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ICT APPLICATION FOR PREDICTIVE MAINTENANCE AND LOGISTICS EFFICIENCY IN INDUSTRIAL ENTERPRISES

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Abstract: This paper examines the use of information and communication technologies for predictive maintenance and logistics efficiency in industrial enterprises, with a focus on Serbia. The study discusses digital tools such as sensor networks, IoT systems, predictive analytics, and cloud platforms that support data-driven decision-making. A theoretical model is proposed, consisting of three main elements: ICT infrastructure for predictive maintenance, data-driven logistics systems, and organizational and implementation frameworks. Each element includes sub-elements that explain the connections between data collection, processing, workforce capacity, financial planning, and security. The analysis identifies challenges related to cost, skills, and cybersecurity, while also presenting opportunities through government support, industry collaboration, and scalable technologies. The findings suggest that a structured combination of technological solutions and organizational measures can improve maintenance reliability, logistics transparency, and operational efficiency in industrial enterprises.
Key words: predictive maintenance, logistics, industrial enterprises, ICT application

INTRODUCTION

Information and communication technologies are becoming increasingly present in the management of industrial systems. Predictive maintenance represents one of the most relevant applications, as it allows companies to monitor machinery performance and anticipate failures. Instead of relying only on scheduled inspections or reacting to breakdowns, enterprises can collect continuous streams of data from sensors and diagnostic tools. This information is processed through predictive models that compare current equipment performance with historical patterns. When deviations are detected, the system can suggest intervention before a failure occurs [1]. The same logic applies to logistics operations, where ICT provides tools for integrating multiple activities into a single coherent process. Logistics traditionally includes storage, transport, and distribution, but coordination of these functions is often complex. Digital platforms make it possible to connect suppliers, manufacturers, distributors, and customers in a transparent chain [2]. Tracking systems provide visibility of shipments and allow companies to respond to delays or disruptions with greater accuracy. Route optimization software uses traffic and weather data to recommend more efficient paths for transport vehicles. In warehouses, automated systems supported by ICT improve inventory management and reduce manual errors [3]. The outcome of such integration is a logistics process that uses time and resources more efficiently while meeting customer requirements more consistently.
The use of ICT in industrial enterprises also depends strongly on the ability to generate reliable data. Predictive maintenance cannot function effectively without large datasets describing equipment usage, operating conditions, and past incidents [4]. Similarly, logistics efficiency depends on accurate information about demand, delivery schedules, and transportation capacity. Enterprise resource planning systems combine these streams of

data into centralized platforms, allowing managers to observe key performance indicators in real time. Analytical dashboards help identify trends, forecast demand fluctuations, and make informed decisions. A data-driven approach allows enterprises to align production planning with logistics capacity, which reduces bottlenecks and idle time. In addition, companies can compare current performance with expected benchmarks and adjust operations accordingly [5]. Although the advantages of ICT application are well documented, enterprises often encounter barriers when attempting to adopt such systems. One of the most common obstacles is the high cost of implementation, especially for small and medium-sized firms that operate with limited financial resources [6]. Another challenge is the need for employees to acquire new skills. Maintenance engineers, warehouse staff, and logistics planners may require training to use predictive analytics software and cloud-based platforms. Data security also represents a growing concern, as the exchange of sensitive operational information across networks exposes enterprises to cyber threats [7].

The application of ICT to predictive maintenance and logistics efficiency is closely connected with the broader trends of industrial development. Industry 4.0 is characterized by cyber-physical systems, IoT networks, and data analytics, all of which form the basis for digital transformation in manufacturing and logistics. Enterprises that adopt predictive maintenance are better prepared to achieve continuous production without interruptions, while those that apply ICT to logistics gain more responsive supply chains [8]. These developments show that the integration of ICT into industrial enterprises is not a temporary trend but rather an evolving practice that aligns technical capacity with operational demands.

DIGITAL TOOLS FOR PREDICTIVE MAINTENANCE AND ICT IN LOGISTICS OPERATIONS

Digital tools designed for predictive maintenance are becoming increasingly relevant for industrial enterprises that depend on uninterrupted production. Traditional maintenance strategies often rely on fixed schedules or reactive approaches once failures occur. Such methods can lead to unnecessary costs, since equipment may be serviced too early or too late, and breakdowns may interrupt production. Predictive maintenance supported by ICT addresses these issues through continuous monitoring of machines and equipment. Sensors measure vibration, temperature, pressure, and other variables that indicate the condition of machinery components [9]. The data collected are processed in real time through algorithms that compare current performance with historical records. When patterns deviate from expected conditions, the system signals that maintenance will soon be required. This allows companies to intervene before a breakdown takes place, scheduling service at the most appropriate time.

