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INTEGRIRANI SUSTAV ZA UPRAVLJANJE ODRŽAVANJEM BOLNIČKE OPREME

INTEGRATED SYSTEM FOR MANAGING THE MAINTENANCE OF HOSPITAL EQUIPMENT

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SAŽETAK

Održavanje medicinske opreme u hrvatskim bolnicama otežano je zbog slabe integracije postojećih rješenja i njihove usmjerenosti na servisere, dok je uloga bolnica uglavnom ograničena na prijavu kvarova. Sustavi poput CloudFSM, WorkTrek ili Fiix nude široke funkcionalnosti, ali nisu prilagođeni specifičnostima zdravstvenog sustava gdje je potrebna uska suradnja i transparentno praćenje procesa. U članku se predstavlja novi integrirani sustav koji povezuje bolnice i servisere unutar jedinstvene platforme. Digitalizira cijeli životni ciklus radnog naloga, počevši od kreiranja zahtjeva do izvršenja i elektronički potpisanog izvještaja, te uklanja dvostruke evidencije i smanjuje papirologiju. Sustav uključuje i analitičke prikaze koji omogućuju praćenje troškova, trajanja naloga i učestalosti kvarova. Jedan od glavnih doprinosa čini i modul strojnog učenja koji na temelju povijesnih naloga generira prijedloge preventivnih pregleda, čime se uvodi proaktivan model održavanja i povećava pouzdanost opreme.

Ključne riječi: *održavanje opreme, digitalna platforma, bolnički sustavi, suradnički model, preventivna analiza*

ABSTRACT

Maintenance of medical equipment in Croatian hospitals is hindered by poor integration of existing solutions and their focus on service providers, while hospitals are largely limited to reporting malfunctions. Systems such as CloudFSM, WorkTrek, and Fiix offer broad functionalities but are not tailored to the specific needs of the healthcare sector, where close collaboration and transparent process tracking are essential. This paper presents a new integrated system that connects hospitals and service providers on a single platform. It digitalises the entire lifecycle of a work order, from request creation to task execution and electronically signed reports, while eliminating duplicate records and reducing paperwork. The system also provides analytical dashboards that enable monitoring of costs, task duration, and failure frequency. One of the main contributions is a machine learning module that generates preventive inspection proposals based on historical orders, thus introducing a proactive maintenance model and increasing equipment reliability.

Keywords: *equipment maintenance, digital platform, hospital systems, collaborative model, preventive analytics*

1. UVOD

1. INTRODUCTION

The maintenance of medical equipment is a key factor in ensuring the continuity and quality of healthcare services [1]. The functionality and reliability of equipment directly affect patient safety and the efficiency of medical staff in their daily work [2]. However, in many healthcare institutions, maintenance is still based on outdated practices that focus on reactive repairs rather than proactive management of equipment life cycles [3]. This approach leads to prolonged device downtimes, increased costs, and hindered resource planning [1, 2].

Current trends in maintenance management rely on the digitalisation of processes, integration of various stakeholders, and the use of analytical tools and artificial intelligence for predictive maintenance [4]. Several global solutions have been developed, such as CloudFSM, WorkTrek, and Fiix, which offer a wide range of functionalities for work order management. However, these systems are not fully adapted to the specific requirements of the healthcare sector, where close cooperation between hospitals and service organisations and transparent process monitoring are essential.

