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THE IMPACT OF SUSTAINABLE LOGISTICS AND ICT-BASED MAINTENANCE ON BUSINESS PERFORMANCE IN MANUFACTURING ENTERPRISES

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Original Scientific Paper

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This paper analyzes the influence of sustainable logistics practices and ICT based maintenance on business performance in manufacturing enterprises in Serbia. The study focuses on green transportation practices, efficient warehousing operations, sustainable packaging and materials management, and ICT based maintenance. A quantitative survey was conducted with 42 managers, and all constructs were measured with a seven point Likert scale. The results show that all four independent variables have positive and statistically significant effects on business performance. Efficient warehousing operations show the strongest influence, while green transportation, sustainable packaging, and ICT based maintenance also contribute to performance improvement. The findings indicate that sustainability oriented logistics practices and digital maintenance systems act as complementary sources of operational progress in manufacturing. The study has several limitations, including a small sample size, and a single country context. Future research may include larger samples, comparative sector analyses and longitudinal designs. The results provide guidance for managers who aim to improve business performance through coordinated sustainability and digitalization activities. The regression analysis shows that the model explains 57.6% of the variance in business performance ($R^2 = 0.578$). Efficient warehousing operations have the strongest standardized effect ($\beta = 0.314$), followed by green transportation practices ($\beta = 0.265$), ICT-based maintenance ($\beta = 0.245$), and sustainable packaging and materials management ($\beta = 0.198$)

Key words: Sustainable logistics; Business performance; ICT-based maintenance; Productivity; Manufacturing enterprises.

INTRODUCTION

Sustainable logistics has gained attention in manufacturing enterprises as a response to environmental regulations, rising operational costs, and customer expectations for responsible business practices. Many organizations adjust transportation, warehousing, and packaging processes in order to

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reduce emissions, waste, and resource consumption (Chen et al., 2024; Jazairy et al., 2021). Interest in these activities continues to grow as enterprises assess how environmental initiatives in logistics influence both operational efficiency and financial outcomes (Prataviera et al., 2024; Wang et al., 2023). Transportation-related emissions, inefficient warehousing layouts, and excessive packaging remain persistent sources of environmental and economic burdens across global supply chains (Creazza et al., 2024; Lai et al., 2023). Enterprises that adjust these areas often achieve improvements in cost efficiency, service reliability, and organizational legitimacy (Ellram et al., 2022; Silva et al., 2021). ICT-based maintenance represents another domain that shapes performance in manufacturing. Digital tools such as IoT systems, sensor networks, CMMS platforms, and predictive analytics are now common elements of maintenance strategies that aim to reduce downtime and improve equipment condition (Mendes et al., 2023a; Tortorella et al., 2024). These tools allow maintenance departments to detect irregularities, analyze patterns, and plan interventions with greater accuracy (Bousdekis et al., 2021; Mołęda et al., 2023). Many manufacturing enterprises increasingly integrate digital maintenance practices with existing frameworks such as Total Productive Maintenance, which supports smoother production flows and fewer operational disruptions (Samadhiya et al., 2023; Tortorella et al., 2024). Digital maintenance does not only support operational outcomes but also contributes to lower resource consumption and reduced waste, aligning maintenance decisions with broader sustainability goals (El Kihel et al., 2022; Franciosi et al., 2020).

Although existing studies cover sustainable logistics and ICT-based maintenance extensively, research that connects both areas within one empirical model remains limited. Some previous work examines the influence of green transportation, warehousing efficiency, or packaging practices on environmental and operational outcomes (Mudgal et al., 2024; Prataviera et al., 2023). Other research focused on predictive maintenance, digital twins, or maintenance digitalization and discussed their implications for equipment reliability and productivity (Achouch et al., 2022; Nunes et al., 2023). Much fewer studies investigate these two domains together, especially within manufacturing enterprises in developing or transitional economies (Geng et al., 2024; Layaoen et al., 2024). The significance of this paper lies in the development and assessment of an integrated model that examines how sustainable logistics practices together with ICT-based maintenance affect business performance in manufacturing enterprises. The study provides empirical insights that expand current knowledge in both fields. Organizations often consider these domains separately, which restricts their ability to observe complementarities between environmentally responsible logistics processes and digitally supported maintenance activities. The paper therefore contributes to the existing body of literature regarding performance improvement in manufacturing (Karaman et al., 2024; Wen et al., 2023).

Although both fields are well explored separately, research rarely examines sustainable logistics and ICT-based maintenance within the same empirical framework. Existing studies usually focus on single sustainability domains or isolated maintenance strategies without analyzing how these areas function together in manufacturing enterprises. This gap is more visible in developing and transitional economies, where enterprises introduce sustainability initiatives and digital tools at different intensities. The present study addresses this gap by investigating how these constructs jointly relate to business performance and by providing an integrated assessment that is currently limited in the literature.