Predictive maintenance also provides enterprises with more accurate information about the expected lifespan of their equipment. Instead of replacing parts based only on manufacturer guidelines, companies can rely on data that reflect actual operating conditions [10]. This reduces waste and lowers the risk of unnecessary downtime. Maintenance teams can plan their work schedules with more precision, which improves the allocation of human resources. Spare parts can also be ordered in advance, avoiding delays and excess inventory. The adoption of ICT for predictive maintenance therefore contributes to a more organized and cost-effective maintenance process. In addition, detailed historical records of equipment performance help enterprises understand long-term patterns, which informs investment decisions when older machinery needs to be replaced or upgraded.

Another dimension of predictive maintenance is the integration of machine learning models. These models can analyze large datasets from multiple machines simultaneously and detect subtle patterns that human observation would not capture. Over time, the models adapt and improve their predictions, which strengthens the reliability of the system [11]. Enterprises that combine predictive maintenance with such analytical capabilities can reduce both planned and unplanned downtime, improve machine utilization, and manage operational risks more effectively. Although the introduction of these technologies requires investment in equipment and training, the long-term savings and increased reliability of production make predictive maintenance an attractive option for a wide range of industries.

While predictive maintenance focuses on equipment, ICT also brings extensive opportunities for improving logistics operations. Logistics involves the movement of materials, products, and information across different stages of production and distribution. Inefficiencies in logistics can create delays, raise costs, and reduce customer satisfaction [12]. ICT applications provide solutions to these challenges by integrating the various elements of the logistics process into a coherent system. Transportation management systems, for example, use data about routes, fuel consumption, and delivery schedules to recommend the most efficient allocation of vehicles. Real-time tracking allows enterprises to follow shipments as they move through the supply chain, providing visibility that supports better coordination.

Warehouse operations also benefit significantly from ICT integration. Automated systems supported by barcode scanning, RFID technology, and warehouse management software reduce the possibility of human error in inventory control [13]. Data from these systems indicate which products need to be restocked and where bottlenecks in storage occur. ICT tools can also analyze order patterns and propose adjustments to warehouse layouts to improve efficiency. In combination with predictive analytics, these systems support just-in-time deliveries and help enterprises avoid both overstocking and shortages [14]. The overall effect is a logistics process that uses fewer resources to achieve more reliable outcomes.

The integration of ICT in logistics further extends to collaboration across the supply chain. Cloud-based platforms connect suppliers, manufacturers, and distributors, allowing them to share information in real time. This transparency reduces delays caused by miscommunication and supports more effective planning of production and transport activities. In addition, route optimization software uses traffic and environmental data to identify alternatives that reduce transportation costs and delivery times [15, 16]. Such applications become increasingly valuable when dealing with large and complex supply chains that operate across multiple regions.

DATA DRIVEN DECISION-KING AND CHALLENGES OF ICT IMPLEMENTATION

Innovations in gree The introduction of ICT in industrial enterprises has brought increasing attention to the use of data for decision-making. Predictive maintenance and logistics processes both rely on large volumes of structured and unstructured information that must be properly organized and analyzed [17]. Data from sensors, enterprise systems, and external sources are integrated into central platforms such as enterprise resource planning systems. These systems allow managers to observe performance indicators across maintenance, production, and logistics in one environment [18]. The integration of information reduces the likelihood of decisions based only on partial or outdated data. When predictive models process this information, the results provide indications of when interventions are needed in maintenance or when adjustments are required in logistics planning.

The importance of accurate data becomes especially clear when enterprises attempt to align production schedules with transportation capacities. If demand forecasting is inaccurate, companies may produce goods that cannot be delivered on time due to limited logistics resources. ICT applications mitigate this problem by using historical demand data, market trends, and customer orders to generate forecasts with higher precision [19]. Managers can then compare projected demand with available warehouse capacity and transportation assets. This alignment improves operational efficiency and reduces costs associated with excess inventory or underutilized resources. Dashboards and visualization tools are frequently used to present this information in a clear format, allowing decision-makers to identify problems quickly and take corrective action [20].

Another important aspect of data-driven decision-making is the potential to evaluate performance against benchmarks. Enterprises can measure indicators such as equipment uptime, maintenance costs, delivery accuracy, and warehouse efficiency. When deviations from expected benchmarks occur, managers can investigate the causes and implement targeted measures [21]. This process supports continuous improvement and creates a structured framework for evaluating the effectiveness of predictive maintenance and logistics operations. In addition, the availability of reliable data helps enterprises to comply with reporting requirements and to provide transparent information to stakeholders.

