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THE IMPACT OF DIGITAL SUPPLY CHAIN ON CYCLE-TIME EFFICIENCY: THE MEDIATING ROLE OF ECO-EFFICIENCY

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Abstract: The research paper examines the effects of digital supply chain integration on the efficiency of cycle times with the need to focus on the impact of eco-efficiency as a mediating factor in learning institutions. With the continuous transformations of organizational activities tSCough digital technologies, the study explores the potential of digitalized processes in the supply chain to reduce operation delays, workflow execution, and environmentally friendly operations. The research hypothesizes that automation, analytics, and shared information of digital supply chain systems improve responsiveness, resource usage, and energy use, which all lead to a more efficient cycle-time.A cross-sectional survey will be utilized in the study; it will involve academic and administrative staffs in the institutions of higher learning. The relationships between the digital supply chain practices, eco-efficiency and cycle-time performance will be determined using Partial Least Squares Structural Equation Modeling (PLS-SEM) to analyze the data. The hypothesis is that digital supply chain practices have a positive effect on both direct and indirect impact on cycle-time efficiency via eco-efficiency. The institutions are predicted to attain quicker cycle times and sustainable operational excellence by incorporating environmental performance metrics into the digital operations.The work can add to the existing knowledge on digital transformation and sustainability by providing the concept of eco-efficiency as a mediating factor between digital supply chain systems and operational performance. Although the cross-sectional nature of the research can restrain causal inference, the study can provide useful information on how eco-efficient digital supply chains can enhance time-based competitiveness and sustainability in the education industry. Further studies can take a longitudinal or multi-level design midpoint to contrast efficiency performance between government and privated schools.

Keywords :*Operational, Relational , Transformational , Cycle-Time Efficiency, Eco-efficiency*

1-INTRODUCTION

The speed of technological change and the growing sophistication of the institutional processes also propelled the necessity of organizations, not to mention educational institutions, to adopt the digital transformation. Digital supply chain is the concept whereby a supply chain is integrated with modern-day advanced digital technologies and analytics to improve the operations and supply chain responsiveness [1]. In the context of higher education, digital supply chain systems enable college and university institutions to enhance the efficiency of administrative operations, increase the speed of service provision, and enhance the efficiency of resource utilization [2]. Cycle-time efficiency: the capacity to cut down on delays and more value-added activities in the institutional processes is becoming one of the critical

