$ = 0.082) does not reach a level of statistical significance. This pattern suggests that while digital tools that focus on internal processes and customer interfaces can directly reduce food losses (for example, by improving demand forecasting or inventory management), a direct technological link to suppliers is not enough on its own.

One important finding from the mediation pathways is that operational efficiency (OE) is an important mediator that can help reduce food loss in all three digital practices. When direct and indirect effects come together through operational efficiency, they make the overall results stronger, turning small or insignificant direct contributions into strong overall impacts. The total indirect effect is big and significant for all practices, with DIC making the biggest mediated contribution (β = −0.174). As a result, the total effects are much stronger than just the direct effects. DIP's total effect (β = −0.323) is 61% bigger than its direct effect, for example. Most importantly, DIS's effect changes: its direct path, which was not significant (β = −0.127, $p$ = 0.082), becomes a significant total effect (β = −0.224, $p$ = 0.002) through the mediation of operational efficiency. Thus, based on the results of

this study, it can be argued that digitalization can help reduce food waste, but it works better when it helps make supply chain organizations more efficient.

To sum this section, all these digital practices are significantly related to reducing food loss, where DIC has the highest total effect in reducing food loss, followed by DIP and then DIS, whose total effects in reducing food loss are given by β = −0.416, β = −0.323, and β = −0.224, respectively. According to the opinion of the respondents, operational efficiency is the mediator variable through which these relations are realized. The result, therefore, implies to managers that digital investments should be made in enhancing operational efficiency in order to achieve the objective of reducing food losses, which is a great problem in developing countries like Ethiopia.

Effect on Supply Chain Environmental Sustainability Performance (SEn):

Table 13 shows how digital practices affect environmental sustainability (SEn). One practice shows a direct significant effect, while the other two only have an effect through mediated channels.

**Table 13.** Direct, indirect, and total effect of digital practices on environmental sustainability (SEn).

| | | | | | | | | 95% CI | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | **Std. Estimate** | ***p*** | **Lower** | **Upper** |
| **Direct effect paths of independent variables on Sen** | | | DIP | → | SEn | 0.046 | 0.501 | −0.087 | 0.179 |
| | | | DIS | → | SEn | 0.011 | 0.859 | −0.110 | 0.132 |
| | | | DIC | → | SEn | 0.405 | <0.001 | 0.229 | 0.581 |
| **Indirect effect paths on SEn through each mediation variable** | DIP | → | OE | → | SEn | 0.005 | 0.850 | −0.042 | 0.051 |
| | DIP | → | Tru | → | SEn | 0.032 | 0.127 | −0.009 | 0.073 |
| | DIP | → | Tra | → | SEn | 0.051 | 0.037 | 0.003 | 0.098 |
| | DIS | → | OE | → | SEn | 0.003 | 0.850 | −0.029 | 0.035 |
| | DIS | → | Tru | → | SEn | 0.069 | 0.012 | 0.015 | 0.123 |
| | DIS | → | Tra | → | SEn | 0.052 | 0.025 | 0.007 | 0.098 |
| | DIC | → | OE | → | SEn | 0.004 | 0.850 | −0.037 | 0.045 |
| | DIC | → | Tru | → | SEn | 0.109 | 0.007 | 0.030 | 0.188 |
| | DIC | → | Tra | → | SEn | 0.181 | 0.002 | 0.065 | 0.297 |
| **Total indirect effect of each independent variable on Sen** | | | DIP | → | SEn | 0.087 | 0.027 | 0.010 | 0.165 |
| | | | DIS | → | SEn | 0.124 | <0.001 | 0.053 | 0.196 |
| | | | DIC | → | SEn | 0.294 | <0.001 | 0.172 | 0.416 |
| **Total effect of each independent variable on SEn** | | | DIP | → | SEn | 0.133 | 0.061 | −0.006 | 0.272 |
| | | | DIS | → | SEn | 0.135 | 0.036 | 0.009 | 0.262 |
| | | | DIC | → | SEn | 0.699 | <0.001 | 0.540 | 0.858 |

In the direct pathways, digital integration with customers (DIC) has a strong and significant positive effect (β = 0.405, $p < 0.001$). Conversely, the direct effects of digital internal practices (DIP: β = 0.046, $p = 0.501$) and digital integration with suppliers (DIS: β = 0.011, $p = 0.859$) are statistically non-significant. Through mediation paths, practices that lack significant direct influence achieve impact via indirect routes. DIP affects SEn significantly through the transparency pathway (DIP → Tra → SEn: β = 0.051, $p = 0.037$). DIS improves SEn through mediated routes involving both trust (DIS → Tru → SEn: β = 0.069, $p = 0.012$) and transparency (β = 0.052, $p = 0.025$). DIC further amplifies its already significant direct effect through substantial mediation via transparency (β = 0.181, $p = 0.002$) and trust

(β = 0.109, $p$ = 0.007). These findings highlight that environmental sustainability would be driven basically by the relational and informational capabilities of trust and transparency.

The total effects for DIP and DIS are composed mostly of mediated contributions, which is what the sum of effects reports. The overall indirect effects for DIS (β = 0.124) and DIP (β = 0.087) are significant because they compose 92% and 65% of their total effects, respectively. This is remarkable, particularly in the case of DIS because it transforms a direct effect that was not statistically significant into a significant total effect.

Digital integration with customers is like an engine on multiple dimensions, improving the environmental sustainability performance directly and indirectly. It also builds the trust and transparency needed for long-term environmental sustainability co-creation. Overall, the results demonstrate that digitalization is good for the environmental sustainability performance enhancement; however, the main way it does this is by making the supply chain more transparent and trustworthy. This motivates joint investment to achieve environmental sustainability standards from all supply chain actors.

In sum, digital practices have a significant relationship with the enhancement of environmental sustainability through trust and transparency. It is observed that the total effect of DIC is the highest, at 0.699, with 42% of its effect mediated. On the other hand, the effect of DIS is almost entirely mediated, with 92%, while the effect of DIP is 65% mediated, largely through transparency. This means that, in practical terms, as digital integrations contribute to the enhancement of transparency and trust, the supply chain partners are motivated to achieve environmental sustainability goals. This may be due to the fact that the essence of environmental sustainability is beyond the organizational boundaries, such that joint investments, coordination, and compliance are required, for which trust and transparency are essential.

Effect on Supply Chain Economic Sustainability Performance (SEc):

Table 14 presents the effects of digital practices on economic sustainability performance (SEc). The results reveal how different forms of digitalization translate into economic sustainability.

On the direct pathways, the result in Table 14 shows digital integration with customers (DIC) exerts a strong and significant direct effect (β = 0.570, $p$ < 0.001). However, the direct effects of digital internal practices (DIP: β = 0.087, $p$ = 0.116) and digital integration with suppliers (DIS: β = 0.067, $p$ = 0.181) are not statistically significant.

On the mediation paths, the effect of the three types of digital practices on supply chain economic sustainability (SEc) is unlocked through targeted mediated pathways. Digital internal practices (DIP) achieve a significant indirect effect on SEc primarily through operational efficiency (DIP → OE → SEc: β = 0.045, $p$ = 0.040). Digital integration with supplier (DIS) influences SEc through a significant path involving trust (DIS → Tru → SEc: β = 0.043, $p$ = 0.034). Digital integration with customers (DIC) complements its strong direct effect with a significant additional mediated contribution through trust (DIC → Tru → SEc: β = 0.068, $p$ = 0.026).

The effects are important for all three practices when looking at the total indirect paths. These mediation effects explain 44% and 53% of the total effect for DIP and DIS, respectively. Mediation impacts the situation by rendering their statistically non-significant direct effects as total significant effects. On the total effects strength basis, the total effect strength is largest for DIC (β = 0.690), followed by DIP (β = 0.155), and then DIS (β = 0.144). The DIC has the strongest ability to impel the economic sustainability performance of the supply chain. The key mechanism through which the digitalization of internal practices (DIP) of the organizations impacts the achievement of the economic sustainability measure is through the operational efficiency (OE) mechanism. On the other hand, digital integration with suppliers (DIS) mainly improves economic sustainability by building trust (Tru).

