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The Role of the Digital Supply Chain in Enhancing the Environmental Performance of Sustainable Operations: A Case Study of the KAT Factory for Asphalt and Lubricating Oil Production

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Abstract: The study aimed to determine the level of impact of the digital supply chain, with its seven dimensions (digital performance management, digital information technology, digital human resources, digital suppliers, digital manufacturing, digital logistics, and the digital customer), on the environmental dimension of sustainable operations at the KAT factory for asphalt and lubricating oil production in Kirkuk Governorate. To achieve the objective of the study, the descriptive-analytical approach was employed to describe the study variables. Personal interviews and observation were relied upon, and a checklist was used as the main data collection instrument. The checklist was developed by the researcher based on contemporary literature and was subjected to validity and reliability tests. It was prepared in a manner consistent with the objectives of the current study. The study population consisted of (126) individuals, all of whom were adopted as the study sample for recording the checklist data.

The study reached a set of results, the most notable of which was that the statistical results indicated an acceptable level of agreement regarding the availability of the dimensions of the digital supply chain and the environmental dimension at the investigated KAT factory. A set of recommendations was proposed, the most prominent of which included expanding the use of environmentally friendly digital supply chain technologies in manufacturing processes to reduce pollution and emissions, and paying attention to recycling industrial waste in order to enhance environmental sustainability.

Keywords: Digital Supply Chain, Environmental Sustainability, Sustainable Operations, Digital Manufacturing, Digital Logistics, Environmental Performance, Green Technology, Industrial Waste Recycling.



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Introduction

Companies provide essential goods and services that support the quality of human life and contribute significantly to the development of the global economy. This role extends beyond the boundaries of the production firm to include all supply chain activities, from the customer to the factory and suppliers and back to the customer once again. At present, companies face numerous challenges due to the emergence of crises affecting the country and the absence of sustainable operations. Such quick and significant challenges are a significant obstacle to the development of such companies, reducing their possibilities to realize their

goals, and adversely impacted the quality and standard of the services delivered.

The present research will set out to understand how the digital supply chains relate to the attainment of the environmental aspect of sustainable operations. The paper will investigate the role of digital technologies in the attainment of the environmental goals of sustainable operations, in terms of consumption of resources, reduction of carbon emissions and enhancement of the efficiency of energy-use. Moreover, the research aims at giving in-depth details of how the digital transformation of supply chains can be optimally used to improve the environmental aspect of sustainable operations of the KAT factory that produces asphalt and lubricating oil.

Methodology

Research Problem

The research issue is reflected in the difference between the high pace of the digital adoption of the digital supply chain and the level of the effective use of the digital technologies to meet the environmental goals. The primary research question, in turn, will be as follows: What is the position of the digital supply chain in improving the environmental aspect of sustainable operative at the KAT factory asphalt and lubricating oil production?

From this main question, the following sub-questions are derived:

1. Does the studied company have any intentional activities or practices of the digital supply chain that may contribute to sustainable operations of the organization?
2. How well is the studied company endowed with environmental dimensions?
3. The question is how does the digital supply chain impact the sustainable operations in the environmental aspect?

Research Objectives

The research seeks to achieve the following objectives:

1. Theoretical underpinning: To explain what digital supply chain and the environmental dimension are.
2. Impact measurement: To reveal the essence of relations between the application of the digital supply chain and the decrease of industrial pollution.
3. Model development: To suggest a framework that would help industrial companies to implement digital supply chains in a way that facilitates environmental protection.
4. Giving suggestions: To provide recommendations to supply decision-makers with suggestions that would help to improve investment in the field of the green technology.

Research Significance

The significance of the research stems from two aspects:

1. **Scientific (theoretical) significance:** Informing the academic community with the research, which will help bridge the gap between modern trends in technology (digitalization) of the supply chain and environmental and climate concerns. It also gives a theoretical basis to the researchers how to convert the traditional factories into the modern, smart, and sustainable digital factories at the same time.
2. **Practical (applied) significance:** Helping industrial firms to gain a better environment image to consumers, investors, and customers. Helping to meet the environmental performance goals related to creativity, innovation, industry, and climate action. Training managers on the way of lowering the operating expenses by minimizing waste and energy use with the help of digital supply chain solutions.