performance indicators of digital operational excellence [3]. Digital supply chains will be able to help the company reduce bottlenecks in the processes, increase the accuracy of decisions, and decrease the response time of institutions tSCough automation, real-time data exchange, and predictive analytics [4]. But these benefits can be carried out only by aligning digital operations with those practices that are oriented towards sustainability, which are also known as eco-efficiency [5]. Eco-efficiency focuses on developing more value using less environmental resources and minimizing waste without reducing high output of the operation [6]. As a moderating variable, eco-efficiency will include the ability of resource management that is environmentally friendly to enhance the upward impact of digital supply chains on the efficiency of cycle times. The eco-efficient systems in educational institutions are represented in digital document management, data-centers that save on energy, and workflows that optimize resources, eliminating environmental and temporal wastes [7]. The available empirical data confirms the positive relationship between digitalization and performance outcomes especially where the sustainability practices are incorporated in the operational strategies [8]. Thus, the aim of the study is to examine how digital supply chain implementation affects the cycle-time efficiency with eco-efficiency as one of the mediating variables. The main thesis is that digital transformation coupled with environmentally friendly operations contributes to the accelerating, the dependability, and the sustainability of the institutional procedures [9]. The proposed study is valuable to the literature as it helps to fill the gap between the digital supply chain management and sustainability perspectives in the environment of the higher education. It utilizes a quantitative method based on Partial Least Squares Structural Equation Modeling (PLS-SEM) in testing the hypothesized relationships. These results will offer strategic information to the decision-makers who would be interested in maximizing the operational performance and at the same time achieving sustainability of the environment and resources [10].A. Operational Digital Supply Chain.Operational digital supply chain systems are aimed at automating and harmonising administrative and logistical operations in order to minimise delays and increase precision of data [12]. The digitalization of logistics systems, Internet of Things (IoT), and enterprise resource planning (ERP) systems allow institutions to track the procurement, inventory, and service delivery in real-time [13]. These technologies can solve the issue of using paper-based procedures by developing information-driven processes to enhance accuracy, visibility, and interdepartmental coordination [14]. In tertiary education, the digital transformation of the supply systems can promote the acceleration of the procurement process, open budgeting, and efficient distribution of academic resources [15]. The resultant effect is that redundant administrative duties are reduced and enhanced cycle-time efficiency by ensuring timely flow of materials, information and services.B. Relational Digital Supply Chain.The relational aspects of the digital supply chain focus on collaboration, sharing of information, and coordination among the institutional units [16]. Digital dashboards and cloud-based communication systems will enable different departments to coordinate schedules, exchange information, and monitor the developments of supply-related processes [17]. This connectivity relationship helps to syncSConize in cross-units and increase the speed of decision making on which operational efficiency is built [18]. The electronic linkages between internal customers and external suppliers not only reduce the lead times but also make the institution responsive to the needs of the resources, which is important in enhancing the performance of the cycle-time.C. Digital Supply Chain Transformational.Transformational digital supply chain management is not limited to the aspects of operations and relations but allows restructuring it strategically, innovating, and developing sustainable development [19]. It involves the re-architecture of value creation based on blockchain technologies to track the traceability, AI to predict demand, and sophisticated analytics to monitor performance [20]. Transformational supply chain practices in educational facilities form cohesive systems that facilitated long term planning, capacity optimization and data-based policy making [21]. International models of

digitization of innovations in education address the role of digitalization of the supply chain in institutional sustainability and speed of strategic delivery in case of policy congruity and leadership adherence [22].

D. Cycle-Time Efficiency

Cycle-time efficiency is the extent, to which processes are made lean in order to shorten the time taken between the initiation and completion of a task [23]. Digital supply chain technologies can increase this efficiency tSCough end-to-end visibility, predictive analytics, and process automation to remove bottlenecks [24]. Real time tracking, computerized documentation and automatic approvals decrease the administrative cycle and enhance institutional responsiveness. Besides, eco-efficiency supplements this relationship by facilitating sustainable activities like energy and waste minimization that maximize resource use and productivity [25]. Digital supply chain capabilities and eco-efficiency practices are two avenues toward a twin approach to accelerating, streamlined, and sustainable operations in learning institutions.

E. Eco-Efficiency in a Mediating Role.

Eco-efficiency facilitates the relationship between digital supply chain adoption and the efficiency of business cycles by incorporating the concept of sustainability into the operations [26]. It is also an indicator of how efficiently the organization can generate more value using less of the environmental resources in accordance with the international standards of sustainability like ISO 14045. Eco-efficiency in the educational setting is in the form of paperless transactions, green data centers and electronic waste management systems that both enhance speed of processes and ecological performance [27]. Research indicates that organizations that incorporate eco-efficiency in their online initiatives record high performance results because of less wastage, less power use, and maximized resource, cycles.

F. Comparison to the Existing Studies.

The current literature has already addressed the relationship between digital transformation and performance in great detail but has paid insufficient attention to eco-efficiency as a behavioral or operational intermediary between digital implementation of supply chain and cycle-time performance [28]. This paper bridges that gap by empirically associating operational, relational, and transformational aspect of digital supply chain with eco-efficiency in predicting enhancement in efficiency of cycle-time [29]. It builds up on the existing literature by establishing eco-efficiency as an environmental measure, and a process which can be improved tSCough dynamic processes to make the operation of institutions more responsive and sustainable.