**Table 14.** Direct, indirect, and total effect of digital practices on economic sustainability (SEc).

| | | | | | | | 95% CI | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Std. Estimate | *p* | Lower | Upper |
| **Direct effect paths of independent variables on SEc** | | | DIP | → SEc | 0.087 | 0.116 | −0.021 | 0.195 |
| | | | DIS | → SEc | 0.067 | 0.181 | −0.031 | 0.165 |
| | | | DIC | → SEc | 0.570 | <0.001 | 0.428 | 0.712 |
| **Indirect effect paths on SEc through each mediation variable** | DIP | → OE | → | SEc | 0.045 | 0.040 | 0.002 | 0.088 |
| | DIP | → Tru | → | SEc | 0.020 | 0.155 | −0.008 | 0.048 |
| | DIP | → Tra | → | SEc | 0.003 | 0.791 | −0.021 | 0.028 |
| | DIS | → OE | → | SEc | 0.031 | 0.058 | −0.001 | 0.062 |
| | DIS | → Tru | → | SEc | 0.043 | 0.034 | 0.003 | 0.083 |
| | DIS | → Tra | → | SEc | 0.003 | 0.791 | −0.022 | 0.029 |
| | DIC | → OE | → | SEc | 0.039 | 0.058 | −0.001 | 0.080 |
| | DIC | → Tru | → | SEc | 0.068 | 0.026 | 0.008 | 0.129 |
| | DIC | → Tra | → | SEc | 0.012 | 0.790 | −0.076 | 0.100 |
| **Total indirect effect of each independent variable on SEc** | | | DIP | → SEc | 0.068 | 0.010 | 0.016 | 0.120 |
| | | | DIS | → SEc | 0.077 | 0.002 | 0.029 | 0.126 |
| | | | DIC | → SEc | 0.119 | 0.010 | 0.029 | 0.210 |
| **Total effect of each independent variable on SEc** | | | DIP | → SEc | 0.155 | 0.005 | 0.048 | 0.262 |
| | | | DIS | → SEc | 0.144 | 0.004 | 0.047 | 0.242 |
| | | | DIC | → SEc | 0.690 | <0.001 | 0.567 | 0.813 |

In summary of this section, it can be stated that all three digital practices are significantly related to economic sustainability performance, but the mechanisms are different for each digital practice. The total effect is highest for DIC (β = 0.690), which combines both direct and indirect effects through trust. DIP affects economic sustainability performance through operational efficiency (44% mediated), while DIS affects economic sustainability performance through trust (53% mediated). The implications of these results are very important, as they indicate how digital practices are linked to ensuring economic sustainability in food supply chains by optimizing internal operations and building trust between suppliers and consumers, which are identified as the key factors for economic sustainability in this study.

Effect on Supply Chain Social Sustainability Performance (SSs):

The decomposition of results of the direct, indirect, and total effects of digital practices on social sustainability performance is presented in Table 15. Unlike the other performance outcomes in the previous section with mixed direct and mediated effects, social sustainability emerges as a performance dimension that is entirely influenced through mediation, underscoring that ethical and social value is co-created indirectly through enhanced capabilities rather than delivered directly by technology applications.

On the direct effect paths, digital internal practices (DIP: β = 0.085, *p* = 0.323), digital integration with suppliers (DIS: β = 0.092, *p* = 0.242), and digital integration with customers (DIC: β = 0.068, *p* = 0.552) are all non-significant.

On mediation paths, digital internal practices (DIP) contribute to SSs primarily through a strong, significant pathway via operational efficiency (DIP → OE → SSs: β = 0.135, *p* = 0.002). Digital integration with supplier (DIS) enhances social sustainability through significant mediated routes involving both operational efficiency (DIS → OE → SSs: β = 0.092,

$p = 0.008$) and trust (DIS → Tru → SSs: β = 0.072, $p = 0.027$). Digital integration with customers (DIC) shows the strongest mediated effect with the most substantial indirect paths via operational efficiency (β = 0.118, $p = 0.009$) and trust (β = 0.114, $p = 0.02$). The overall indirect effects are large and significant for all practices. In DIC, for example, the mediated effect (β = 0.315) represents an impressive 82% of its total effect. In DIP and DIS, it represents an impressive 69% and 67%, respectively.

**Table 15.** Direct, indirect, and total effects of digital practices on social sustainability (SSs).

| | | | | | | | | 95% CI | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Std. Estimate | *p* | Lower | Upper |
| **Direct effect paths of independent variables on SSs** | | | DIP | → | SSs | 0.085 | 0.323 | −0.084 | 0.255 |
| | | | DIS | → | SSs | 0.092 | 0.242 | −0.062 | 0.247 |
| | | | DIC | → | SSs | 0.068 | 0.552 | −0.156 | 0.293 |
| **Indirect effect paths on SSs through each mediation variable** | DIP | → | OE | → | SSs | 0.135 | 0.002 | 0.050 | 0.220 |
| | DIP | → | Tru | → | SSs | 0.034 | 0.147 | −0.012 | 0.079 |
| | DIP | → | Tra | → | SSs | 0.023 | 0.279 | −0.019 | 0.066 |
| | DIS | → | OE | → | SSs | 0.092 | 0.008 | 0.024 | 0.160 |
| | DIS | → | Tru | → | SSs | 0.072 | 0.027 | 0.008 | 0.136 |
| | DIS | → | Tra | → | SSs | 0.024 | 0.270 | −0.019 | 0.067 |
| | DIC | → | OE | → | SSs | 0.118 | 0.009 | 0.030 | 0.205 |
| | DIC | → | Tru | → | SSs | 0.114 | 0.020 | 0.018 | 0.210 |
| | DIC | → | Tra | → | SSs | 0.083 | 0.242 | −0.056 | 0.223 |
| **Total indirect effect of each independent variable on SSs** | | | DIP | → | SSs | 0.192 | <0.001 | 0.085 | 0.298 |
| | | | DIS | → | SSs | 0.188 | <0.001 | 0.091 | 0.286 |
| | | | DIC | → | SSs | 0.315 | <0.001 | 0.152 | 0.478 |
| **Total effect of each independent variable on SSs** | | | DIP | → | SSs | 0.277 | 0.003 | 0.096 | 0.459 |
| | | | DIS | → | SSs | 0.280 | <0.001 | 0.116 | 0.445 |
| | | | DIC | → | SSs | 0.383 | <0.001 | 0.172 | 0.594 |

In the total effect path, overall effects become important and relevant for all three types of digitalization practices. Total effect is highest for DIC (β = 0.383), followed by DIS (β = 0.280), and third is DIP (β = 0.277).

To sum up the association of digital practices with the social sustainability performance, it is found that no digital practice has a significant direct effect. All the relations are achieved entirely through indirect pathways; DIC shows the strongest total effect (β = 0.383), with 82% mediated through operational efficiency and trust. DIS (67% mediated) and DIP (69% mediated) also operate solely through these mediators. Practically, this means that digital practices and integrations are contributing to the social sustainability aspects of the supply chain only through their effects on enhancing efficient processes and trustworthy relationships, as these capabilities are identified as the key drivers of social sustainability, according to this study.

#### 4.2.3. Hypothesis Testing Summary

The results of this study, summarized in Figure 2, provide a clear visualization of the central finding: the relationship between digital practices and supply chain performance

is not solely direct but is fundamentally channeled through and amplified by enhanced capabilities (key mediators).