Despite the clear benefits of ICT applications, industrial enterprises encounter several challenges when adopting new technologies. One of the most frequently mentioned obstacles is the cost of investment. Predictive maintenance requires installation of sensors, data storage systems, and analytical software, while logistics efficiency depends on tracking devices, warehouse management systems, and cloud platforms. These costs can be substantial, particularly for small and medium-sized enterprises [22]. Many companies must carefully assess the expected return on investment before committing to large-scale adoption.

Another barrier is the lack of adequate skills among employees. Maintenance engineers and logistics managers who are accustomed to traditional approaches may find it difficult to adapt to data-driven methods. Training programs and professional development initiatives are required to build competence in using ICT tools effectively. In many cases, companies must rely on external consultants or technology providers to support implementation, which can increase costs and prolong the adoption process. Workforce resistance to change is also a factor, as employees may be hesitant to adopt new systems that alter established routines.

Data security and privacy concerns also present significant challenges. Industrial enterprises exchange sensitive operational information across networks, which makes them vulnerable to cyberattacks. Security breaches can disrupt operations and lead to financial losses or reputational damage [23]. Companies adopting ICT must therefore invest in cybersecurity measures, including firewalls, encryption, and monitoring systems. Regular audits and compliance with international standards are also required to reduce risks. These protective measures add to the overall cost and complexity of ICT adoption but are necessary to ensure reliable and safe operation.

Despite these challenges, opportunities for implementing ICT continue to expand. Cloud-based solutions reduce the need for significant upfront investment in infrastructure, since companies can access software and storage through subscription models. This approach allows smaller enterprises to adopt ICT at a manageable cost and scale the systems as their needs grow. Government programs and industry associations also provide incentives, funding, and technical support for digital transformation projects. Such initiatives create a more favorable environment for enterprises to experiment with predictive maintenance and logistics technologies. Based on the analyzed literature a model for improving predictive maintenance and logistics efficiency is developed. The model is presented on Figure 1.

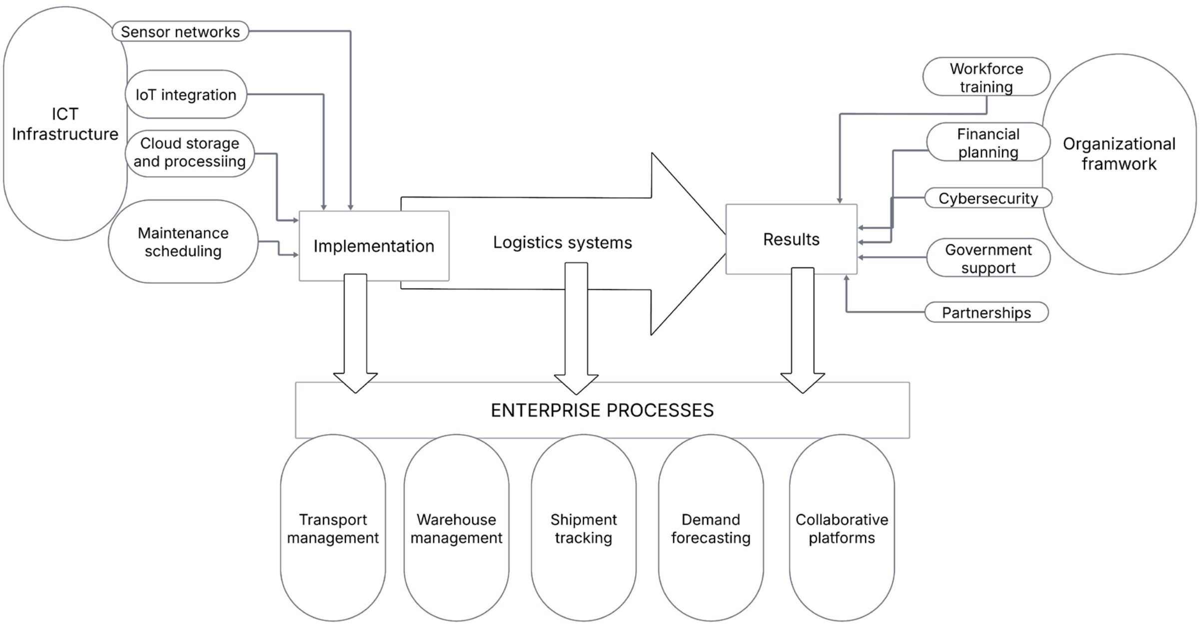

Fig. 1. *Model for improving predictive maintenance and logistics efficiency*

The model shows relations between three main elements and their sub-elements in a structured way. ICT infrastructure forms the technical base for predictive maintenance. Sensor networks provide information about equipment condition, while IoT integration connects machines so that data can be exchanged automatically. Predictive analytics processes these data and identifies patterns that may indicate future equipment problems. Cloud storage supports the management of large volumes of information and allows continuous access. Maintenance scheduling then applies the findings of analytics to plan interventions and organize resources. These sub-elements link together and direct outputs into the implementation stage where enterprise processes receive information needed for maintenance decisions.