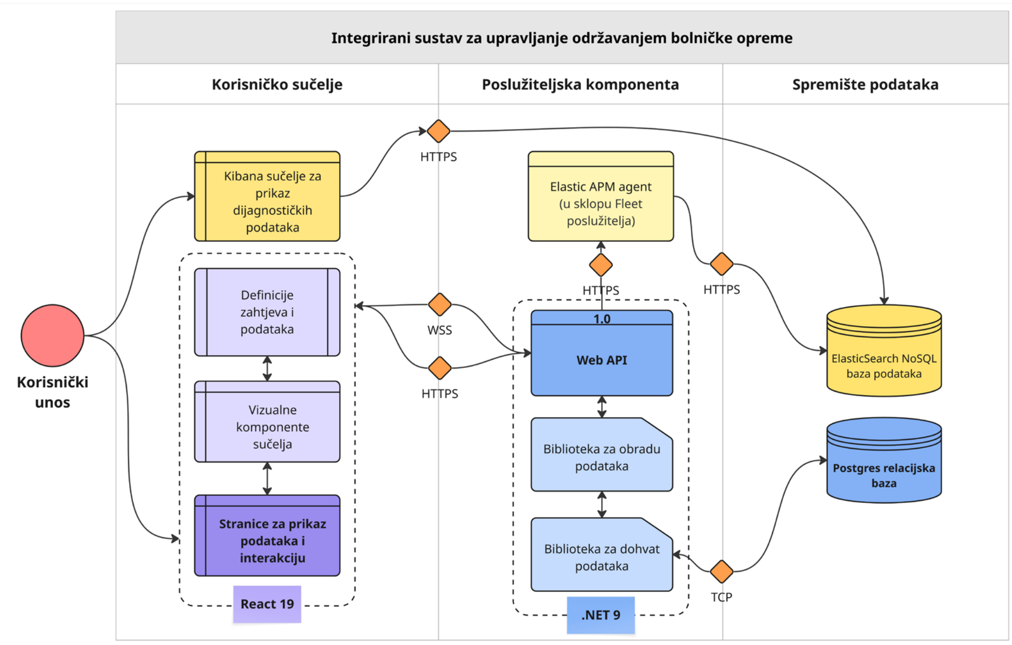
In Croatian hospitals, this issue is further exacerbated by the fragmentation of existing solutions and the fact that hospitals are often limited to reporting failures, while subsequent steps fall entirely within the domain of external service providers. The lack of integration and analytical capabilities complicates strategic decision-making and prevents long-term planning of preventive inspections and resource optimisation. In this context, there is a growing need for the development of integrated systems that cover the entire lifecycle of work orders, from registration, through execution, to evaluation and analysis.

The development of integrated systems for specific domains has been the subject of previous research by the author, such as software solutions for travel order management [5], a tourism information and process system [6], and an application for managing climbing gyms [7]. These projects highlight the importance of domain-adapted digital platforms which, although applied in different sectors, share a common goal: improving efficiency, transparency, and decision-making processes. Based on that experience, this paper presents an integrated system tailored to the requirements of hospital equipment maintenance.

The aim of this paper is to present a new integrated system for hospital equipment maintenance management that introduces digitalisation of work orders, reduces paperwork, ensures transparency, and enables predictive analytics based on machine learning [8, 9]. In this way, the transition is made from a reactive to a proactive maintenance model, thereby increasing equipment reliability and reducing overall operational costs [3].

2. ARHITEKTURA SUSTAVA
2. SYSTEM ARCHITECTURE

The solution comprises six interconnected container components that communicate via network protocols, as illustrated in Figure 1 and is intended for cloud-based use. The design was primarily influenced by the dual approach



Slika 1 *Arhitektura sustava*

Figure 1 *System architecture*

and flow control, ease of use, and the capability for extension through additional diagnostic, analytical, and integration modules essential for business operations.