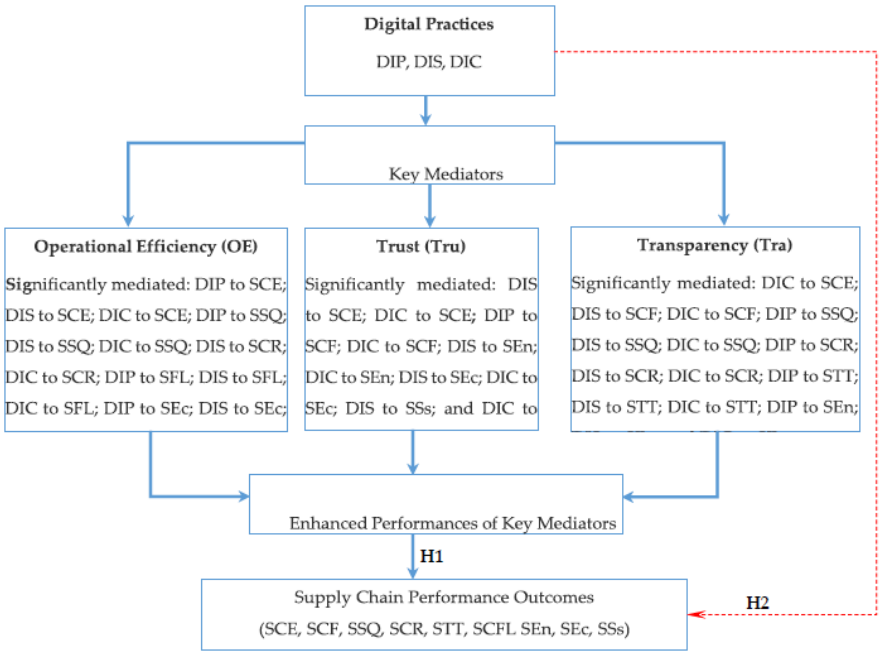


**Figure 2.** Summary of the hypothesis testing results.

The result shown in Figure 2 shows that digital practices (DIP, DIS, DIC) have an effect on performance outcomes through two types of pathways: direct effects (shown by broken red lines) and indirect, mediated effects (shown by solid blue lines). The lines in the diagram show how digitalization affects the performance outcomes of the supply chain. The bold, solid blue lines (H1) show the indirect paths. The study result fully supports the first hypothesis (H1), which states that digital supply chain practices have a significant effect on all performance outcomes through mediated pathways. The thin, broken red lines, on the other hand, show the second hypothesis (H2), which stated that digitalization would have a direct positive effect on performance. The line representation shows that this hypothesis was only partially supported, since more than half of the direct paths that were supposed to be there were not statistically significant. More importantly, the effect size for the significant direct paths was much smaller than for the mediated paths, both in terms of standardized estimates and *p*-values. In summary, these results support the main point that digitalization mostly affects supply chain performance in an indirect way, by improving capabilities instead of having a direct effect on each performance outcome. In conclusion, the solid lines dominate the model, showing that digitalization's strength comes from its ability to create the basic capabilities of operational efficiency, transparency, and trust, which in turn lead to better supply chain performance.

## 5. Discussion and Implication

This research aimed to determine the effect of digitalization on supply chain performance outcomes. The results reveal empirical support for a model of capabilities-based mediated model for the effect of digital practices on supply chain core and sustainability performance outcomes. The following section discusses some of the most interesting key findings, which are assumed to contain highly valuable insights for both theory and practical applications. This discussion is accomplished with the aid of relating to previously developed theories.

### 5.1. Implications for Theory

**Verified Mediation Model and Contributions to Existing Theories:** The essential result of this study is that the impacts of digitalization are predominantly realized through enhanced capabilities. This finding fits very well with basic strategic theories: the resource-based view (RBV), sociotechnical systems theory, and dynamic capabilities theory.

**Resource-Based View (RBV):** The results resonate with the resource-based view (RBV). According to RBV, a resource's value is typically demonstrated in one of two ways: either by its ability to lower a firm's costs or by its capacity to generate higher revenue [87]. Here, digital practices (DIP, DIS, DIC) are the valuable resources, but their economic and operational value is largely unlocked only when converted into the higher-order capabilities of operational efficiency (OE), transparency (Tra), and trust (Tru). Thus, our findings contribute to the core concept of RBV by showing the empirical results related to digital resources and the importance of focusing on the capabilities they foster rather than the technologies themselves.

**Sociotechnical Systems Theory:** The fact that digital practices are highly mediated by relational aspects such as trust and transparency is also supported by sociotechnical principles. As summarized from the 19 specific principles presented by ref. [88], sociotechnical principles form a framework intended to guide the design of work systems by ensuring that social (human, organizational) and technical (technological, procedural) aspects are treated as interdependent and jointly optimized. In line with this framework, the present study provides supporting evidence that challenges simplistic, techno-deterministic views of digital investment. Instead, it affirms a sociotechnical system's perspective, where optimal outcomes arise from the synergistic interaction of technology (the digital practices) and relational dynamics (the social subsystem) to maximize the potential of available resources.

**Dynamic Capabilities Theory:** *"Dynamic capabilities are a firm's behavioural orientation constantly to integrate, reconfigure, renew and recreate its resources and capabilities and, most importantly, upgrade and reconstruct its core capabilities in response to the changing environment to attain and sustain competitive advantage."* ([89], p. 35). This paper makes a contribution to the theory as it offers an empirical verification of its fundamental proposition that "the relationship between a firm's resource base and long-run performance is indirect, mediated by capability development and subject to strategic choice influence" ([89], p. 42). In the authors' hierarchical model representation, digital technologies/practices represent the zero-order resource base of a firm, the initial given resource base of a firm. In our model, the mediation variables: operational efficiency, transparency, and trust represent the first-order capabilities that utilize these resource bases effectively. Finally, the parameters of supply chain performance, including supply chain efficiency, flexibility, reliability, traceability, and sustainability, represent the performance outcomes that result when these capabilities are developed to a high degree to align with firm strategy. The high mediation effects demonstrate that dynamic capabilities do not act as direct variables but as indirect variables mediated through other variables. In our study, digital customer integration enables knowledge absorption via transparency; digital supplier integration enables learning via trust and transparency; digital internal practices optimize processes to heighten adaptive responsiveness. In sum, these findings support the dynamic capabilities theory that asserts that dynamic capabilities act as transformational mechanisms that reconfigure resource bases to create competitive advantage.

**Insight from the Minimal to Insignificant Direct Effects Compared to the Strong Indirect Paths:** This study shows that the value of digital investment comes more from its strategic purpose than from the technology itself. This is evidenced by the results, which show that the practices of digitalization enhance efficiency, trust, or transparency, and the like, which are drivers of supply chain efficiency.

The findings indicate the variation in impacts of the different digital practices on the outcome of the supply chain, where the effect of digital internal practices (DIP) occurs mainly through efficiency enhancement, but the activities of digital integration with customers (DIC) and digital integration with suppliers (DIS) appear to be undertaken for mediation (creation of trust and transparency) purposes. The findings are evidence of the applicability of the sociotechnical perspective that the key role of management is making design decisions [88]. Here, the critical managerial choice is defining the primary mediation purpose of the technological application. Thus, the managerial focus must shift from simply applying digital tools to different supply chain functions and expecting immediate outcome enhancements to strategically designing each tool's role within the sociotechnical system to target specific organizational capabilities such as operational efficiency, trust, or transparency.

**Unpacking the Pathways to Performance:** The main contribution of this research work is that it explores the role of digital practices in relation to different dimensions of performance. The outcomes of the proposed research work will provide empirical evidence regarding the role of digital practices in improving different dimensions of supply chain performance. The study found that the extent to which the three primary mediating factors, viz., operational efficiency, trust, and transparency, impact the realization of the three digital practices, viz., DIP, DIS, and DIC, is different.

Operational efficiency is found to be the basic engine that mediates around 60% of the important paths and is considered to be the most significant competency that enables the effective benefits of digital applications in general. It mediated DIP to supply chain efficiency and food loss reduction, among others. This emphasizes that to achieve the crucial role of digitalization, its design and evaluation need to be critically considered for their potential to improve operational efficiency. Trust is found to be acting as a relationship catalyst. It mainly mediated on paths of external integration practices (DIS, DIC) on adaptability and social benefits like supply chain flexibility and social sustainability. This shows an important boundary condition for enhancing relationship and adaptability capacities through digitalization. This result shows that it is essential to go beyond efficiency and develop partnership credibility. On the basis of the findings, transparency is found to be acting as an informational integrator. It is discovered to be a most significant mediator of benefits, demanding alignment and proper confirmation of specified information like supply chain food safety and quality, supply chain reliability, and tracking and traceability.

**Concise Comparison with Previous Studies:** In this sub-section, we briefly discuss some previous studies in comparison to the findings of the current study.

Although we took into consideration points of divergence in methodology and operationalization, our study is in agreement with ref. [90]. The study stated that e-business technologies do not directly impact and enhance efficient operational benefits but leverage through supplier integration and hence boost overall benefits of cost, quality, and adaptability.

Similarly, ref. [91] claims inter-organizational interactions mediate IT capabilities' consequences. According to the author, first, IT capabilities directly affect agri-food supply chain performance, and second, IT promotes inter-organizational interactions. Third, inter-organizational links improve agri-food supply chains. Finally, inter-organizational relationships mediate IT capabilities' indirect impact on the performance of agri-food supply chains. The authors' work has similarities with current findings in that both show the central importance of mediating factors, including inter-organizational capabilities.

Under a similar theme, ref. [92] demonstrated the mediating role of information integration and IT capabilities in achieving supply chain resilience in Uganda's agro-food supply chain. The research by ref. [93] also indicates that the importance of strategic inte-

gration of sustainable practices with particular digital technologies, such as IoT and machine learning, enhances circular supply chains and elevates organizational performance.