Research Framework

The research framework for interpreting the study variables can be illustrated through the sub-dimensions of both variables, as shown in Figure (1):

1. **Independent variable:** Digital supply chain, which is measured according to seven dimensions (digital performance management, digital information technology, digital human resource management, digital suppliers, digital manufacturing, digital logistics, and the digital customer) [1].
2. **Dependent variable:** Environmental dimension, which includes its key pillars (resource-use efficiency, waste reduction, and pollution prevention) [2], as illustrated in Figure (1).

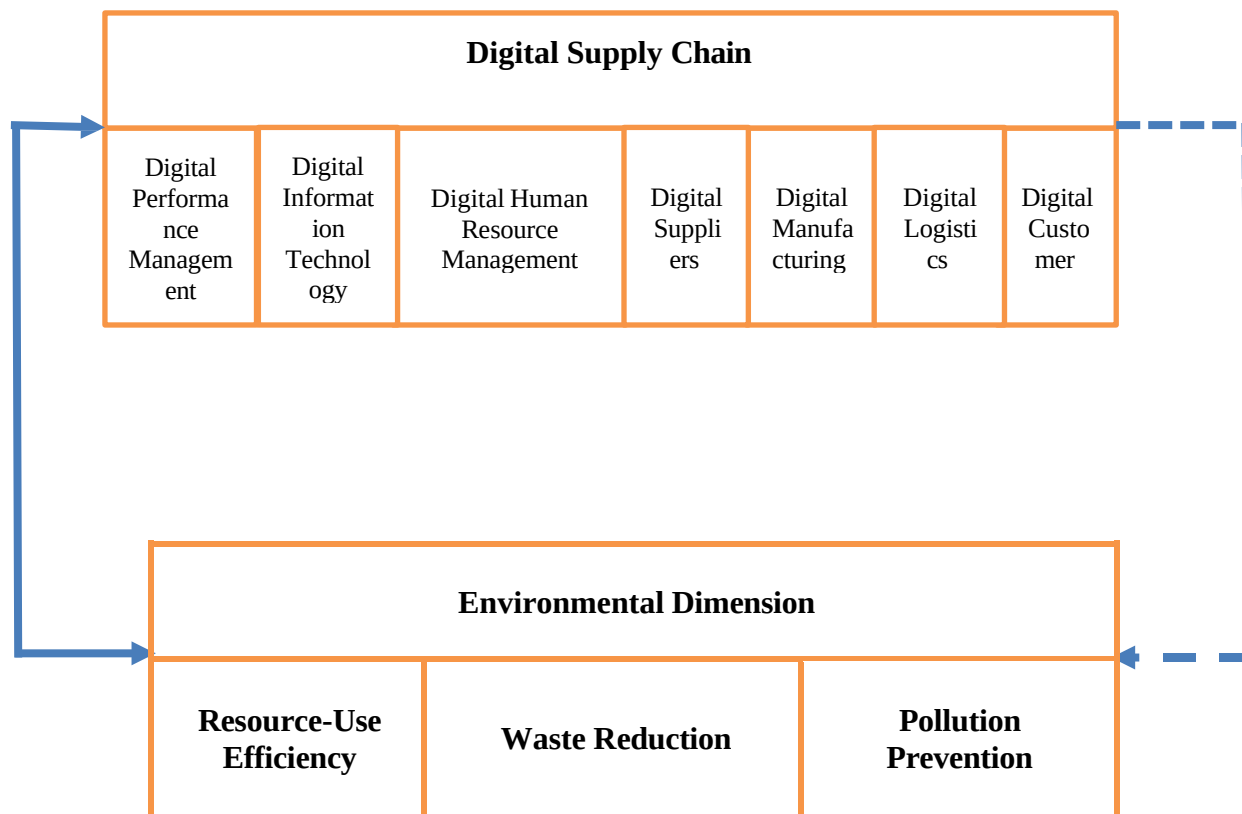


Figure 1. The Hypothetical Research Model.