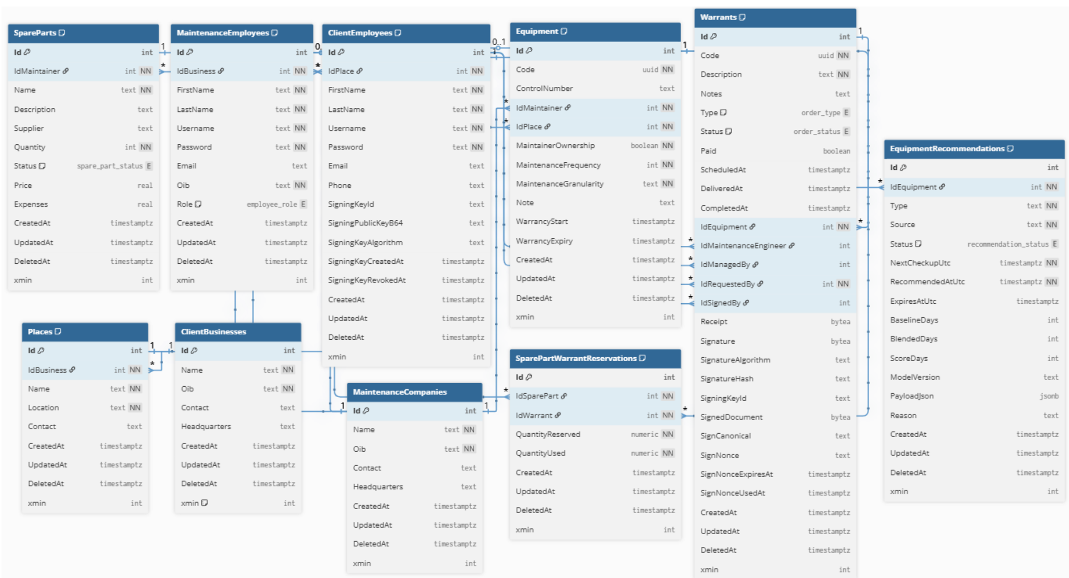
The solution relies on a multi-user relational database, the structure of which is shown in Figure 2. This model enables precise authorisation at the application level and clear tracking of the lifecycle of work orders. In addition to tables, the database includes numerous views, triggers, and enumeration fields that ensure system consistency, minimise redundancy, and improve query efficiency.

Alongside the relational database, a NoSQL database has been implemented to store server telemetry, metrics, and logs for throughput analysis and system monitoring. This implementation enables more efficient queries over large data volumes and real-time aggregations, as well as the separation of rapidly growing telemetry from operational data, thus avoiding unnecessary burdens on the relational database from diagnostic and monitoring requests.

The server layer is implemented using .NET technology and consists of a Web API project and two class libraries, which contain the business rules and repositories for database access, in line with a three-tier architecture design. Appropriate conversion and cleaning of entities are performed between layers to prevent leakage of sensitive data. Authentication and authorisation are managed via JWT tokens, with the framework verifying the attached role at access points. Within dedicated services, data isolation is enforced by ownership based on role and assignment to a specific workplace.

Communication with the database is handled via the Entity Framework Core library, where all entities are mapped to corresponding models accessible through a generic repository for DML commands or a specific repository for data retrieval. Repositories are called by services if all business rules are satisfied; otherwise, the solution throws a custom exception, which is handled in the appropriate middleware layer and returned as a suitable status and response according to RFC 9457 standards. Upon a successful response, data is mapped into a strictly defined transfer object, without exposing sensitive or supporting data. Supporting columns include primary keys, columns for digital signatures, and columns intended for auditing, optimistic locking, or soft deletion. The soft deletion column is designed to record a timestamp upon user request instead of executing a DDL command for permanent deletion, and a global filter is implemented on it to exclude such marked data from further processing and display.

The diagnostic layer of the system is designed to provide measurable, repeatable, and correlated insight into the application's behaviour in real time; therefore, logs are enriched with data on execution traces, events, and metrics that allow



Slika 2 Relacije među entitetima

Figure 2 Relationships between entities for analysis of performance degradation causes and anomaly detection. Application traces are generated in the .NET Web API component via the Elastic APM agent, which forwards them to the Fleet Server for processing prior to permanent storage in the ElasticSearch database. Kibana is used exclusively for visualisation and management, where all control panels, the APM interface, and log and metric searches read data directly from the database.