The literature related to the digitalization of food supply chains in different countries indicates a certain degree of divergence. In developed countries with well-developed digital infrastructures, recent research in this area tends to focus on a number of cutting-edge technologies. For example, as far as the applications of digitalization in the agri-food system are concerned, in developed countries, the literature shows that technology-wise the application of blockchain technologies (BCT), which are often related to Internet of Things (IoT) devices and radio-frequency identification (RFID) tags is dominating while purpose wise food traceability and safety are dominant issues of the discussions [54,94]. These studies are based on the analysis of existing evidence of implemented systems and thus indicate a well-developed digital environment in which different technologies can be implemented and analyzed separately. With a constrained state of digital and supporting infrastructures, the literature related to developing countries, especially those in Africa, in contrast, focuses on basic digitalization, often in packages rather than specific cutting-edge technologies or the feasibility and constraints of the applications of cutting-edge technologies [95,96]. The studies in developing countries mainly underline the importance of practicality, adoption constraints, scalability issues, and context-sensitive solutions that take into consideration socioeconomic and infrastructure realities. This discrepancy in the literature serves to highlight the significance of contextualizing digitalization literature; that is, while literature from developed nations seeks to identify how particular digital technologies might be used to further optimize already efficient systems, the literature from developing nations seeks to identify how digital technologies might be used to develop basic capabilities, which is in line with the findings of the current study.

As we enter the transition toward the Industry 5.0 concept, which underscores human–machine collaboration, sustainability, and the circular economy, digitalization is the central enabling mechanism offering a framework for the advancement of all sectors (agriculture, health, food systems, etc.) [97]. However, in order to use the resources' promise effectively to enhance efficiency, reliability, resilience, traceability, and overall sustainability, it is essential to study and document where digitalization offers value and plan accordingly. Thus, studies like ours are essential for uncovering the potential of these digital technologies. Hence, the capabilities digitalization fosters, which ultimately lead to better performance outcomes, require great attention by managers of food supply chains in developing countries like Ethiopia.

In sum, the main point of the current study and a few similar previous studies is that leaders must plan their digitalization strategies by asking, "What core capabilities do we need to develop through our digitalization initiatives to achieve our end goals?" If the main goal is to achieve profitability, economic sustainability, or improve efficiency, or something related to that, the digitalization effort should be planned and evaluated primarily based on how much it improves operational efficiency (OE). Building trust and transparency must come first in the process if the goal is to make it a more reliable, flexible, or traceable food supply chain. Overall, digitalization practices need to be planned and evaluated based on how well they help to enhance operational efficiency, build trust along the supply chains, and create information transparency. These efforts together help to achieve the most difficult and multifaceted goals, like achieving holistic sustainability of food supply chains.

### *5.2. Implications for Practice and Policy*

Our research provides clear recommendations to managers and policymakers in developing countries. Our key finding is that the value of digitalization does not lie in the

adoption of technology but rather in the strategic development of the key capabilities identified in this research: operational efficiency, trust, and transparency.

Our research provides the following recommendations to managers of firms operating in developing countries. The value of digitalization does not lie in the adoption of technology but rather in the strategic development of the key capabilities identified in this research: operational efficiency, trust, and transparency. Therefore, managers should evaluate their investments based on their capacity to strengthen the identified key capabilities rather than the sophistication of the technology. For instance, according to the findings of this study, if the objective is to improve efficiency or reduce food loss, then the investment in digital technology should improve operational efficiency by internal process optimization. If the objective is flexibility, reliability, or traceability, then investment in external integration with customers and suppliers should improve trust and transparency. Digital integration with customers was found to have the greatest power as a driver for various performance dimensions, implying that investment in this area would yield the greatest return if relational capital and information sharing are achieved. Managers should therefore assess investment in digital technology based on the ability to improve these capabilities.

For policymakers, the implication of the study remains the same as for managers, i.e., the need to support capability development rather than the promotion of technology acquisition. For policymakers, the digital policies should aim at capability development and be aligned with organizational strategies for economic viability, environmental sustainability, and social responsibility, as these are dependent on internal operational efficiency, information sharing (transparency), and trust. Therefore, food supply chain digital policies, as they are crosscutting and integral to all objectives, should be evaluated with the capabilities they develop instead of the size and complexities of the technological facilities themselves.

### *5.3. Limitations of the Study and Future Research Directions*

Although the insights from this research are valuable, the limitations of the research methodology need to be acknowledged. As the research is based on data derived from a single firm, self-reported, same source perceptual, and for conceptually interconnected constructs using survey research methodology, the results will be prone to the "optimistic bias," whereby people tend to overestimate the advantages of their digital practices because they tend to embrace digitalization positively. Moreover, the five-point Likert scale may not capture the full range of responses and may be affected by response biases such as central tendency and extreme response biases. The research team attempted to alleviate this problem through preliminary interviews and personal observation of the digitalization practices at the case company, but future research should attempt to validate the results using objective, quantitative measures of performance outcomes such as cycle times and waste ratios, etc.

Moreover, due to the cross-sectional, self-reported nature of the data, the findings represent statistical associations; hence, the term 'effect' is used in the statistical sense to denote estimated path coefficients and represents associations, not real causal effects. The other limitation is the aggregated digitalization measurement. This study looks at digital transformation as a whole, not just specific technologies like blockchain, the Internet of Things, or data analytics. Additionally, the limited number of external respondents impedes the execution of multi-group SEM analysis, constraining the comparative examination of various stakeholders' perspectives.

Thus, specific technology-oriented studies involving multi-group and multi-industry contexts and further studies are needed in different contexts to further corroborate the findings. Moreover, how Industry 5.0 will affect the digitalization of food supply chains in developing countries requires further research attention.

## 6. Conclusions

This study has conducted an in-depth analysis of the pathways through which digitalization influences supply chain performance, using data from K.O.J.J. Food Complex in Ethiopia and its suppliers and customers. The research tested direct and indirect pathways linking three digital practices through three mediators to nine supply chain performance outcomes. The findings validate a dual-pathway influence model, confirming that digital practices (DIP, DIS, DIC) affect performance through both direct and indirect, capability-mediated routes, with the mediation route emerging as the more significant and transformative mechanism for performance enhancement.

The analysis produces several significant insights. First, while direct effects exist and are significant for certain relationships (particularly for digital integration with customers concerning outcomes such as economic and environmental sustainability), a solely direct-impact model is inadequate. More than half of the proposed direct paths did not show statistical significance. Second, and most importantly, the total effects of digitalization are universally important and much stronger than direct effects. That indicates that the core value of digitalization comes from assisting organizations in building their core capabilities.

Operational efficiency is the most crucial mediator for mediating digital practices to the largest number of performance outcomes (60% of the paths through operational efficiency were statistically significant), including supply chain efficiency, cutting down on food waste, and economic sustainability. Transparency is the most important mediator that links digitalization effect to information-dependent supply chain outcomes such as food safety and quality, reliability, flexibility, environmental sustainability, and traceability. Similarly, trust is a key factor in relationship-dependent supply chain performance outcomes, as it mediates external digital integration influence on supply chain flexibility and economic and social sustainability outcomes.

The findings support the sociotechnical, resource-based, and dynamic capabilities theories because digital technologies are valuable assets whose potential is realized through converting them into advanced capabilities. Success for managers, therefore, has to arise from carefully planning a digital project with the view to developing certain capabilities. In this case, operational efficiency for process excellence, transparency for visibility and control, and finally, trust for collaborative adaptability are emphasized.

In sum, digitalization is a powerful driver of supply chain performance, but direct influences are far less significant compared to its strong indirect influences on performance outcomes. Therefore, leaders must design a digital transformation with a capabilities-first mindset. In other words, this calls for alignment so that technology investments are carefully matched with the development of an operational, informational, and relational fabric that will be necessary for efficient, reliable, flexible, and sustainable supply chains.

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**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study.

**Data Availability Statement:** The raw data supporting the conclusions of this article will be made available by the authors on request.