In this paper, the main goal is to analyze the impact of sustainable logistics and ICT-based maintenance on business performance. Sustainable logistics is analyzed through green transportation practices, efficient warehousing operations, and sustainable packaging and materials management. Additionally, a theoretical model is developed for improving business performance based on the analyzed factors. The paper consists of six main sections. First, the Introduction, then the Theoretical background is developed. Next, the Research methodology is noted in detail. Afterwards, the results are presented. Next, the results are discussed and finally conclusions are drawn.

THEORETICAL BACKGROUND

Sustainable logistics and business performance

Sustainable logistics represents a group of activities that aim to reduce environmental impact through transportation, warehousing, and packaging processes while the level of business performance remains the same or improves (Chen et al., 2024; Kitsis & Chen, 2021). This includes

green transportation practices, efficient warehousing operations, and sustainable packaging and materials management. Previous research shows that these activities influence the competitiveness of companies, since they increase efficiency, reduce waste, and support the market and regulatory requirements related to environmental responsibility (Geng et al., 2024; Prataviera et al., 2024). Green transportation practices include the use of low-emission vehicles, route optimization, fuel-efficient driving, and shifts toward rail or other modes that emit less carbon. These activities reduce emissions and other negative effects of logistics, while the overall cost efficiency improves through lower fuel consumption and better use of vehicles (Ellram et al., 2022; Thanh Ha, 2024). Companies adopt electric or alternative-fuel vehicles in freight transport in order to lower the use of fossil fuels and to align their operations with international carbon-reduction initiatives. These investments can support operational savings and improve the environmental reputation of companies (Eggert & Hartmann, 2021; Karaman et al., 2024).

Efficient warehousing operations represent another important part of sustainable logistics (de Souza et al., 2022). Lean warehousing practices also support sustainability because they reduce activities that do not add value, eliminate unnecessary movement, and improve layout and storage organization. These activities improve the use of space and lower energy needs through smoother process flows and fewer material handling operations (Samadhiya et al., 2023; Prataviera et al., 2023). Companies which combine sustainability initiatives with digital technologies, such as automated storage systems, IoT-based monitoring, and predictive analytics, achieve better warehouse productivity, lower downtime, and reduced operational costs (Đorđević et al., 2023; Mendes et al., 2023a; Werbińska-Wojciechowska & Winiarska, 2023). Increasing pressure to reduce carbon emissions also motivates companies to introduce green building standards in warehouses, including better insulation, solar rooftops, and modern equipment upgrades (Lintukangas et al., 2023; Tetteh et al., 2024).

Sustainable packaging and materials management represents the third important element of sustainable logistics. Packaging has a strong effect on logistics efficiency and environmental performance because it influences volume, weight, recyclability, and the amount of generated waste (Mudgal et al., 2024; Wamalwa & Meyer, 2024). This trend is supported by regulatory requirements, expectations of customers, and corporate sustainability goals (Sabat et al., 2023; Youngswaing et al., 2024). Packaging solutions have to balance durability, product protection, and environmental characteristics while the cost and customer needs are taken into consideration (Mudgal et al., 2024). Using lighter or modular packaging improves transport efficiency because vehicle capacity increases and fuel consumption per transported unit decreases (Wen et al., 2023). Effective materials management also includes reverse logistics activities, such as collecting used packaging for recycling, redesigning packages for reuse, and including circular economy principles in packaging strategies (Bag et al., 2022; Nureen et al., 2022). Sustainable logistics is linked with higher operational efficiency, lower costs, better environmental results, and a stronger corporate reputation (Chen et al., 2024; Wen et al., 2023). Companies that adopt green supply chain practices, such as eco-friendly transportation, efficient warehousing, and sustainable packaging, often report higher profitability, noticeable cost savings, and improved competitive positions on the market (Geng et al., 2024; Silva et al., 2021). Previous studies also suggest that sustainability activities reduce resource consumption, decrease waste, and increase process reliability, which together support business performance (Bag et al., 2022; Prataviera et al., 2024).

However, companies can face financial and operational challenges when they transition toward sustainable logistics. These challenges include investment costs, coordination issues with supply chain partners, and additional skill requirements (Kitsis & Chen, 2021; Layaoen et al., 2024). Previous studies show that top management support, employee involvement, and cooperation within the supply chain are important for successful implementation of sustainable logistics (Silva et al., 2021; Youngswaing et al., 2024).