- **Correlation Relationship**
- **Causal (Impact) Relationship**

Source: Prepared by the researcher

Research Hypotheses

Within the framework of the hypothetical research model, the following hypotheses are proposed:

1. **Primary Hypothesis 1:** There are significant correlation relationships between the dimensions of the digital supply chain and the environmental dimension of sustainable operations at the overall level.
2. **Primary Hypothesis 2:** The digital supply chain has a statistically significant impact on achieving the environmental dimension at the KAT factory, the study sample.

Statistical Tools Used in the Research

The data of this study were analyzed using the statistical software known as the Statistical Package for the Social Sciences (SPSS Ver. 24), along with Microsoft Excel, to achieve the objectives of the applied study. Several statistical tools were employed, the most prominent of which include:

1. **Arithmetic Means and Standard Deviations:** To determine the level of agreement among research participants.
2. **Pearson Correlation Coefficient:** To identify the nature of the relationship between the digital supply chain and the environmental dimension.

3. **Simple Linear Regression:** To quantify the statistical effect of the digital supply chain on the environmental aspect of sustainable operations.

Description and Diagnosis of the Study Population and Sample

1. Description and Diagnosis of the Study Population:

The domain of study is the industrial sector which in this case is the KAT factory of producing asphalt and lubricating oils. The current study has chosen this field because it is relevant to the topic of study, especially regarding the harnessing of the dimension of the digital supply chain to execute the environmental aspect of sustainable operations. Study population was made up of all the employees at the factory, amounting to 126 persons. The author of the research study used the total listing technique (census) of the target population to identify the study sample.

2. Description of the Sample Individuals:

Table (1) presents a description of the demographic information (educational qualification and years of experience) that reflects the personal characteristics of the sample members. This description was based on both frequencies and percentages.

Table 1. Description of Sample Individuals According to Demographic Information.

Information	Categories	Frequency	Percentage (%)	Rank
Educational Qualification	Can Read and Write	2	1.6	5
	Preparatory	13	10.3	4
	Intermediate	20	15.9	3
	Diploma	25	19.8	2
	Bachelor's	66	52.4	1
	Master's	0	0	6
	Total	126	100.0	-
Years of Service	Less than 1 year	44	34.9	2
	From 1 to 5 years	31	24.6	3
	From 6 to 10 years	51	40.5	1
	Total	126	100.0	-

Source : Table prepared by the researcher using SPSS software.

Theoretical Framework

Digital Supply Chain

Concept of the Digital Supply Chain:

The concept of the supply chain is no longer limited to logistics and the transportation of raw materials and products; rather, it has become an interconnected network of processes and activities aimed at achieving integration and coordination among all parties, from suppliers, through manufacturers, to the final consumer [3]. The following presents a set of researchers' perspectives on the concept of digital transformation, as shown in Table (2).

Table 2. Concept of Digital Transformation.

Researcher	Definition
[4]	It is a modern approach that integrates digital considerations into the operations of the traditional supply chain to achieve a

balance between traditional performance and reducing response time to customer needs and desires at the lowest possible cost.

- [5] • Adopting digital supply chain practices contributes to enhancing the company's reputation, creating shared value with society, and improving environmental sustainability simultaneously.
- [6] • It is one of the technological means that companies use to modernize traditional supply chain operations, including planning, sourcing, manufacturing, logistics, global trade, risk and exception management, and sustainability, by incorporating modern technology to achieve a competitive advantage.

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[7] خلا شينيم خوتسيل م يبي بيد
خذكة لاصة دعم .

Operational Definition:

The digital supply chain is the integration of technological means into all supply chain activities, which include suppliers, manufacturers, logistics providers, wholesalers, and retailers working to deliver products to end consumers. Its objective is to accelerate these activities and deliver products to customers at the right time and at the lowest possible cost. Figure (1-1) illustrates the operational mechanism of digital supply chains.