**Conflicts of Interest:** The authors declare no conflict of interest.

## Abbreviations

The following abbreviations are used in this manuscript:

| | |
|---|---|
| AI | Artificial Intelligence |
| BCT | Blockchain Technology |
| BDA | Big Data Analytics |
| EDI | Electronic Data Interchange |
| ERP | Enterprise Resource Planning |
| GIS | Geographic Information Systems |
| IoT | Internet of Things |
| ML | Machine Learning |
| MRP | Material Requirements Planning |
| MRPII | Manufacturing Resource Planning |
| RFID | Radio-Frequency Identification |
| SMA | Social Media Analytics |
| VMI | Vendor Managed Inventory |
| DIP | Digital Internal Practices |
| DIS | Digital Integration with Suppliers |
| DIC | Digital Integration with Customers |
| OE | Operational Efficiency |
| Tra | Transparency |
| Tru | Trust |
| SCE | Supply Chain Efficiency |
| SCF | Supply Chain Flexibility |
| SSQ | Supply Chain Food Safety and Quality |
| SCR | Supply Chain Reliability |
| STT | Supply Chain Tracking and Traceability |
| SFL | Supply Chain Food Loss |
| SEn | Supply Chain Environmental Sustainability |
| SEc | Supply Chain Economic Sustainability |
| SSs | Supply Chain Social Sustainability |

## Appendix A. Complete Set of Model Fit Indices

***Model Fit***

| | | | | n (Parameters) | | Baseline Test | | |
|---|---|---|---|---|---|---|---|---|
| | **AIC** | **BIC** | **n (Observations)** | **Total** | **Free** | $\chi^2$ | **Df** | **p** |
| Model 1 | −579.9 | −279.8 | 153 | 99 | 99 | 32.08 | 15.00 | 0.006 |

Note: Estimator is ML. The model test is standard. An information matrix is expected. Standard errors are standard.

**Additional Fit Measures**

| *Fit Indices* | |
|---|---|
| **Index** | **Value** |
| Comparative Fit Index (CFI) | 0.996 |
| Tucker–Lewis Index (TLI) | 0.976 |
| Bentler-Bonett Non-normed Fit Index (NNFI) | 0.976 |
| Bentler-Bonett Normed Fit Index (NFI) | 0.993 |
| Parsimony Normed Fit Index (PNFI) | 0.146 |
| Bollen's Relative Fit Index (RFI) | 0.956 |
| Bollen's Incremental Fit Index (IFI) | 0.997 |
| Relative Noncentrality Index (RNI) | 0.996 |
| Root mean square error of approximation (RMSEA) | 0.086 |
| RMSEA 90% CI lower bound | 0.044 |
| RMSEA 90% CI upper bound | 0.128 |
| RMSEA *p*-value | 0.073 |
| Standardized root mean square residual (SRMR) | 0.005 |
| Hoelter's critical N ($\alpha = 0.05$) | 120.206 |
| Hoelter's critical N ($\alpha = 0.01$) | 146.827 |
| Goodness of fit index (GFI) | 1.000 |
| McDonald fit index (MFI) | 0.946 |
| Expected cross validation index (ECVI) | 1.504 |
| Log-likelihood | 388.931 |
| Number of free parameters | 99.000 |
| Akaike (AIC) | −579.862 |
| Bayesian (BIC) | −279.849 |
| Sample-size adjusted Bayesian (SSABIC) | −593.190 |

| *T-Size Fit Indices* | | |
|---|---|---|
| | **CFI** | **RMSEA** |
| Estimate | 0.991 | 0.128 |
| Poor-fair limit | 0.819 | 0.124 |
| Fair-close limit | 0.892 | 0.098 |

Note: T-size statistics are computed for $\alpha = 0.05$.

| *R-Squared* | |
|---|---|
| | **$R^2$** |
| SCE | 0.952 |
| SEc | 0.947 |
| SSQ | 0.934 |
| SCR | 0.953 |
| STT | 0.925 |
| SFL | 0.890 |

| *R-Squared* | |
|---|---|
| | **$R^2$** |
| SEn | 0.922 |
| SCF | 0.948 |
| SSs | 0.870 |
| OE | 0.857 |
| Tru | 0.865 |
| Tra | 0.919 |

## Appendix B. Confirmatory Factor Analysis—For One Variable—DIP

**Model fit**

| *Chi-Square Test* | | | |
|---|---|---|---|
| **Model** | **$X^2$** | **Df** | **p** |
| Baseline model | 1244.110 | 6 | |
| Factor model | 5.111 | 2 | 0.078 |

Note: The estimator is DWLS. The test statistic is scaled and shifted. The standard error method is robust.

| *R-Squared* | |
|---|---|
| | **$R^2$** |
| DIP1 | 0.510 |
| DIP2 | 0.728 |
| DIP3 | 0.712 |
| DIP4 | 0.563 |

**Parameter estimates**

| *Factor Loadings* | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | **95% Confidence Interval** | |
| **Factor** | **Indicator** | **Std. Estimate** | **Std. Error** | **z-Value** | ***p*** | **Lower** | **Upper** |
| Factor 1 | DIP1 | 0.714 | 0.037 | 19.53 | <0.001 | 0.642 | 0.786 |
| | DIP2 | 0.853 | 0.030 | 28.14 | <0.001 | 0.794 | 0.912 |
| | DIP3 | 0.844 | 0.033 | 25.30 | <0.001 | 0.779 | 0.909 |
| | DIP4 | 0.750 | 0.030 | 25.41 | <0.001 | 0.693 | 0.808 |

| *Factor Variances* | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | **95% Confidence Interval** | |
| **Factor** | **Std. Estimate** | **Std. Error** | **z-Value** | **p** | **Lower** | **Upper** |
| Factor 1 | 1.000 | 0.000 | | | 1.000 | 1.000 |

| *Residual Variances* | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | 95% Confidence Interval | |
| **Indicator** | **Std. Estimate** | **Std. Error** | **z-Value** | **p** | **Lower** | **Upper** |
| DIP1 | 0.490 | 0.052 | 9.383 | <0.001 | 0.388 | 0.592 |
| DIP2 | 0.272 | 0.052 | 5.269 | <0.001 | 0.171 | 0.374 |
| DIP3 | 0.288 | 0.056 | 5.104 | <0.001 | 0.177 | 0.398 |
| DIP4 | 0.437 | 0.044 | 9.854 | <0.001 | 0.350 | 0.524 |

| *Thresholds* | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | 95% Confidence Interval | |
| **Indicator** | **Threshold** | **Estimate** | **Std. Error** | **z-Value** | **p** | **Lower** | **Upper** |
| DIP1 | t1 | −2.224 | 0.274 | −8.120 | $4.441 \times 10^{-16}$ | −2.761 | −1.687 |
| | t2 | −1.293 | 0.139 | −9.271 | 0.000 | −1.566 | −1.020 |
| | t3 | 0.074 | 0.102 | 0.725 | 0.468 | −0.126 | 0.273 |
| | t4 | 0.904 | 0.118 | 7.642 | $2.132 \times 10^{-14}$ | 0.672 | 1.136 |
| DIP2 | t1 | −2.224 | 0.274 | −8.120 | $4.441 \times 10^{-16}$ | −2.761 | −1.687 |
| | t2 | −1.035 | 0.124 | −8.337 | 0.000 | −1.278 | −0.792 |
| | t3 | 0.173 | 0.102 | 1.691 | 0.091 | −0.027 | 0.373 |
| | t4 | 0.904 | 0.118 | 7.642 | $2.132 \times 10^{-14}$ | 0.672 | 1.136 |
| DIP3 | t1 | −2.224 | 0.274 | −8.120 | $4.441 \times 10^{-16}$ | −2.761 | −1.687 |
| | t2 | −1.123 | 0.129 | −8.722 | 0.000 | −1.375 | −0.871 |
| | t3 | 0.074 | 0.102 | 0.725 | 0.468 | −0.126 | 0.273 |
| | t4 | 0.981 | 0.122 | 8.066 | $6.661 \times 10^{-16}$ | 0.742 | 1.219 |
| DIP4 | t1 | −2.482 | 0.356 | −6.964 | $3.298 \times 10^{-12}$ | −3.180 | −1.783 |
| | t2 | −1.256 | 0.137 | −9.174 | 0.000 | −1.524 | −0.988 |
| | t3 | 0.107 | 0.102 | 1.047 | 0.295 | −0.093 | 0.306 |
| | t4 | 0.787 | 0.114 | 6.904 | $5.043 \times 10^{-12}$ | 0.563 | 1.010 |

| *Residual Covariance Matrix* | | | |
|---|---|---|---|
| **DIP1** | **DIP2** | **DIP3** | **DIP4** |
| <0.0 | | | |
| <0.0 | <0.0 | | |
| <0.0 | 0.022 | <0.0 | |
| 0.041 | <0.0 | <0.0 | <0.0 |

| *Heterotrait-Monotrait Ratio* |
|---|
| **Factor 1** |
| 1.000 |

**Modification Indices**

The analysis result showed no modification index was above the cutoff

How the composite reliability (CR) and average variance extracted (AVE) are calculated

| Item | Loading (λ) | $\lambda^2$ | $1-\lambda^2$ |
|---|---|---|---|
| **DIP1** | 0.714 | 0.510 | 0.490 |
| **DIP2** | 0.853 | 0.728 | 0.272 |
| **DIP3** | 0.844 | 0.712 | 0.288 |
| **DIP4** | 0.750 | 0.563 | 0.437 |
| **SUM** | 3.161 | 2.513 | 1.487 |