ICT-based maintenance and productivity

Digitalization of maintenance has become an important part of modern manufacturing systems because companies require higher equipment reliability, shorter response times, and better operational performance (Shaheen & Németh, 2022; Tortorella et al., 2024). ICT-based maintenance allows companies to monitor asset conditions continuously, detect irregularities, and

react before equipment failures interrupt production. The transition from reactive and time-based maintenance toward predictive and condition-based maintenance is often described as a main approach for improving equipment availability and operational productivity (Nunes et al., 2023). Predictive maintenance uses real-time sensor data to estimate when equipment should be serviced. Unlike preventive maintenance based on fixed time intervals, predictive maintenance relies on actual machine conditions such as vibration, noise, temperature, or pressure to determine when maintenance is needed (Achouch et al., 2022). Machine learning and AI algorithms help detect faults and predict failures with higher accuracy, which reduces unplanned downtime and extends the useful life of equipment (Keleko et al., 2022; Siraskar et al., 2023). Predictive maintenance reduces maintenance costs and prevents production losses, especially in capital-intensive industries such as power generation, machining systems, and transportation infrastructure (Gbadamosi et al., 2021). The use of IoT-based predictive systems in railway operations has shown positive results in monitoring critical components and improving maintenance scheduling, which improves operational safety and reliability (Gbadamosi et al., 2021). Digital twins further support predictive maintenance because they create virtual models of physical assets for testing, diagnostics, and performance optimization. These models allow maintenance teams to simulate equipment behavior under different conditions, observe how faults progress, and identify maintenance strategies before the actual intervention takes place (Patange et al., 2024; Shao & Kumral, 2024). Digital twins in manufacturing improve prediction accuracy and maintenance decision-making, which results in higher equipment uptime and better production planning (Bousdekis et al., 2021; Mendes et al., 2023b). E-maintenance and integrated maintenance management systems represent another important element of ICT-based maintenance. These systems include CMMS platforms, mobile maintenance applications, cloud-based documentation tools, and remote assistance technologies which use augmented reality. CMMS platforms organize work orders, maintenance schedules, inventory management, and reporting by centralizing maintenance data and connecting it with real-time machine information (Shaheen & Németh, 2022). Augmented reality tools overlay digital information onto physical equipment during inspection and repair, helping technicians with visual guidance and reducing the time required for diagnostics and corrections (Suresh & Dharunanand, 2023). These technologies improve maintenance efficiency and productivity because they reduce administrative delays and provide accurate and timely information to maintenance personnel (Ahmed et al., 2023).

When unplanned failures are reduced through predictive analytics or real-time monitoring, production interruptions occur less often, equipment availability increases, and production throughput becomes higher (Mendes et al., 2023a; Mołęda et al., 2023). Research in manufacturing also suggests that integrating IoT sensors with TPM routines improves early detection of equipment deviations, supports faster corrective actions, and reduces waste of resources (Samadhiya et al., 2023). Data-based decision-making can also contribute to productivity improvement. Maintenance managers increasingly use analytics platforms and decision-support tools to detect patterns, prioritize maintenance tasks, and distribute resources more effectively (Bousdekis et al., 2021). For example, prediction and classification algorithms can estimate the remaining useful life (RUL) of components, while optimization models help schedule maintenance activities at times when production interruptions are minimized (Nunes et al., 2023). Remote monitoring reduces the need for frequent manual inspections, which allows maintenance staff to focus on tasks with higher added value (Achouch et al., 2022).

The existing body of literature also indicates that ICT-based maintenance contributes to sustainability performance. Efficient and timely maintenance lowers unnecessary energy use, prevents premature equipment failure, and supports longer equipment lifecycles (Franciosi et al., 2020). These outcomes connect maintenance activities with environmental goals and create a link between digitalization and sustainability in manufacturing operations (Achouch et al., 2022; Mendes et al., 2023b). For example, research reports lower waste of spare parts and higher machine efficiency when predictive maintenance is used, which indicates that digital tools support resource conservation together with productivity improvement (Samadhiya et al., 2023).

The constructs examined in this study are connected through their influence on operational efficiency and organizational adaptability. Sustainable logistics practices improve resource

use and reduce inefficiencies in transportation, warehousing, and packaging activities. ICT-based maintenance contributes to the stability and reliability of equipment used within these logistics processes. When combined, these constructs form an integrated set of operational factors that influence business performance and reflect the parallel development of sustainability and digitalization in manufacturing enterprises.

METHODOLOGY

Research framework and hypotheses

After the thorough literature review, the following hypotheses are proposed as guidelines for the research:

H1: Green transportation practices (GTP) positively affect business performance (BP).
H2: Efficient warehousing operations (EWO) positively affect business performance (BP).
H3: Sustainable packaging and materials management (SPMM) positively affect business performance (BP).
H4: ICT-based maintenance (ICTM) positively affect business performance (BP).