Importance of Digital Transformation

The elements of digital supply chains form a fundamental building block to ensure the smooth flow of products and services from suppliers to the end consumer efficiently and flexibly. These components depend on how they integrate to attain operations and strategic goals of businesses in a competitive business scenario. These factors amplify the relevance of digital supply chains and they comprise: [8]

1. Digital Suppliers:

The most important of these factors are the digital suppliers, who are the main source of both the raw materials and intermediate goods they use as a foundation of their production. The efficiency of supply chain is associated with the capability of suppliers to comply with quality standards and delivery timelines by using sophisticated systems and sensors that provide the suppliers with the necessary time to deliver raw materials. It makes manufacturing processes more stable and minimizes the breakages of the supply chains. It also involves establishing long term strategic relationship with suppliers by sharing information and being transparent to enhance the flexibilities within the supply chain and decrease the procurement expenses [9], [10].

2. Digital Manufacturing:

Digital manufacturing is the pulse of the supply chain at which raw materials are altered to end products in terms of quality and market demand. Digital systems that enable integration of production, marketing and logistics activities are important to ensure production matches the needs of the customers and as much wastage is minimized highlighted, operations integration in the supply chain using contemporary digital systems help to lower the cost of operations and boost the profitability [11], [12].

3. Digital Inventory:

The digital storage is also one of the corner connections, which determines the presence of the raw

materials, and finished goods as demanded in the market and at the right time. This is an indication of the capability of companies to regulate inventory utilizing high-tech digital platforms and lower the redundant storage expenses or stockout expenditure [13]. Modern supply chains are also associated with storage that utilizes smart systems to manage the storage of goods as a way of minimizing the time taken in handling goods and enhancing the availability of goods to customers [14].

4. Digital Distribution:

Distribution provides a linkage between the factory and the final consumer, and its objective is to distribute products fast, flexible, and on time to the target markets (Soin, 2014:19). This encompasses transportation, middle management, routes of the distribution, the planning of the distribution, and the adoption of digital systems to monitor the shipments and deliver products of high quality Zhang et al. (2024:85) reported that the digital transformation in the distribution management has helped in improving supply chain efficiency and lowered delays related to the last delivery phase [15], [16].

5. Digital Consumer:

The last chain in the supply chain is the end consumer; here the quality of performance of the chain is seen in customer satisfaction achieved through timely delivery of goods in modern technologies and systems with the desired quality. This also involves offering after sales services to build loyalty and also attain sustainable competitive advantage [17], [18]. emphasized the fact that those companies that incorporate customer relationship management systems into the supply chain can enhance their responsiveness to customer needs and high levels of satisfaction.

Pillars of Digital Transformation

The dimensions of digital supply chains and the influence of the relationship between digital supply chains and corporate performance are discussed herein explaining why digital technology plays a role in enhancing the efficiency of operations, quality, responsiveness, and sustainability in growth of companies, and how it contributes to the effectiveness of organisational integration and sustainable competitive advantage of companies in the global markets [19] [20], [21]. indicated that there are seven main dimensions of digital supply chains:

1. Digital Performance Management:

Digital performance management is the use of electronics in management of the entire functions of the company where digital tools are used to process the data of the supply chain and identify patterns and trends and make informed decision to enhance performance. It helps companies to perform transactions within a short time, optimize processes, increase accuracy and save time and effort.

2. Digital Information Technology:

The old fashioned ways of management cannot cope with the contemporary changes. As technological changes occur at a very fast rate, organizations should embrace the use of modern technologies and incorporate them in their operations to remain abreast with the working environment and beat competition. The digital supply chain relies on digital information technology which comprises the main systems like Enterprise Resource Planning (ERP), supply chain management systems, demand forecasting systems among others.

3. Digital Human Resources:

The human resource management has evolved in great ways especially over the past twenty years whereby the advancement in technology and digital transformation has been central in improving efficiencies and broadening human capital management, in building the digital capabilities of the employees and in managing the digital talents.