$CR = (\Sigma\lambda)^2/[(\Sigma\lambda)^2 + \Sigma(1 - \lambda^2)]$
$CR = (3.161)^2/[(3.161)^2 + 1.487] = 9.992/(9.992 + 1.487) = 9.992/11.479 = 0.870$
$AVE = \Sigma(\lambda^2)/n$
$AVE = 2.513/4 = 0.628$

## Appendix C. Bootstrap Confidence Intervals for Indirect Effects

*Indirect Effects*

| | | | | | | | | | 95% Confidence Interval | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Std. Estimate | Std. Error | z-Value | p | Lower | Upper |
| DIP | → | OE | → | SCE | 0.096 | 0.042 | 2.310 | 0.021 | 0.037 | 0.191 |
| DIP | → | Tru | → | SCE | 0.031 | 0.021 | 1.465 | 0.143 | −0.004 | 0.082 |
| DIP | → | Tra | → | SCE | 0.028 | 0.015 | 1.871 | 0.061 | 0.006 | 0.068 |
| DIS | → | OE | → | SCE | 0.065 | 0.028 | 2.344 | 0.019 | 0.024 | 0.138 |
| DIS | → | Tru | → | SCE | 0.067 | 0.026 | 2.622 | 0.009 | 0.027 | 0.134 |
| DIS | → | Tra | → | SCE | 0.029 | 0.017 | 1.674 | 0.094 | 0.006 | 0.077 |
| DIC | → | OE | → | SCE | 0.084 | 0.037 | 2.275 | 0.023 | 0.034 | 0.194 |
| DIC | → | Tru | → | SCE | 0.106 | 0.038 | 2.764 | 0.006 | 0.049 | 0.202 |
| DIC | → | Tra | → | SCE | 0.099 | 0.046 | 2.169 | 0.030 | 0.019 | 0.202 |
| DIP | → | OE | → | SEc | 0.045 | 0.024 | 1.863 | 0.062 | 0.010 | 0.106 |
| DIP | → | Tru | → | SEc | 0.020 | 0.017 | 1.210 | 0.226 | −0.001 | 0.067 |
| DIP | → | Tra | → | SEc | 0.003 | 0.013 | 0.260 | 0.795 | −0.025 | 0.028 |
| DIS | → | OE | → | SEc | 0.031 | 0.017 | 1.806 | 0.071 | 0.006 | 0.080 |
| DIS | → | Tru | → | SEc | 0.043 | 0.024 | 1.792 | 0.073 | 0.009 | 0.112 |
| DIS | → | Tra | → | SEc | 0.003 | 0.013 | 0.256 | 0.798 | −0.023 | 0.030 |
| DIC | → | OE | → | SEc | 0.039 | 0.020 | 1.961 | 0.050 | 0.010 | 0.100 |
| DIC | → | Tru | → | SEc | 0.068 | 0.038 | 1.820 | 0.069 | 0.014 | 0.172 |
| DIC | → | Tra | → | SEc | 0.012 | 0.046 | 0.260 | 0.795 | −0.083 | 0.102 |
| DIP | → | OE | → | SSQ | 0.107 | 0.047 | 2.292 | 0.022 | 0.039 | 0.223 |
| DIP | → | Tru | → | SSQ | 0.010 | 0.015 | 0.644 | 0.520 | −0.006 | 0.072 |
| DIP | → | Tra | → | SSQ | 0.061 | 0.037 | 1.615 | 0.106 | 0.005 | 0.158 |
| DIS | → | OE | → | SSQ | 0.073 | 0.031 | 2.350 | 0.019 | 0.029 | 0.154 |
| DIS | → | Tru | → | SSQ | 0.021 | 0.026 | 0.813 | 0.416 | −0.021 | 0.101 |
| DIS | → | Tra | → | SSQ | 0.062 | 0.040 | 1.576 | 0.115 | 0.008 | 0.180 |
| DIC | → | OE | → | SSQ | 0.093 | 0.039 | 2.406 | 0.016 | 0.037 | 0.211 |
| DIC | → | Tru | → | SSQ | 0.034 | 0.038 | 0.887 | 0.375 | −0.029 | 0.124 |

***Indirect Effects***

| | | | | | | | | | 95% Confidence Interval | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Std. Estimate | Std. Error | z-Value | p | Lower | Upper |
| DIC | → | Tra | → | SSQ | 0.216 | 0.083 | 2.613 | 0.009 | 0.060 | 0.392 |
| DIP | → | OE | → | SCR | 0.052 | 0.030 | 1.747 | 0.081 | 0.015 | 0.156 |
| DIP | → | Tru | → | SCR | 0.013 | 0.011 | 1.127 | 0.260 | −0.001 | 0.045 |
| DIP | → | Tra | → | SCR | 0.081 | 0.029 | 2.744 | 0.006 | 0.033 | 0.149 |
| DIS | → | OE | → | SCR | 0.035 | 0.022 | 1.596 | 0.110 | 0.006 | 0.097 |
| DIS | → | Tru | → | SCR | 0.028 | 0.021 | 1.331 | 0.183 | −0.003 | 0.076 |
| DIS | → | Tra | → | SCR | 0.083 | 0.031 | 2.678 | 0.007 | 0.031 | 0.156 |
| DIC | → | OE | → | SCR | 0.045 | 0.027 | 1.681 | 0.093 | 0.011 | 0.135 |
| DIC | → | Tru | → | SCR | 0.044 | 0.034 | 1.288 | 0.198 | −0.005 | 0.126 |
| DIC | → | Tra | → | SCR | 0.288 | 0.092 | 3.140 | 0.002 | 0.141 | 0.496 |
| DIP | → | OE | → | STT | 0.032 | 0.027 | 1.196 | 0.232 | −0.004 | 0.108 |
| DIP | → | Tru | → | STT | 0.005 | 0.017 | 0.285 | 0.775 | −0.017 | 0.050 |
| DIP | → | Tra | → | STT | 0.074 | 0.029 | 2.528 | 0.011 | 0.031 | 0.147 |
| DIS | → | OE | → | STT | 0.022 | 0.015 | 1.404 | 0.160 | −0.001 | 0.063 |
| DIS | → | Tru | → | STT | 0.010 | 0.030 | 0.341 | 0.733 | −0.043 | 0.070 |
| DIS | → | Tra | → | STT | 0.076 | 0.035 | 2.152 | 0.031 | 0.023 | 0.169 |
| DIC | → | OE | → | STT | 0.028 | 0.020 | 1.367 | 0.172 | 0.001 | 0.096 |
| DIC | → | Tru | → | STT | 0.016 | 0.046 | 0.347 | 0.728 | −0.067 | 0.109 |
| DIC | → | Tra | → | STT | 0.264 | 0.115 | 2.288 | 0.022 | 0.087 | 0.501 |
| DIP | → | OE | → | SFL | −0.097 | 0.049 | −1.987 | 0.047 | −0.225 | −0.028 |
| DIP | → | Tru | → | SFL | −0.005 | 0.013 | −0.358 | 0.720 | −0.042 | 0.015 |
| DIP | → | Tra | → | SFL | −0.021 | 0.023 | −0.899 | 0.368 | −0.071 | 0.020 |
| DIS | → | OE | → | SFL | −0.066 | 0.033 | −2.041 | 0.041 | −0.153 | −0.021 |
| DIS | → | Tru | → | SFL | −0.010 | 0.024 | −0.412 | 0.680 | −0.055 | 0.035 |
| DIS | → | Tra | → | SFL | −0.021 | 0.025 | −0.858 | 0.391 | −0.078 | 0.019 |
| DIC | → | OE | → | SFL | −0.085 | 0.038 | −2.217 | 0.027 | −0.191 | −0.029 |
| DIC | → | Tru | → | SFL | −0.016 | 0.040 | −0.389 | 0.697 | −0.107 | 0.047 |
| DIC | → | Tra | → | SFL | −0.073 | 0.086 | −0.855 | 0.392 | −0.273 | 0.065 |
| DIP | → | OE | → | SEn | 0.005 | 0.029 | 0.154 | 0.878 | −0.042 | 0.082 |
| DIP | → | Tru | → | SEn | 0.032 | 0.023 | 1.382 | 0.167 | −0.003 | 0.086 |
| DIP | → | Tra | → | SEn | 0.051 | 0.030 | 1.684 | 0.092 | 0.008 | 0.133 |
| DIS | → | OE | → | SEn | 0.003 | 0.020 | 0.153 | 0.878 | −0.025 | 0.063 |
| DIS | → | Tru | → | SEn | 0.069 | 0.032 | 2.166 | 0.030 | 0.022 | 0.144 |
| DIS | → | Tra | → | SEn | 0.052 | 0.034 | 1.528 | 0.127 | 0.008 | 0.140 |
| DIC | → | OE | → | SEn | 0.004 | 0.024 | 0.166 | 0.868 | −0.033 | 0.071 |
| DIC | → | Tru | → | SEn | 0.109 | 0.055 | 1.995 | 0.046 | 0.024 | 0.235 |
| DIC | → | Tra | → | SEn | 0.181 | 0.123 | 1.473 | 0.141 | 0.007 | 0.458 |
| DIP | → | OE | → | SCF | 0.017 | 0.023 | 0.746 | 0.456 | −0.016 | 0.080 |