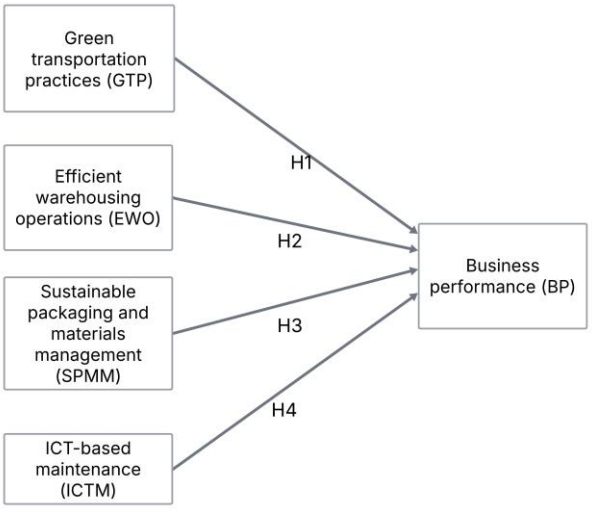

Figure 1: Research framework

Sample size and data analysis

This research uses a quantitative approach based on a survey distributed to managers working in manufacturing enterprises in Serbia. The goal of the survey was to examine how sustainable logistics practices and ICT-based maintenance together relate to business performance. Managers were selected as respondents because they have direct insight into logistics activities, maintenance processes, and business outcomes in their organizations. A total of 42 respondents participated in the research, which reflects the structure of manufacturing enterprises in the region where small and medium-sized companies represent the dominant part of the industrial environment.

The survey included items that measured four constructs: green transportation practices (GTP), efficient warehousing operations (EWO), sustainable packaging and materials management (SPMM), and ICT-based maintenance (ICTM). Business performance (BP) was included as the dependent construct. All items were evaluated on a seven-point Likert scale ranging from 1 ("strongly disagree") to 7 ("strongly agree"). The Likert scale format supports the assessment of subjective managerial perceptions and allows the use of parametric statistical analyses. The items were developed based on earlier studies in the domains of sustainable logistics, maintenance digitalization, and performance measurement.

Before data collection, the questionnaire was reviewed to ensure clarity and content validity. Minor adjustments were made so that the items would correspond to the terminology that is commonly used in Serbian manufacturing enterprises. The survey was distributed electronically in order to increase response speed and reach managers from different regions of Serbia. Participation was voluntary, and respondents were informed that the data would be used only for academic purposes.

The sample size of 42 respondents reflects the structure of manufacturing enterprises in the region but represents a limitation of the study. The results should be interpreted with this limitation in mind, and the findings are considered indicative rather than generalizable to all manufacturing contexts.

The data analysis included several steps. First, descriptive statistics were calculated to show the central tendency and variability of each construct. These values provided an overview of managers' perceptions about logistics sustainability and digital maintenance activities. Second, the reliability of each construct was tested using Cronbach's alpha. All constructs showed acceptable internal consistency, which indicates that the items measured their intended concepts adequately. Third, a Pearson correlation analysis was conducted to

identify the strength and direction of the relationships between the independent constructs and business performance. Linear regression analysis was conducted to examine how each independent variable predicts business performance. This step follows recommendations from recent studies that analyze sustainability-related factors influencing performance in manufacturing.

Table 1: Respondents' information

Respondents' information		
Gender:	Male	33 (78.57%)
	Female	19 (21.43%)
Age:	under 30	2 (5%)
	from 30 to 50	29 (69%)
	over 50	11 (26%)
Education:	Elementary	00 (00%)
	High school	00 (00%)
	College	3 (7.5%)
	Bachelor's degree	34 (80%)
	Master's degree	4 (10%)
	Magistrate	00 (00%)
	PhD	1 (2,5%)
Enterprise size	micro (1-10 employ.)	7 (17.5%)
	small (11-50 employ.)	21 (52.5%)
	medium-sized 51-250 employees)	10 (22.5%)
	Large (251 and more employs)	3 (7.5%)

The chosen methodology allows a structured examination of both areas within a single empirical model. Survey-based quantitative analysis is suitable for this type of research because it captures managerial perceptions and enables the testing of clearly defined relationships between constructs that are well established in the literature. Although the sample size is modest, the obtained dataset reflects the structure of manufacturing enterprises in the region, where small and medium-sized enterprises are dominant. Multicollinearity was assessed using VIF and tolerance values, and no issues were identified. Standard errors of the coefficients were within ranges commonly reported in studies that use similar analytical procedures. Linear regression was applied because Likert-type multi-item constructs are frequently treated as continuous variables in management research when reliability is high. Cronbach's alpha values in this study were well above recommended values, which supports the reliability of the constructs and allows the use of parametric statistical techniques. The questionnaire included items adapted from previous studies on sustainable logistics and digital maintenance. The information about the sample, more precisely, the respondents' information is presented in Table 1.