4. Digital Suppliers:

This is the incorporation of suppliers with the electronic system of the company to enhance communication and the collaboration between the company and suppliers. Companies must integrate digital aspects into their business operations, substitute the usual manual activities with digital activities, and keep on using

digital media to communicate with suppliers. This makes sure that raw materials are received on time based on the low level of inventory using digital sensors which inform the suppliers to set up the materials as the inventory level decreases [22].

5. Digital Manufacturing:

In the recent past, there has been an increasing necessity of companies to shift towards modern to sophisticated digital manufacturing, comprising smart manufacturing, holonic manufacturing, reverse engineering, advanced manufacturing systems (0.4 and 0.5) and dark factories, among others. This means incorporation of digital technologies in traditional manufacturing processes which include additive manufacturing and robotics.

6. Digital Logistics:

The concept of logistics has always been linked with the methods that a company follows during transportation, storage, and distribution. Digital logistics, in its turn, signifies the application of digital technologies as the way to optimize the work of transportation, storage, and distribution.

7. Digital Customer:

Customer satisfaction is the main aim of every company. In the recent past, firms have embraced superior business models that incorporate modern technology to fulfill customer demands and requirements at the right time. This includes satisfying customers via the digital platform and a smooth customer experience.

Concept of the Environmental Dimension

The environmental aspect of sustainable functionality is one of the main features that international corporations aim at developing to warrant the minimization of environmental impact caused by industrial and logistic processes on production, transport, and distribution levels. Research has shown that there has been an increase in global recognition of the climate change crisis and the decline of environmental resources thereby forcing the companies to redesign their operations policies in order to strike a balance between economic performance and environmental conservation [23].

Mentioned that environmental conservation has turned out to be an inseparable part of corporate activity, which compels businesses to use digital technologies to transform the traditional mode of operations to smart digital processes. The artificial intelligence software has made more efficient analysis of customer needs, allowing faster decisions to make, producing products that satisfy the customer needs at the most efficient production, reducing human mistakes, using less of resources, producing zero waste, and maintaining production continuity without damaging the ecosystem [24].

1. Pillars of the Environmental Dimension:

This aspect is aimed at minimizing the adverse effects of the manufacturing process on the environment. The importance of companies in environmental sustainable management is essential in the realization of the environmental laws and policies. Quality corporate practices may also help in reducing emissions by ensuring that strict environmental regulations are imposed [25]. specified that the environmental dimension of sustainable operation involves the effects that the company activities have on the environment, both the direct effects as reported by the companies and indirect effects as caused by the third party whether the supplier of raw material with harmful toxic substances or the consumer of the material that can have adverse effects to the environment.

It also considers environmental pressure, as in many cases, it is concerned only with short-term profits and pays little attention to sustainability or restoration of resources [26]. The key sub-dimensions are:

a. Resource-Use Efficiency:

It is crucial to decrease the quantity of raw materials consumed and enhance the use of resources. Resource efficiency is described as being the successful utilization of finite, non-renewable natural resources (that are not able to replenish themselves once depleted) and renewable natural resources (that are capable of returning to their earlier inventory levels through the process of natural growth or regeneration) in the process of exploiting nature as a production and consumption factor (UNEP Finance Initiative, 2021:5).

According to the need to curb emissions and attain environmental friendliness, resource efficiency is necessary. Corporate social responsibility initiatives frequently extend further than adherence to environmental laws and actively participate in the welfare of the society. The effect of such strategies must be felt on the efficiency in the use of resources, which will impact positively on the performance of environment and economy. As the demands on the natural resources and environmental pollution continue to increase, there is a need to define and advance the activities that optimize the efficiency of the available resources in the name of ensuring sustainability (Handoyo, 2024:1-2). In order to produce environmentally friendly products, the modern firms embrace green environmental practices that include minimizing energy usage, use of optimal industrial practices to ensure the supply chain is eco friendly, rationalize usage of natural resources in the packaging processes, recycling and reuse of materials and cutting down on the emissions during the production processes (Al-Hadithi, 2014:4).

b. Waste Reduction:

This aspect is aimed at minimizing the amount of waste created and introducing efficient waste management measures. Efficiency may similarly be enhanced in the production process, which involves having less resource utilization and minimizing wastes, but with production of the same amount of goods and services. The resource productivity and consumption and the attendant environmental effects, and the resource security have become prominent issues in the manufacturing industry. The policies that many organizations have set up have aimed at enhancing the productivity of the resources at different levels of economic activities and also minimizing the adverse environmental effects of the use of resources during the lifecycle of the product and service [27].