Logistics systems are the second major component and include several connected functions. Transport management supports decisions about vehicle routes and schedules. Warehouse management improves tracking of goods and inventory flows. Shipment tracking adds visibility to the movement of goods, allowing more accurate monitoring of supply chains. Demand forecasting uses past data and current trends to adjust production and delivery plans. Collaborative platforms connect suppliers, manufacturers, and distributors to reduce delays caused by missing information. All of these sub-elements influence enterprise processes in areas such as transportation, storage, and distribution, creating more efficient flows of materials and products. The organizational framework provides conditions that support predictive maintenance and logistics systems. Workforce training ensures that employees have the skills to use digital tools for analytics, transport, and warehouse management. Financial planning allows companies to gradually introduce ICT solutions and manage costs over time. Cybersecurity protects operational information against risks linked to digital connectivity. Government support creates standards, incentives, and regulations that guide enterprises in adoption. Partnerships with universities and technology providers contribute to knowledge transfer and help enterprises adapt solutions to their specific context. These sub-elements influence the effectiveness and stability of predictive maintenance and logistics activities and help ensure that results are sustainable. The model indicates that ICT infrastructure and organizational framework direct their influence toward implementation, logistics systems, and measurable results. The outputs then connect with enterprise processes such as transport management, warehouse management, shipment tracking, demand forecasting, and collaboration across supply chains. The relations demonstrate that technological measures and organizational arrangements must work together to achieve improvements. Each sub-element contributes through data provision, structured decision support, or the creation of organizational conditions, and together they support predictive maintenance and logistics efficiency in industrial enterprises.

SUGGESTIONS AND GUIDELINES

Based on the developed model presented in Figure 1, and the reviewed literature, the following guidelines and suggestions are proposed to improve predictive maintenance and logistics efficiency in industrial enterprises in Serbia:

- Governments can introduce financial incentives such as tax reliefs or subsidies for enterprises investing in predictive maintenance and logistics ICT systems.
- National institutions can develop standardized frameworks and technical guidelines for predictive maintenance and logistics systems.
- Enterprises should prioritize the installation of sensor networks and IoT systems to collect real-time data on equipment and logistics processes. Companies can adopt cloud-based platforms that allow scalable data storage and processing for both maintenance and logistics.

- Workforce training programs should be introduced within enterprises to prepare employees for using predictive analytics, transport management software, and warehouse management systems.
- Enterprises can establish partnerships with universities and technology providers to gain access to expertise and tailored solutions.
- Governments can invest in nationwide digital infrastructure, such as broadband expansion, to support ICT adoption in all regions.
- Enterprises should gradually implement cybersecurity measures such as encryption, monitoring systems, and regular audits.
- Individuals working in industrial enterprises can engage in continuous learning through workshops, certifications, and online courses.
- Industry associations can coordinate pilot projects that demonstrate the benefits of predictive maintenance and ICT-based logistics systems.

CONCLUSION

The analysis of predictive maintenance and logistics efficiency in industrial enterprises demonstrates that ICT provides practical solutions for reducing downtime, optimizing resources, and improving decision-making processes. Predictive maintenance supported by sensor networks, IoT integration, and analytics allows equipment monitoring to move from reactive to data-driven approaches. The model developed connects ICT infrastructure, data-driven logistics, and organizational frameworks as the main elements required for improvement. Each element consists of sub-elements that build a structured pathway for enterprises to adopt modern practices. Data integration, financial planning, training, and cybersecurity represent the foundations for long-term success. When these elements are aligned, enterprises are better positioned to manage maintenance and logistics in an efficient and systematic manner.

The findings also highlight that challenges remain in terms of high initial costs, skills gaps, and data security. These barriers are particularly visible among small and medium-sized enterprises in Serbia, where resources are limited. Government support, academic partnerships, and gradual adoption strategies represent ways to address these issues. The combined efforts of institutions, enterprises, and individuals are required to build sustainable systems that rely on ICT for predictive maintenance and logistics efficiency.

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