| *Indirect Effects* | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 95% Confidence Interval | |
| | | | | | Std. Estimate | Std. Error | z-Value | p | Lower | Upper |
| DIP | → | Tru | → | SCF | 0.026 | 0.020 | 1.260 | 0.208 | −0.002 | 0.080 |
| DIP | → | Tra | → | SCF | 0.041 | 0.022 | 1.843 | 0.065 | 0.007 | 0.095 |
| DIS | → | OE | → | SCF | 0.012 | 0.015 | 0.762 | 0.446 | −0.011 | 0.056 |
| DIS | → | Tru | → | SCF | 0.055 | 0.027 | 2.019 | 0.043 | 0.016 | 0.127 |
| DIS | → | Tra | → | SCF | 0.042 | 0.026 | 1.621 | 0.105 | 0.007 | 0.110 |
| DIC | → | OE | → | SCF | 0.015 | 0.019 | 0.787 | 0.431 | −0.013 | 0.076 |
| DIC | → | Tru | → | SCF | 0.088 | 0.044 | 1.976 | 0.048 | 0.021 | 0.185 |
| DIC | → | Tra | → | SCF | 0.146 | 0.081 | 1.808 | 0.071 | 0.010 | 0.314 |
| DIP | → | OE | → | SSs | 0.135 | 0.067 | 2.005 | 0.045 | 0.036 | 0.318 |
| DIP | → | Tru | → | SSs | 0.034 | 0.030 | 1.103 | 0.270 | −0.003 | 0.117 |
| DIP | → | Tra | → | SSs | 0.023 | 0.023 | 1.036 | 0.300 | −0.012 | 0.078 |
| DIS | → | OE | → | SSs | 0.092 | 0.051 | 1.821 | 0.069 | 0.021 | 0.226 |
| DIS | → | Tru | → | SSs | 0.072 | 0.034 | 2.096 | 0.036 | 0.013 | 0.155 |
| DIS | → | Tra | → | SSs | 0.024 | 0.023 | 1.049 | 0.294 | −0.013 | 0.086 |
| DIC | → | OE | → | SSs | 0.118 | 0.066 | 1.777 | 0.076 | 0.026 | 0.308 |
| DIC | → | Tru | → | SSs | 0.114 | 0.058 | 1.952 | 0.051 | 0.020 | 0.267 |
| DIC | → | Tra | → | SSs | 0.083 | 0.072 | 1.159 | 0.247 | −0.063 | 0.228 |

Note: Estimator is ML. Not all bootstrap samples were successful: CI based on 837 samples.

## Appendix D. Sampling Adequacy and Factorability Assessment

| Kaiser-Meyer-Olkin Test | |
|---|---|
| | **MSA** |
| Overall MSA | 0.954 |
| DIC1 | 0.956 |
| DIC2 | 0.948 |
| DIC3 | 0.949 |
| DIC4 | 0.965 |
| DIP1 | 0.966 |
| DIP2 | 0.976 |
| DIP3 | 0.970 |
| DIP4 | 0.979 |
| DIS1 | 0.962 |
| DIS2 | 0.969 |
| DIS3 | 0.985 |
| DIS4 | 0.980 |
| OE1 | 0.971 |
| OE2 | 0.964 |

| Kaiser-Meyer-Olkin Test | |
|---|---|
| | **MSA** |
| OE3 | 0.973 |
| OE4 | 0.978 |
| SCE1 | 0.932 |
| SCE2 | 0.931 |
| SCE3 | 0.926 |
| SCE4 | 0.932 |
| SCF1 | 0.970 |
| SCF2 | 0.972 |
| SCF3 | 0.959 |
| SCF4 | 0.957 |
| SCR1 | 0.956 |
| SCR2 | 0.936 |
| SCR3 | 0.945 |
| SCR4 | 0.915 |
| SEc1 | 0.913 |
| SEc2 | 0.940 |
| SEc3 | 0.932 |
| SEc4 | 0.923 |
| SEn1 | 0.970 |
| SEn2 | 0.953 |
| SEn3 | 0.971 |
| SEn4 | 0.976 |
| SFL1 | 0.965 |
| SFL2 | 0.964 |
| SFL3 | 0.977 |
| SFL4 | 0.959 |
| SSQ1 | 0.950 |
| SSQ2 | 0.958 |
| SSQ3 | 0.924 |
| SSQ4 | 0.926 |
| SSs1 | 0.969 |
| SSs2 | 0.961 |
| SSs3 | 0.970 |
| SSs4 | 0.970 |
| STT1 | 0.963 |
| STT2 | 0.935 |
| STT3 | 0.937 |
| STT4 | 0.974 |

| Kaiser-Meyer-Olkin Test | |
|---|---|
| | **MSA** |
| Tra1 | 0.927 |
| Tra2 | 0.940 |
| Tra3 | 0.931 |
| Tra4 | 0.920 |
| Tru1 | 0.980 |
| Tru2 | 0.954 |
| Tru3 | 0.955 |
| Tru4 | 0.964 |

| Bartlett's Test | | |
|---|---|---|
| **$X^2$** | **Df** | **p** |
| 10,480.487 | 1770.000 | <0.001 |

## Appendix E. Data Collection Protocol

Dear Participants,

Thank you for your willingness to take part in this survey, which assesses how digital activities affect various core and sustainability supply chain performance outcomes. Please consider the claims in each area in light of your company's attempts to integrate digital technologies. Give your response based on your level of agreement with the statement, with 1 being the most disagreeable and 5 being the most agreeable. Give your reaction by marking an 'X' in the column (level of agreement on a Likert scale rating) for each statement. Thank you again for your participation, and we assure you that the data will be used for academic purposes; there is no requirement to include your personal details in the questionnaire.

| | | **Level of Agreement** | | | | |
|---|---|---|---|---|---|---|
| **Independent Variables** | | **1** | **2** | **3** | **4** | **5** |
| **Digital Internal Practices (DIP)**—This measures how digital technologies are used to connect and automate internal functions. | | | | | | |
| 1. | We use an integrated software system (like ERP) to keep track of important parts of our business, such as finance, inventory, and production. | 1 | 2 | 3 | 4 | 5 |
| 2. | Data automatically moves between different departments within the company, such as from sales to planning for production. | 1 | 2 | 3 | 4 | 5 |
| 3. | We control how well our internal operations are doing with real-time data dashboards. | 1 | 2 | 3 | 4 | 5 |
| 4. | We automate a lot of our internal processes. | 1 | 2 | 3 | 4 | 5 |