Underlined the fact that the essence of sustainable environmental operations consists in protecting the environment and avoiding destruction, both due to unreasonable or excessive use of natural resources and the careless and destructive dumping of industrial waste. observed that waste has become a worldwide environmental issue that has large-scale repercussions in terms of ecosystems, human health, and sustainability [28]. To address the challenge of the necessity of sustainable waste management and conservation of resources, researchers and specialists are considering the new solutions which will convert the waste into useful materials [29], [30].

c. Pollution Prevention:

This involves reducing air and water pollution and lowering greenhouse gas emissions. Green or environmental technologies are generally divided into two main categories: pollution prevention technologies and pollution control technologies. Pollution prevention technologies, also known as *source reduction technologies*, reduce pollution at the source by redesigning products or making fundamental changes to production processes. Consequently, companies can use eco-friendly alternatives or reduce energy and raw material consumption in production. In contrast, pollution control technologies, also known as *end-of-pipe technologies*, involve measuring, capturing, storing, treating, and disposing of pollutants after they are generated. Companies adopt these technologies by adding cleaning devices at the end of production processes without altering the core production operations [31].

Emphasized that environmental protection requires legislation of regulations and laws that companies must comply with to implement green manufacturing operations, applying the dimensions of green operations to protect the environment and produce eco-friendly products. confirmed that companies have increasingly adopted green supply chain management in their operations, integrating environmental thinking into product design, material sourcing, manufacturing processes, and delivery of final products to consumers, while also considering product reuse at the end of its life cycle [32], [33]

2. Objectives of the Environmental Dimension:

- a. To assist in the optimal use of natural resources and preserve them for future generations.
- b. To protect the environmental climate from global warming and all types of environmental pollution.
- c. To utilize modern technologies and apply legal regulations associated with this field.
- d. To strive to reduce the use of harmful gases and prevent the degradation of the ozone layer.

Field Framework of the Study

1. Descriptive Analysis of the Study Variables

Table (3) presents the descriptive analysis of the study variables (Digital Supply Chain and Environmental Dimension) along with all their sub-dimensions. In this analysis, a number of statistical tools were employed and they are the arithmetic mean, standard deviation, minimum and maximum values.

Table 3. Description of the Study Variables and Their Dimensions.

Variables and Dimensions	Code	Arithmetic Mean	Standard Deviation	Minimum Value	Maximum Value	Relative Importance	Agreement Strength
Digital Supply Chain	X	0.590	0.399	0.00	1.00	58.99%	Acceptable
Environmental Dimension	Y	0.550	0.462	0.00	1.00	55.03%	Acceptable

Source: Table prepared by the researchers using SPSS software

2. Hypotheses Testing

a. (H1) Primary Hypothesis 1: The Statistically significant correlation between the Digital Supply Chain at the overall level and Environmental Dimension in the company under study is statistically significant.

To prove this hypothesis, Pearson correlation coefficient was computed in order to ascertain the significance, direction and strength of the relationship between the variables. Table (4) shows the correlation value between the Digital Supply Chain variable and the Environmental Dimension in the company under study.

Table 4. Relationship between the Digital Supply Chain Variable and the Environmental Dimension in the Company under Study.

Variables		Statement	Environmental Dimension (Y)
Digital Supply Chain	X	Pearson Sig.	0.930** 0.000

(**) Significant at the 1% level, (*) Significant at the 5% level
Source: Table prepared by the researchers using SPSS software

It can be observed from Table (4) that there is a positive (direct) and statistically significant correlation at a significance level of less than 5% between the Digital Supply Chain variable and the Environmental Dimension in the company under study. This indicates that an increase in the level of availability of the Digital Supply Chain variable in the company will be accompanied by an increase in the Environmental Dimension in the same company. Therefore, the first primary hypothesis is accepted. Based on these results, it can be concluded that the first primary hypothesis is supported.

b. (H2) Primary Hypothesis 2: There is a statistically significant impact of the Digital Supply Chain at the overall level on the Environmental Dimension in the company under study.