RESULTS

Statistics

The results of the statistical analysis include descriptive statistics, correlation analysis, linear regression analysis and Cronbach's alpha test. Descriptive statistics are presented in Table 2.

Table 2: Descriptive statistics

Variable	N	Min	Max	Mean	Stand. dev.
Green transportation practices (GTP)	42	1	7	4.26	1.52
Efficient warehousing operations (EWO)	42	1	7	5.11	1.23
Sustainable packaging and materials management (SPMM)	42	1	7	4.43	1.16
ICT-based maintenance (ICTM)	42	1	7	4.52	1.31
Business Performance (BP)	42	1	7	4.63	1.25

Table 2 presents the descriptive statistics for the five observed constructs. All variables were measured on a seven-point Likert scale. The mean values show that respondents generally expressed moderately positive perceptions of sustainable logistics practices and ICT-based maintenance. The relatively large standard deviations, especially for GTP and ICTM, indicate notable differences between enterprises. Some enterprises appear to invest more heavily in green transportation and digital maintenance than others, while the rest of the sample remains closer to the midpoint of the scale. Overall, the descriptive statistics suggest that sustainable logistics and ICT-based maintenance are present in Serbian manufacturing enterprises, although their implementation intensity varies across organizations.

Next, the results of the correlation analysis are presented in Table 3.

Table 3: Correlation analysis results

alfa: 0.05	GTP	EWO	SPMM	ICTM	BP
Green transportation practices (GTP)	1.000				
Efficient warehousing operations (EWO)	0.421	1.000			
Sustainable packaging and materials management (SPMM)	0.365	0.423	1.000		
ICT-based maintenance (ICTM)	0.512	0.474	0.504	1.000	
Business performance (BP)	0.462	0..398	0.465	0.374	1.000

All correlations are positive and of moderate magnitude. GTP correlates positively with EWO (r=0.421), SPMM (r=0.365), ICTM (r=0.512), and BP (r=0.462). These results indicate that enterprises with more advanced green transportation practices also tend to report better warehousing and packaging practices, higher levels of ICT-based maintenance, and higher perceived business performance. EWO shows positive correlations with SPMM (r=0.423), ICTM (r=0.474), and BP (r=0.398). This pattern suggests that efficient warehousing is linked with broader sustainability and digitalization efforts and associates with higher performance outcomes. SPMM correlates positively with ICTM (r=0.504) and BP (r=0.465), so enterprises that invest in sustainable packaging also report more intensive ICT-based maintenance and stronger business performance. ICTM shows a positive correlation with BP (r=0.374), which supports the assumption that digital maintenance practices relate to improved performance indicators. None of the correlations reach values that would suggest severe multicollinearity, which supports the use of all four independent variables in the multiple regression model.

Furthermore, the results of the Cronabach's alpha test are presented in Table 4.

Table 4: Cronbach's alpha test results

Variable	Cronbah-alfa values	Number of questions
Green transportation practices (GTP)	0.823	4
Efficient warehousing operations (EWO)	0.841	4
Sustainable packaging and materials management (SPMM)	0.895	5
ICT-based maintenance (ICTM)	0.905	5
Business performance (BP)	0.942	5

All constructs have alpha values well above the commonly accepted threshold of 0.70, which indicates satisfactory internal consistency. These results provide support for the measurement model. Each construct is represented by items that behave consistently and can be treated as reliable composite indicators in subsequent analyses. This reliability level is particularly important in a study with a relatively small sample size, because unstable scales would introduce additional measurement error and reduce the power of statistical tests. Next, in Table 5., the results of the linear regression analysis are presented.

Table 5: Results of the linear regression analysis

Y	X	β	p-value	R^2	Adjusted R^2
		1.925			
BP	GTP	0.265	<0.0001	0,578	0,576
	EWO	0.314	<0.0001		
	SPMM	0.198	<0.0001		
	ICTM	0.245	<0.0001		

Table 6: Results of the multicollinearity test

Static	BP	GTP	EWO	SPMM	ICTM
Tolerance	0.510	0.374	0.428	0.623	0.482
VIF	2.105	1.952	1.854	1.624	2.054

Table 5 summarizes the results of the multiple linear regression analysis with business performance as the dependent variable and GTP, EWO, SPMM, and ICTM as independent variables. The overall model shows an R^2 value of 0.578 and an adjusted R^2 of 0.576. Thus, the four predictors jointly explain about 58% of the variance in business performance, which can be considered a relatively strong explanatory power in survey-based management research. All four predictors have positive and statistically significant standardized beta coefficients ($p < 0.0001$). EWO has the highest beta coefficient ($\beta = 0.314$), which indicates that efficient warehousing operations represent the strongest predictor of business performance among the analysed variables. GTP ($\beta = 0.265$) and ICTM ($\beta = 0.245$) also show notable positive effects, which suggests that improvements in green transportation and ICT-based maintenance correspond with higher levels of perceived performance. SPMM has a somewhat lower, yet still positive and significant coefficient ($\beta = 0.198$), so sustainable packaging and materials management also contributes to performance. Next, in Table 6. The results of the multicollinearity test are presented.