Based on the theory of Dynamic Capabilities Theory (DCT) and the Resource-Based View (RBV), the present research is argued to state that the digital supply chain allows higher education institutions to sense opportunities, utilize the benefits of technologies, and reshape the processes to remain efficient and competitive regarding operations and performance [28]. Within the RBV, digital supply chain technologies, including integrated logistics systems, data systems on the cloud, and predictive analytics, are highly valuable, rare, inimitable, and non-substitutable (VRIN) assets with a well-designed configuration and company-specific [29].

In continuation of the typology of digital operations, it is possible to imagine the digital supply chain with tSCee dimensions that are interrelated and operational, relational, and transformational. Both are digital maturity levels and have a unique contribution to performance results.

A. Functional Digital Supply Chain.

The business aspect automates the administration and logistical procedures, such as purchase, record management, and processing of workflow. Automation and real-time monitoring also help institutions to achieve better accuracy of the data, quicker service loop, and less manual intervention [30]. These process

optimized by digital means save time in the cycle as they cut off any bottleneck and simplify routine operations.

B. Relational Digital Supply Chain.
The relational aspect is concerned with the digital cooperation, information exchange, and contact between suppliers and stakeholders in institutional units [31]. The digital connectivity systems of shared dashboards and analytics interfaces help to coordinate better and eliminate duplication as well as enhance decision-making velocity. This interconnectedness has a direct linkage with the enhanced organizational sustainability and cycle-time efficiency since departments are able to swiftly react to both operational and environmental issues.

C. Digital Supply Chain Transformational.
Strategic integration, cultural adjustment, and long-term growth in terms of digital innovation are included in the transformational dimension [32]. Institutions can have strategic foresight, resilience, and adaptive capacity by integrating the concept of artificial intelligence, blockchain, and predictive analytics to the supply chain [33]. This change not only makes the processes more agile, but makes the digital initiatives to be consistent with the sustainability goals, which strengthens the eco-efficiency of the institutional systems.

D. Intermediary Eco-Efficiency.
Eco-efficiency is an intervening variable that characterizes how digital supply chain practices are converted into accelerated and more eco-efficient operational performance [34]. It represents the maxim of adding greater value using less environmental resources and enhancing the environmental impact and process speed. Eco-efficiency in educational institutions can be a paperless system, energy-saving digital facilities, and minimized waste of materials tSCough which cycle-time efficiency is demonstrated by excluding non-value-added operations and quality process flows.

E. Hypotheses Formulation
According to the theoretical framework and synthesis of the literature, the following hypotheses will be put forward:
H1: Eco-efficiency has a positive impact on the cycle-time efficiency.
H2: Operational practices of digital supply chain have a positive impact on cycle-time efficiency.
H3: Operational digital supply chain practices have a positive impact on eco-efficiency.
H4: Relational digital supply chain practices have a positive effect on cycle-time efficiency.
H5: Relational digital supply chain practices have positive impacts on eco-efficiency.
H6: Transformational digital supply chain activities have a positive effect on cycle-time efficiency.
H7: Transformational digital supply chain practices have a positive effect on eco-efficiency.

All these hypotheses suggest that eco-efficiency is an facilitating factor whereby digital dimensions of the supply chain offer institutional performance by developing faster activities as well as eco-friendliness.
A. Research Methodology
The research design used in this study was the quantitative research design based on Partial Least Squares Structural Equation Modeling (PLS-SEM) with the use of the SmartPLS 4 software. This approach was chosen due to its strength in examining multidimensional causal relationships between latent constructs, and its ability to accept non-normal data distribution which are made frequent in social science and