To test this hypothesis, a simple linear regression equation was prepared to estimate the Environmental Dimension through the Digital Supply Chain variable, in order to determine the extent of its impact on the Environmental Dimension. Table (5) presents the results of this impact.

Table 5. Impact of the Digital Supply Chain Variable on the Environmental Dimension.

Variables and Dimensions	(R²)	(Adjusted R²)	(F)	(Sig.)
Digital Supply Chain	0.866	0.865	798.760	0.000
Constant (β_0)		Regression Coefficient (β)	(T)	(Sig.)
	0.001	0.981	28.262	0.000

Source: Table prepared by the researchers using SPSS software

It can be observed from Table (19) that the validity of the regression model is confirmed by the F-value of **798.760** at a significance level of less than 5%, which indicates the possibility of estimating the Environmental Dimension of sustainable operations through the Digital Supply Chain. The T-value of **28.262** at a significance level of less than 5% further supports this.

The positive beta (β) coefficient of **0.981** indicates that the effect is positive, meaning that the Digital Supply Chain positively influences the Environmental Dimension of sustainable operations by enhancing the effectiveness and efficiency of this dimension at the KAT factory for asphalt and lubricating oil production, which is the subject of the study.

Additionally, the coefficient of determination (R²) of **0.866** indicates that the Digital Supply Chain explains **86.6%** of the variations in the Environmental Dimension of sustainable operations, while the remaining **13.4%** is attributed to other factors not included in the current model. This helps prove the acceptance of the second main hypothesis.

Conclusions and Recommendations

This part contains a group of conclusions made with references to the study results and provides the recommendations which should help to optimize the application of the study variables to the aim of the achievement of high outcomes in the environmental performance of industrial enterprises.

Conclusions

1. Close Relationship between Digital Supply chain and the Environment:

The research confirmed the fact that there was a positive and statistically significant relationship between the sizes of the Digital Supply Chain and the Environmental Dimension. It proves that the implementation of digital technologies in supply chains will directly lead to the enhancement of the efficiency of industrial processes in terms of the environmental aspect.

2. Basic importance of Digital Supply Chains as an Explanatory Variable:

The research has found out that Digital Supply Chains contribute greatly to the Environmental Dimension. The results of the regression analysis showed that the use of digital technologies and technical platforms in the supply chains led to a decrease in the level of pollution and the improvement of the efficiency of using resources.

3. Relevance of Human Resources and Partners:

The study established that the pillars of people and partners are very critical in the success of the digital supply chain strategies. Awareness of the employees and blending relationships with suppliers would help in enhancing product life cycle evaluation and waste reduction.

4. This is intended to bring about Environmental Competitive Advantage:

It was clear that the Digital Supply Chain does not belong to a technical role but is a strategic means to achieve customer satisfaction and build a better reputation of the company due to compliance with the international environmental standards.

Recommendations

1. Build Digital Infrastructure: There is a need to invest more in the new digital technology infrastructure that can provide real-time and accurate measurements of pollutant emissions and energy use.

2. Improve Awareness and Technical Training: The research suggests that the company should train its human resource on how to relate digital technologies in all its supply chain operations in order to reduce wastage and maximize resource utilization.

3. Introduce Life Cycle Assessment Systems: Use special digital software of product life cycle assessment that helps to make design decisions minimizing environmental wastes associated with the production of the product to its disposal.

4. Grow Green Digital Partnerships: Develop a collaborative network of partners and suppliers to share environmental data, which will contribute to a sustainable digital supply chain to meet the environmental goals of the company.

5. Enable Digital Pollution Prevention Systems: Use artificial intelligence and big data technologies to anticipate environmental problems before they arise and improve the capacity of the company to keep pollution at bay not just to treat it.

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