The variance inflation factor (VIF) values for all predictors were below commonly accepted thresholds, which indicates that multicollinearity was not present. Standard errors were within expected ranges for survey-based models, supporting the reliability of the estimated coefficients.

Developed model

Based on the obtained results and the analyzed literature, a theoretical model for improving business performance based on sustainable logistics and ICT-based maintenance was developed. The model is presented on Figure 2.

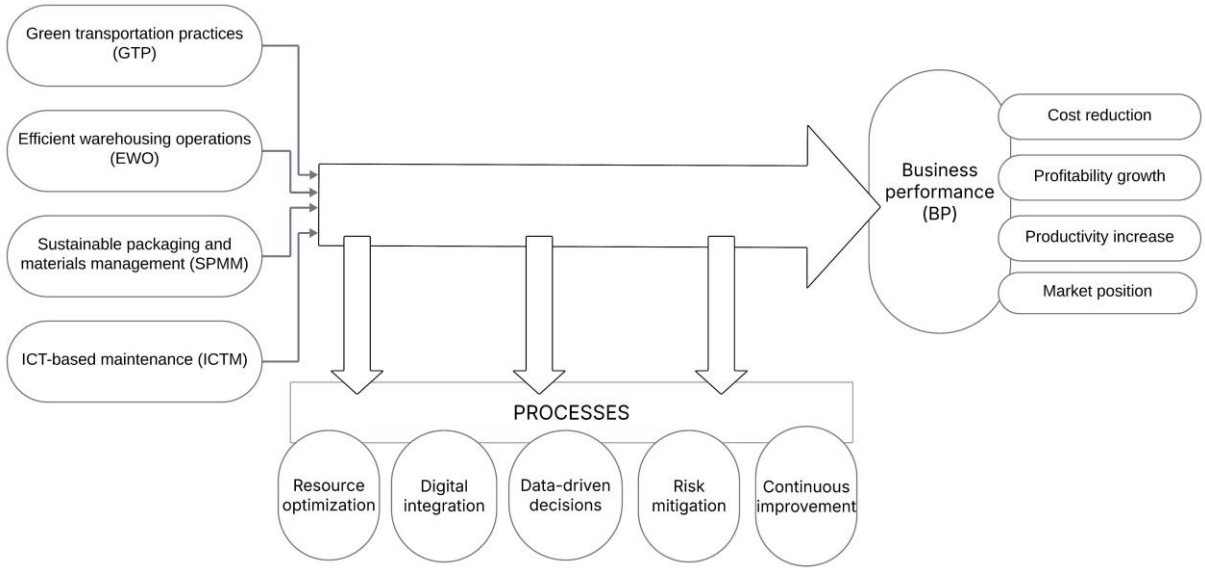

Figure 2: Developed model for improving business performance based on sustainable logistics and ICT-based maintenance

The developed model includes green transportation practices (GTP), efficient warehousing operations (EWO), sustainable packaging and materials management (SPMM), and ICT-based maintenance (ICTM) as predictors of business performance (BP). The empirical results, together with the theoretical background, indicate that these factors interact in a structured and supportive way. Each construct contributes to business performance in a specific manner, and the constructs also show interconnected patterns that reflect broader sustainability and digitalization trends in manufacturing enterprises. The relationship between GTP and BP shows that transportation-related sustainability measures have managerial importance. Higher GTP scores are linked with better business performance, which suggests that enterprises with more fuel-efficient routes, cleaner vehicle fleets, or improved emission control report stronger operational results. Transportation is usually one of the largest cost components in logistics, so improvements in this area influence financial and environmental indicators at the same time. The moderate correlation between GTP and the other

sustainability constructs indicates that enterprises acting in one sustainability domain often undertake improvements in others as well. Managers appear to view transportation sustainability as part of a broader operational adjustment instead of treating it as a separate activity. EWO shows the strongest direct relationship with business performance. Warehousing affects nearly all logistics processes, and well-organized storage systems support higher throughput, fewer delays, and more reliable material handling. The high regression coefficient for EWO suggests that improvements in layout, energy efficiency, inventory handling, and workflow organization have visible effects on business outcomes. EWO also correlates with ICTM, which shows that digital tools often support warehousing operations. This relationship reflects the growing presence of smart warehousing, where sensors, automation, and data systems improve inventory visibility and equipment maintenance. Enterprises with stronger warehousing practices also appear more prepared to adopt ICTM, which strengthens the overall structure of the model.