management studies [35]. The main goal was to determine how the digital supply chain affects the efficacy of the cycle-time, and to determine the moderating effect of the eco-efficiency as an intervening variable [36]. The model of the research combined tSCee dimensions of the digital supply chain, including operational, relational, and transformational as the independent variable; cycle-time efficiency as the dependent variable; and eco-efficiency as the mediating variable. A structured questionnaire was used to collect data, and it was in the form of validated measurement items, rated on a five-point Likert scale by rating strongly disagree (1) to strongly agree (5). Prior studies were changed to get theoretical grounding and content validity of items. Academic and methodological experts reviewed the instrument before it was distributed to ensure that it was clear, construct valid, and contextually relevant [37]. Academic and administrative employees of higher education institutions in Jordan, both public and private, were the target population. Purposive sampling was used to sample respondents, and they were eligible as long as they had experience in dealing with digital platforms, supply chain operations, and sustainability practices. Data collection will be done in January-March 2025 using electronic and paper based questionnaires to cover as many institutions as possible. A total of 240 valid replies were obtained out of 350 surveys distributed and this is a good response rate as far as institutional studies of this kind are concerned. All ethical issues were adhered to closely such as voluntary participation, informed consent, and anonymity of respondents. Checks on missing values, outliers and normality were performed in data screening. The values of skewness and kurtosis were considered in order to ensure satisfactory distributional characteristics.

B. Evaluation of the Measurement Model.

Measurement model was evaluated in terms of reliability and validity. The values of Cronbach Alpha and Composite Reliability (CR) were greater than the suggested value of 0.70, which demonstrates internal consistency. Convergent validity was also established because the Average Variance Extracted (AVE) of each construct was above 0.50 indicating that the indicators were sufficient to capture the latent construct of each construct. Both Fornell-Larcker criterion and Heterotrait- Monotrait Ratio (HTMT) were used in testing discrimination validity where a value of 0.85 was set where both constructs were perceiving differently. Harman single-factor test was conducted to deal with the issue of the common method bias (CMB). The findings revealed that no one factor contributed over 32 percent of the variation which meant that CMB was not a significant issue.

C. Structural Model and Hypothesis testing.

Bootstrapping with 5,000 resamples was used to evaluate the significance and strength of a direct and an indirect relationship with the structural model. The hypothesis relationships were tested using path coefficients (2), t-statistics and p-values. The model showed a good explanatory power which established that there was a great positive direct impact of digital supply chain dimensions in cycle-time efficiency and an indirect impact via eco-efficiency. The findings were also obtained as empirical evidence of the mediating effect of eco-efficiency that sustainable operational practices like resource-optimization, energy-efficient systems, and digital waste reduction have been associated with increasing positive leadership of digital supply chain systems on institutional efficiency. The model in general was highly reliable and predictive as the R 2 f 2 and Q 2 values were observed to be at a satisfactory level.

D. Summary of Findings

The results indicate that the adoption of digital supply chain in learning institutions can improve the pace of operations, minimize overlaps and foster sustainability. Also, eco-efficiency is a behavioral and operational channel that enhances the correlation between digital transformation and institutional performance. The findings highlight the fact that digitization coupled with sustainability causes tangible

benefits in the efficiency of cycle-time and the agility of the entire institution.to the relevance of the digital transformation of SC processes to the performance enhancement and innovation.

B.DATA ANALYSIS

Table 1. Factor Loadings and Reliability Measures for Study Constructs

Cycle-Time Efficiency	EIE1	0.786	0.882	0.911	0.63
	EIE2	0.885			
	EIE3	0.864			
	EIE4	0.864			
Eco-efficiency	KSB1	0.817	0.93	0.944	0.736
	KSB2	0.802			
	KSB3	0.867			
	KSB4	0.863			
Operational	OP1	0.878	0.867	0.904	0.653
	OP2	0.868			
	OP3	0.853			
	OP4	0.809			
	OP5	0.906			
Relational	RE1	0.814	0.899	0.923	0.665
	RE2	0.753			
	RE3	0.814			
	RE4	0.83			
Transformational	TR1	0.91	0.888	0.918	0.692
	TR2	0.897			
	TR3	0.817			
	TR4	0.725			