The user interface component is a single-page web application designed to provide a consistent, domain-adapted interface for three user types: client, manager, and engineer. Pages are built from custom visual components, with content populated according to the logged-in user. More complex workflows, such as the lifecycle of a work order, are modelled as multi-step forms with clear states and safeguards against inconsistent transitions. While most communication between the user interface and the server occurs via RESTful endpoints, the server uses SignalR bidirectional communication to notify all users involved in the process of status changes.

3. ISTAKNUTE FUNKCIONALNOSTI NOVOG SUSTAVA

3. SELECTED FUNCTIONALITIES OF THE NEW SYSTEM

The primary task of the presented collaborative system is the complete digitalisation of the service work order lifecycle, in which the client and service organisation jointly participate in monitoring and maintenance planning—a common scenario in healthcare institutions, where the workflow and obligations of the parties are clearly defined by contracts. The collaborative model ensures that both parties have access to a shared digital record, exchange data in real time, and coordinate activities through the same information system.

The process begins with the creation of an order by the client (clinic or hospital department), continues with processing and execution by the maintenance company, and concludes with the client's final confirmation that the task has been successfully completed. This procedure is fully implemented, and upon completion, both parties gain access to an electronically approved PDF report containing key information suitable for audit and forensics, while reducing paperwork and duplicate data entry. At the end of the process, the order is signed in accordance with the Ed25519 variant of the digital signature, enabling subsequent verification of signature authenticity.

Order data are linked to related entities such as the equipment being maintained, required spare parts, and associated costs, enabling historical data analysis that supports decision-making to improve business processes, especially during equipment and spare parts procurement. For this purpose, an analytical module has been implemented, based on views formed over data on work orders, equipment, and spare parts. The views within the database serve as an aggregation layer that extracts key metrics from operational tables and groups them by various dimensions, most often temporal, allowing managers to monitor business indicators and, based on this information, more efficiently organise field visits, equipment assignments, and the responsible workers for each order.

The ratio of reserved to used parts is determined by comparing data from the reservation junction table and the reserved parts table, where for each work order the difference between planned and actual costs is recorded. The average number of hours per work order is calculated using timestamps for order opening and closing, and grouped by order type, while the distribution by days and hours is obtained from the creation date and time fields.

The most common types of failures are tracked through the order type, indicated by an enumeration field and counted by frequency, while costs by equipment type are calculated based on the sum of labour hours and parts prices. Deadline tracking relies on the difference between order opening and completion dates, with the area and shape of a line chart indicating possible delays and discrepancies in the ratio of open to closed orders on a weekly basis.

In addition to operational functionalities, the system includes a predictive analysis module that uses historical data on failures, services, and parts consumption to forecast maintenance needs and enable earlier identification of potential equipment problems. The implementation is based on machine learning aiming to predict upcoming regular inspections for each item of equipment owned by the clinic or hospital. Models are trained on historical data generated from previously executed work orders, where each order's basic attributes – such as equipment type, device age, order type, reserved and used parts, and actual intervention duration – are stored. By combining this information, datasets are created to serve as input for training. The ML.NET framework was used, with the FastTree algorithm were selected. After training, the model runs once weekly via a background process, generating for each piece of equipment a proposal for the next regular inspection date, which the client can either accept, automatically creating a new work order, or reject, marking the proposal as discarded. Figure 3 displays the proposed upcoming dates produced by the current version of the model.

Since the model is trained on historical data from the database, a materialised view has been created for repeated training. This view can be supplemented with new data, and after training, the new model replaces the existing one. Each proposal also includes information about the model version that generated it, enabling future model evaluation.