SPMM also shows a positive effect on BP, although its influence is slightly weaker compared to GTP and EWO. Packaging decisions affect transportation efficiency, warehouse space usage, and the amount of generated waste. The significant path between SPMM and BP indicates that enterprises with responsible packaging strategies reduce material waste, improve product protection, and lower handling costs. SPMM has moderate correlations with GTP, EWO, and ICTM, which shows that enterprises rarely treat sustainable packaging as an isolated activity. Packaging initiatives often develop together with improvements in warehousing processes or transport planning. This finding suggests that packaging management is part of a coordinated sustainability approach.

ICTM also shows a strong and meaningful relationship with BP. The regression results show that enterprises using predictive analytics, sensor networks, and digital platforms for maintenance achieve higher levels of performance. ICTM contributes through better machine availability, more accurate scheduling, fewer unexpected failures, and more efficient use of labor and spare parts. The correlations between ICTM and the three logistics constructs reflect the gradual introduction of digital technologies into logistics operations. When maintenance is based on real-time data, logistics processes operate with fewer interruptions. Equipment used in transportation, warehousing, and packaging becomes more reliable, which supports performance across the entire logistics chain. The interrelations among GTP, EWO, SPMM, and ICTM indicate that sustainability and digitalization often progress together. Enterprises that invest in environmentally responsible logistics usually invest in ICT-based maintenance as well. This pattern shows that sustainability-oriented enterprises recognize the importance of stable equipment performance, accurate information flows, and data-supported decision-making. ICTM acts both as a performance driver and as a support factor for efficient logistics processes.

Overall, the model shows how these elements align with one another and how they jointly contribute to higher business performance. The findings also indicate that improvements in logistics sustainability and maintenance digitalization develop as connected processes rather than independent activities.

DISCUSSION

Research results and hypotheses

The research examined the relationships between sustainable logistics practices, ICT-based maintenance, and business performance in manufacturing enterprises. The empirical results show positive associations between all independent variables and the dependent variable. These findings support the idea that sustainability-oriented logistics activities and digital maintenance practices contribute to improved organizational outcomes. The significance of EWO indicates that improvements in warehouse layout, material handling, energy efficiency, and workflow organization correspond with noticeable gains in performance. **Hypothesis H2, which states that EWO positively affects BP, is therefore supported.** GTP also shows a significant positive effect on BP. Enterprises that use energy-efficient transport methods, invest in cleaner vehicles, or optimize routing tend to achieve better business performance. This result aligns with the correlation analysis, where GTP shows moderate positive relationships with all other constructs. **The evidence supports H1, which states that GTP positively affects BP.**

SPMM shows a slightly weaker, but still statistically significant effect. Packaging decisions influence transportation efficiency, warehouse usage, and general resource consumption. **Enterprises with**

more sustainable packaging strategies report better performance outcomes, which supports H3. Although the effect size is lower than that of EWO, the significance level indicates that sustainable packaging remains an important dimension of logistics sustainability with direct implications for performance. ICTM also shows a clear and significant relationship with BP. Enterprises that use digital tools for maintenance report fewer disruptions, higher machine availability, and better production continuity. **This finding confirms H4, which states that ICTM positively affects BP.** The strength of ICTM as a predictor suggests that digital maintenance is an important operational factor in manufacturing environments. This outcome indicates that sustainable logistics and digital maintenance jointly contribute to business performance and that manufacturing enterprises in Serbia increasingly recognize their strategic importance.

The observed relationships are in line with previous research that reports positive effects of green logistics practices on operational and financial outcomes (Chen et al., 2024; Prataviera et al., 2024). The strong influence of warehousing efficiency corresponds with studies highlighting the role of layout optimization and energy-efficient operations in improving productivity (de Souza et al., 2022; Mendes et al., 2023a). The findings related to ICT-based maintenance are consistent with research showing that predictive analytics and sensor-based monitoring improve equipment availability and reduce disruptions in production (Bousdekis et al., 2021; Nunes et al., 2023). These similarities suggest that the patterns identified in Serbian manufacturing enterprises follow broader trends reported in international studies, reinforcing the relevance of coordinated sustainability and digitalization efforts. The consistency between the observed patterns and previously published studies suggests that the relationships identified in this sample follow broader trends documented in the literature. At the same time, the limited sample size requires cautious interpretation. The stable correlations and regression results are partly explained by the relatively homogeneous characteristics of the surveyed enterprises, where logistics and maintenance practices develop under similar market and technological conditions. These contextual factors may reduce variability in responses, which contributes to consistent statistical outputs.