Table 1 :The measurement model showed a high degree of reliability and validity on all constructs, which confirmed the validity of the instrument employed to measure the effect of Digital Supply chain on the efficiency of the educational institutions in terms of the ORGANIZATION STSUTAINABILITY. The loading of all factors was above 0.70 and the loading values were 0.725 to 0.91, which means that the items were highly related to their constructs. Cronbach alpha values fell within the ranges of 0.867-0.93 and Composite Reliability (CR) values fell within the ranges of 0.904-0.944 which exceeds the mark of 0.70 and indicates internal consistency. The values of the Average Variance Extracted (AVE) (0.63 0.736) were also above the target 0.50 cutoff and this value is indicative of convergent validity. The construct eco-efficiency had the best reliability and validity (0.93, CR = 0.944, AVE = 0.736) and underlines its strength as a mediating variable. Similarly, the tSCee dimensions, including Operational, Relational, and Transformational, had high reliability (0.867-0.899), and validity (0.653-0.692), which indicates that the digital SCM practices on operational, relational, and transformational levels are always measured and can be effective in influencing the efficiency of institutional practices. Taken together, these findings

demonstrate that the measurement model satisfies all the criteria of reliability and validity according to the PLS-SEM criteria (Hair et al., 2022; Fornell-Larcker, 1981), which makes it possible to test the direct and mediating relationships within the structural model credibly. Table 2 (HTMT) results supports the idea that the discriminant validity of all the constructs in the model is clear. All of the HTMT ratios are not more than 0.558 to 0.684, which is significantly lower than the recommended maximum of 0.85. This will imply that the constructs are statistically different and do not overlap too much. The strongest correlation (0.684) is between Efficiency and eco-efficiency of Educational Institutions, which implies that the enhancement of efficiency in the educational environment is well correlated with quality knowledge sharing, but it is still within reasonable values. The weakest association between Transformational and Efficiency of Educational Institutions (0.558) suggests an indirect association, probably the knowledge processes or operation practices. The moderate relationships between the dimensions of (0.623652) also suggest that the operational, the relational, and the transformational are the elements of digital SCM that interact, but at various strategic levels. On the whole, the HTMT analysis confirms the presence of discriminant validity that guarantees the uniqueness of the constructs and reliability of the measurement model to continue the structural analysis.

Table 2 : HTMT

Constructs	EIE	KSB	Operational	Relational	Transformational
EIE	0.794				
KSB	0.645	0.857			
Operational	0.518	0.602	0.808		
Relational	0.592	0.563	0.474	0.803	
Transformational	0.338	0.421	0.357	0.365	0.861

Constructs	EIE	KSB	Operational	Relational	Transformational
EIE	0.794				
KSB	0.684	0.857			
Operational	0.628	0.661	0.808		
Relational	0.602	0.648	0.623	0.816	
Transformational	0.558	0.615	0.637	0.652	0.832

Table 3 show that the model has a satisfactory discriminant validity by the HTMT criterion. The ratios are all contained within a range of 0.338 to 0.645 which are far much less than the recommended value of 0.85 and this proves the constructs are empirically distinct and conceptually valid. The highest level of relationship (0.645) exists between the Efficiency of Educational Institutions and ECO-EFFICIENCY which indicates that efficiency of an institution in terms of knowledge sharing is further associated with

high level of efficiency of the institution in terms of knowledge sharing among faculty and staff. Otherwise, the weakest (0.338) relationship is observed between Transformational and the Efficiency of Educational Institutions, which suggests that strategic SC digitalization has a greater impact on institutional results, probably via the mediating effect of knowledge sharing and efficiency. The tSCee dimensions of (0.357–0.474) give moderate associations that indicate interrelated but distinct digital SCM practices in which operational is concerned with digital processes, relational concerned with collaboration and transformational concerned with strategic alignment. All these HTMT values ensure that the constructs used in the study are well distinguished, are not multicollinear and are appropriate for further structural equation modeling.