| | | Level of Agreement | | | | |
|---|---|---|---|---|---|---|
| **Independent Variables** | | **1** | **2** | **3** | **4** | **5** |
| **Digital Integration with Supplier (DIS)**—This measures how well digital technologies are used to work with suppliers. | | | | | | |
| 1. | We send our main suppliers electronic copies of our production plans and demand forecasts. | 1 | 2 | 3 | 4 | 5 |
| 2. | Most of the time, we use EDI to place orders with our suppliers. | 1 | 2 | 3 | 4 | 5 |
| 3. | We can see our suppliers' inventory levels and production status online. | 1 | 2 | 3 | 4 | 5 |
| 4. | We work with suppliers to plan, carry out, and solve problems using a digital platform. | 1 | 2 | 3 | 4 | 5 |
| **Digital Integration with Customer (DIC)**—Measures how well a business uses digital tools to interact with and serve customers. | | | | | | |
| 1. | Customers can place orders directly through our digital platforms, like our website and order portal. | 1 | 2 | 3 | 4 | 5 |
| 2. | We give our customers real-time updates on the status of their orders. | 1 | 2 | 3 | 4 | 5 |
| 3. | We use digital channels to collect and study what customers say and want. | 1 | 2 | 3 | 4 | 5 |
| 4. | Our billing and payment processes with customers are done online. | 1 | 2 | 3 | 4 | 5 |
| **Mediating Variables** | | | | | | |
| **Operational Efficiency (OE)**—This measures how well and how efficiently work gets done inside the company. | | | | | | |
| 1. | Our order processing time has gone down a lot thanks to digital systems. | 1 | 2 | 3 | 4 | 5 |
| 2. | Automating routine operational tasks has cut our labor costs. | 1 | 2 | 3 | 4 | 5 |
| 3. | Using real-time data has helped us keep our inventory levels just right, which has cut down on carrying and associated inventory costs. | 1 | 2 | 3 | 4 | 5 |
| 4. | Adding digital technologies has made us more productive. | 1 | 2 | 3 | 4 | 5 |
| **Transparency (Tra)**—This measures how easy it is to see information throughout the supply chain. | | | | | | |
| 1. | Our digital platforms give us a clear, up-to-date picture of how things are going inside the company. | 1 | 2 | 3 | 4 | 5 |
| 2. | Digital connections let us see what suppliers are doing, like how much they are producing and when they are shipping. | 1 | 2 | 3 | 4 | 5 |
| 3. | We can use digital tools to give customers accurate, up-to-date information about their orders. | 1 | 2 | 3 | 4 | 5 |
| 4. | Digital traceability systems let us see the whole journey of a product from its source to the customer. | 1 | 2 | 3 | 4 | 5 |

| | | Level of Agreement | | | | |
|---|---|---|---|---|---|---|
| **Independent Variables** | | **1** | **2** | **3** | **4** | **5** |
| **Trust (Tru)**—This is a measure of how much the stakeholders in the supply chain can rely on and believe in their supply chain partners. | | | | | | |
| 1. | We believe that the information our digital systems (like ERP) give us is correct. | 1 | 2 | 3 | 4 | 5 |
| 2. | We trust that the digital platforms we use with our partners are safe and reliable. | 1 | 2 | 3 | 4 | 5 |
| 3. | Digital systems make things clearer, which makes us trust our partners' actions more. | 1 | 2 | 3 | 4 | 5 |
| 4. | Digital contracts and automated execution have made it easier to do business with partners. | 1 | 2 | 3 | 4 | 5 |
| **Dependent Variables** | | | | | | |
| **Supply Chain Efficiency (SCE)** | | | | | | |
| 1. | Our digital tools have helped cut down on the total costs of the supply chain. | 1 | 2 | 3 | 4 | 5 |
| 2. | Planning based on real-time data has helped us keep the right amount of stock in all of our supply chains. | 1 | 2 | 3 | 4 | 5 |
| 3. | Digital integration has made it possible to fill customer orders more quickly, hence, helped us to be time efficient. | 1 | 2 | 3 | 4 | 5 |
| 4. | Digital joint planning and monitoring have helped us make better use of our resources, like warehouse space and transportation in the supply chain. | 1 | 2 | 3 | 4 | 5 |
| **Flexibility in the Supply Chain (SCF)** | | | | | | |
| 1. | Digital systems have made it easier for us to quickly adjust to changes in what customers want. | 1 | 2 | 3 | 4 | 5 |
| 2. | Our digital visibility makes it easier for us to deal with problems in the supply chain. | 1 | 2 | 3 | 4 | 5 |
| 3. | We can easily change our production or distribution schedules thanks to our digital platforms. | 1 | 2 | 3 | 4 | 5 |
| 4. | Our digital systems let us handle a wide range of products and customers quickly and easily. | 1 | 2 | 3 | 4 | 5 |
| **Food Safety and Quality in the Supply Chain (SSQ)** | | | | | | |
| 1. | Our digital traceability systems have made it easier for us to keep track of food safety standards. | 1 | 2 | 3 | 4 | 5 |
| 2. | Process controls based on digital data have made the quality of our products more consistent. | 1 | 2 | 3 | 4 | 5 |
| 3. | Digital data lets us find and fix quality or safety problems much faster. | 1 | 2 | 3 | 4 | 5 |
| 4. | Our digital systems help us make sure that we meet the quality and safety standards set by the regulatory body. | 1 | 2 | 3 | 4 | 5 |

| | | Level of Agreement | | | | |
|---|---|---|---|---|---|---|
| **Independent Variables** | | **1** | **2** | **3** | **4** | **5** |
| **Supply Chain Reliability (SCR)** | | | | | | |
| 1. | Our digital systems enable us to monitor our suppliers' performance in real-time to ensure that we consistently meet our schedules. | 1 | 2 | 3 | 4 | 5 |
| 2. | Data analytics enable us to make accurate predictions and ensure consistency in lead times to avoid delays. | 1 | 2 | 3 | 4 | 5 |
| 3. | Digital integration with our logistics partners enables us to ensure the timely and accurate delivery of our products to the right place and at the right time. | 1 | 2 | 3 | 4 | 5 |
| 4. | Our digital systems enable us to respond to unexpected disruptions to our delivery schedules. | 1 | 2 | 3 | 4 | 5 |
| **Supply Chain Tracking and Traceability (SCTT)** | | | | | | |
| 1. | Our digital systems let us keep track of where products are in real time very well. | 1 | 2 | 3 | 4 | 5 |
| 2. | Digital records make it easy and quick to find out where a product has been and what it has done. | 1 | 2 | 3 | 4 | 5 |
| 3. | Our tracking systems give us data that is very reliable and correct. | 1 | 2 | 3 | 4 | 5 |
| 4. | Our digital platforms make it easy to share traceability data with the right partners and regulators. | 1 | 2 | 3 | 4 | 5 |
| **Supply Chain Food Loss (SFL)**—Note: A lower score means a better performance for SFL. | | | | | | |
| 1. | We still lose a lot of food along our supply chain, even though we use digital tools for such planning and forecasting. | 1 | 2 | 3 | 4 | 5 |
| 2. | Even after we started using digital inventory management tools, food loss in our operations is still a big problem. | 1 | 2 | 3 | 4 | 5 |
| 3. | Our efforts to go digital did not help us much to find products that were close to their expiration date with real-time inventory data, so we could sell or redirect them quickly and cut down on losses. | 1 | 2 | 3 | 4 | 5 |
| 4. | After we went digital, the quality and shelf life of our products are still not effective, and we cannot effectively monitor storage conditions (like temperature) digitally; hence, food losses are still high. | 1 | 2 | 3 | 4 | 5 |
| **Supply Chain Sustainability Performance** | | | | | | |
| **Environmental Sustainability (SEn)** | | | | | | |
| 1. | Our digital monitoring has helped us use less energy. | 1 | 2 | 3 | 4 | 5 |
| 2. | We have cut down on waste and packaging materials by using processes that are optimized for data. | 1 | 2 | 3 | 4 | 5 |
| 3. | We believe that the digital logistics planning has helped us cut down on the amount of carbon we put into the air. | 1 | 2 | 3 | 4 | 5 |
| 4. | Digital tools help us follow and control how well we follow environmental rules. | 1 | 2 | 3 | 4 | 5 |

| | | Level of Agreement | | | | |
|---|---|---|---|---|---|---|
| **Independent Variables** | | **1** | **2** | **3** | **4** | **5** |
| **Economic Sustainability (SEc)** | | | | | | |
| 1. | Digital practices have made us more efficient, which has helped us make more revenue and profits. | 1 | 2 | 3 | 4 | 5 |
| 2. | Digitalization has made it possible for us to use sustainable practices that have saved us a lot of money/cost cuts/. | 1 | 2 | 3 | 4 | 5 |
| 3. | Digital integration has given our business new ways to make money or new markets to sell to. | 1 | 2 | 3 | 4 | 5 |
| 4. | Overall, our digital supply chain projects have given us a good return on investment (ROI). | 1 | 2 | 3 | 4 | 5 |
| **Social Sustainability (SSs)** | | | | | | |
| 1. | Digital tools help us keep an eye on our operations and make sure that everyone is safe at work; hence, the use of digital technology has made our employees safer and happier at work. | 1 | 2 | 3 | 4 | 5 |
| 2. | The digital applications work we do helps us to collaborate with our stakeholders on works/projects that benefit broader communities. | 1 | 2 | 3 | 4 | 5 |
| 3. | We use digital systems to make sure that our suppliers are honest and fair when they give us goods/the digital integration helps us to observe that suppliers' activities are free from fraud and in line with ethical values/ | 1 | 2 | 3 | 4 | 5 |
| 4. | Digital systems enable ethical and transparent communication with customers, providing production, inventory, and product information for planning and tracking without deception (e.g., re-labeling). | 1 | 2 | 3 | 4 | 5 |

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