Suggestions and guidelines

The findings provide several recommendations for enterprises that aim to improve business performance through sustainability and digitalization initiatives. These are the following:

- Enterprises should reorganize warehouse layouts to shorten material handling distances and improve internal flow.
- Enterprises should adopt energy-efficient lighting and climate systems in warehousing to reduce operating costs.
- Organizations should implement route-planning tools that reduce empty mileage and improve transport efficiency.
- Managers should increase the use of recyclable or reusable packaging materials to lower waste levels.
- Companies should introduce sensor-based monitoring systems to track equipment conditions and reduce unexpected breakdowns.
- Enterprises should integrate CMMS platforms into maintenance routines to improve scheduling and documentation accuracy.
- Logistics departments should redesign packaging dimensions to reduce shipment weight and increase vehicle utilization.
- Enterprises should offer digital maintenance training for technicians to strengthen their ability to interpret machine-generated data.
- Organizations should establish performance indicators that track both sustainability outcomes and maintenance reliability to support long-term improvements.

CONCLUSION

The study examined how sustainable logistics practices and ICT-based maintenance relate to business performance in manufacturing enterprises. The findings support the integrated model and indicate that sustainability-oriented logistics and digital maintenance act as complementary elements that support performance improvement in Serbian manufacturing. Several limitations should be considered. The sample size is relatively small and comes from a single national context, which limits the wider applicability of the findings. The cross-sectional research design does not allow an analysis of long-term changes in sustainability and maintenance practices. Future research can address these limitations by using larger and more diverse samples that include additional countries or regions. Longitudinal studies may offer insight into how

logistics sustainability and digital maintenance develop over time.

As for theoretical implications, the results provide evidence that sustainability-oriented logistics practices and ICT-based maintenance can be examined within a joint conceptual framework, which may guide future research in integrating these domains. The findings indicate that improvements in warehousing, transportation, packaging, and maintenance activities progress as related processes rather than isolated practices, which contributes to the broader understanding of performance drivers in manufacturing environments.

The practical implications of the findings indicate that manufacturing enterprises may benefit from coordinating sustainability initiatives with digital maintenance practices. Improvements in warehousing efficiency, responsible packaging, and transport planning are more effective when supported by reliable equipment and timely maintenance interventions. Enterprises that combine sustainability measures with digital tools for monitoring and scheduling maintenance can achieve more stable operations, lower resource consumption, and better utilization of labor and equipment. These coordinated efforts may also support long-term competitiveness by aligning operational processes with environmental expectations and technological developments. Additional studies that examine organizational culture, employee skills, and technology adoption may clarify the internal conditions that support stronger outcomes.

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UTICAJ ODRŽIVE LOGISTIKE I ODRŽAVANJA ZASNOVANOG NA IKT-U NA POSLOVNE PERFORMANSE U PROIZVODNIM PREDUZEĆIMA

Rad ispituje uticaj održivih logističkih praksi i IKT održavanja na poslovne performanse proizvodnih preduzeća u Srbiji. Istraživanje obuhvata zelene transportne prakse, efikasne skladišne operacije, održivo pakovanje i upravljanje materijalima i IKT održavanje. Kvantitativno istraživanje je sprovedeno sa 42 menadžera, pri čemu su sve konstrukcije merene sedmostepenom Likert skalom. Rezultati pokazuju da sve četiri nezavisne varijable imaju pozitivan i statistički značajan uticaj na poslovne performanse. Efikasne skladišne operacije imaju najveći uticaj, a zeleni transport, održivo pakovanje i IKT održavanje takođe doprinose poboljšanju rezultata. Nalazi ukazuju da održive logističke aktivnosti i digitalizovano održavanje funkcionišu kao komplementarni izvori operativnog napretka u proizvodnim preduzećima. Ograničenja istraživanja uključuju mali uzorak, fokusiranje na jednu zemlju i oslanjanje na samoprocene ispitanika. Buduća istraživanja mogu uključiti veće uzorke, uporedne analize sektora, longitudinalne pristupe i objektivne pokazatelje performansi. Rezultati pružaju smernice menadžerima koji žele da unaprede poslovne performanse kroz usklađene aktivnosti održivosti i digitalizacije. Regresiona analiza pokazuje da model objašnjava 57,6% varijanse poslovnih rezultata (R^2 = 0,578). Efikasne skladišne operacije imaju najjači standardizovani efekat (β = 0,314), zatim prakse zelenog transporta (β = 0,265), IKT zasnovano održavanje (β = 0,245) i održivo pakovanje i upravljanje materijalima (β = 0,198).

Ključne reči: Održiva logistika; Poslovne performanse; Održavanje zasnovano na IKT-u; Produktivnost; Proizvodna preduzeća.