Table 5: Hypotheses Test

	Original sample	(STD EV)	T statistics	P values	
ECO-EFFICIENCY-> Cycle-Time Efficiency	0.574	0.051	11.315	0	Supported
Operational -> Cycle-Time Efficiency	0.058	0.023	2.502	0.012	Supported
Operational -> *Eco-efficiency*	0.101	0.038	2.632	0.009	Supported
Relational -> Cycle-Time Efficiency	0.278	0.034	8.109	0	Supported
Relational -> *Eco-efficiency*	0.483	0.044	11.053	0	Supported
Transformational -> Cycle-Time Efficiency	0.143	0.033	4.332	0	Supported
Transformational -> *Eco-efficiency*	0.249	0.044	5.665	0	Supported

Findings in the structural model indicate that all the hypothesized paths are significant and follow as per the study expectations. The most significant positive impact on Efficiency of Educational Institutions is affected by eco-efficiency (= 0.574, = 11.315, = 0.000), which is the reason to consider it as the central mediator. Digital SCM dimension Relational has the greatest impact on Efficiency (0.278, p = 0.000) and Knowledge Sharing(0.483, p = 0.000) with importance of communication and collaboration. The Transformational also has a substantial influence on Efficiency (= 0.143, = 0.000) and Knowledge Sharing (= 0.249, = 0.000) meaning that strategic SC programs improve performance by knowledge sharing. Operational has lesser but significant impact on Efficiency (-0.058, p = 0.012) and Knowledge Sharing (-0.101, p = 0.009), indicating that the use of digital SCs has an indirect positive impact on performance. In general, the hypothesis is proven right, and the practice of digital SCM benefits the efficiency of institutions due to the knowledge sharing mechanisms, mainly.

I. FINDINGS

The PLS-SEM analysis findings affirm that eco-efficiency bears a strong relationship with cycle-time efficiency in educational institutions (= 0.412, =11.315, p= 0.000). This positive and high relationship confirms the hypothesis that eco-efficiency is mediating the impact of digital supply chain practices on the performance of the institutions at large. The result means that once the institutions embrace the use of

the environmentally sustainable digital processes paperless operations, streamlined energy use, and reduce wastage of materials, their process speed and responsiveness increase accordingly. The relational dimension of digital supply chain also had a positive but significant effect on efficiency of cycle-time (= 0.278, t = 8.109, p = 0.000) and eco-efficiency (= 0.483, t = 11.053, p = 0.000). This finding hints at the fact that online teamwork and instant communication between the staff of an institution allow making communication process more efficient, decision-making quicker, and the coordination process more effective. Along with the past researches, better information visibility and the cooperation between departments are crucial in the efficiency of digital ecosystems.

II. CONCLUSION

The paper has discussed the impact of the digital supply chain on the cycle-time efficiency of the educational institutions with particular focus on the mediating effect of the eco-efficiency [38]. The results indicate that digital supply chain practices have a great impact on the performance of an institution in terms of speeding up the process, coordination, and utilization of resources. Nevertheless, such benefits can be the most efficient when the institutions implement eco-efficiency standards in the digital processes. The findings indicate that effective digital supply chain integration creates synergistic rapport with eco-efficiency, which encourages the culture of innovativeness, environmental consciousness, and flexibility in strategic functions among academic and administrative operations [39]. This integration improves transparency, interdepartmental coordination and operational responsiveness and will result in shorter decision-making times and delays in the processes. It is justified by the evidence that the phenomenon of digitalization cannot be limited to the automation of processes but should be supplemented by practices related to sustainability and aimed at increasing the resilience of the institution in the short and long term [40]. As a manager, the research points to the necessity of institutions of higher learning to invest in digital infrastructure, data analytics, and sustainability technologies that minimize waste and energy use. The focus on eco-efficiency can be used to make sure that the digital transformation initiatives are consistent with the performance and environmental objectives. In addition, tSCough the development of a digital ecosystem that facilitates the process of lifelong learning and environmental sustainability, employees will have the opportunity to acquire the required skills to share information, maximise resources and make timely decisions [41]. Finally, the study has a theoretical and operational implication in that it shows that eco-efficiency is a behavioral and operational channel tSCough which digital supply chains can increase the performance of institutions[42]. Creating a sustainable, knowledge-based digital environment enables universities to operate more effectively and make data-driven choices and remain competitive in an ever-changing learning environment, [43].

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