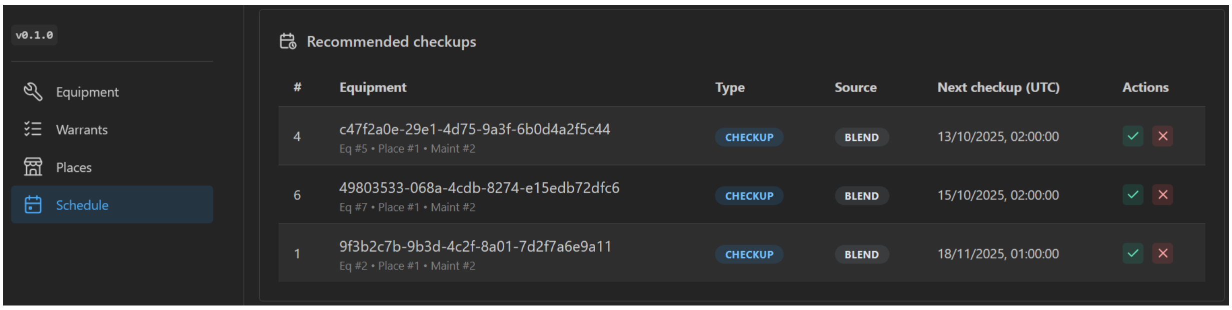
4. REZULTATI
4. RESULTS

Testing the system in practice produced results that demonstrate clear added value in digitalising the medical equipment maintenance process. The basic functionality of work order recording and management was enhanced by an analytical module that transforms operational data into visual insights for maintenance department managers. The views are designed to address questions that most frequently arise in the daily work of service companies and provide a clear basis for decision-making aimed at optimising business processes. Such optimisation results in faster closure of work orders, more efficient scheduling of service technicians, and timely ordering of spare parts, thereby reducing downtime during inspections and repairs and improving the throughput of the operational cycle.

One of the key views presents a comparison between reserved and used spare parts. Comparing planned and actually consumed quantities reveals discrepancies that indicate incorrect estimates, lack of experience, or systemic problems with a particular equipment type. Results show that such insight reduces storage costs and prevents the accumulation of surpluses while simultaneously increasing the availability of parts most commonly used in practice.

The analysis of the average number of hours per work order proved extremely useful for understanding the complexity of individual interventions. Tracking the time from order opening to closing, that is, technician working hours, enabled a more precise assessment of the demands of certain types of orders. The observed differences between routine inspections and complex failures lead to better resource planning, timely engagement of larger teams, and targeted employee training in areas where interventions regularly take longer.

The distribution of work by days and hours revealed clear patterns in task execution demand, allowing for adjustments to on-call scheduling



Slika 3 *Prijedlozi preventivnih pregleda nad opremom*

Figure 3 *Preventive maintenance recommendations for equipment* and preventive inspections. This results in better technician availability during peak demand periods and reduces the time from order reporting to resolution.

A simple yet informative view is grouping orders by type, which provides an overview of the main sources of maintenance difficulty, such as failures, complaints, or periodic inspections. In cases with a notably high number of complaints, managers receive a clear signal to reconsider procurement quality or maintenance procedures.

Finally, monitoring order completion trends and their compliance with expected throughput thresholds has proved key in assessing the operational stability of the service company. A continuous rhythm of order closures indicates even workload distribution and sufficient capacity, while deviations from expected thresholds signal operational difficulties or process delays. Such insight is especially valuable when there are many open orders requiring prioritisation and estimation of start and finish dates. By comparing execution times with defined deadlines, areas where delays occur have been identified, but consistency in fulfilling client obligations has also been confirmed, while he introduction of a self-monitoring mechanism contributes to raising service quality.

The results show that the system is no longer just a tool for recording and tracking work orders but has become a strategic means of managing maintenance processes. The analytical modules, a sample of which is shown in Figure 4, have enabled the transformation of historical and operational data into concrete insights that lead to cost reduction, optimisation of human and material resources, and faster service for end users. At the same time, predictive analytics based on machine learning facilitates the assessment of failure probabilities and recommends preventive equipment inspections. Thus, the system has achieved its goal: to digitalise not only the workflow of work orders but also to provide added value through business intelligence and decision support.

5. ZAKLJUČAK
5. CONCLUSION

Unlike existing solutions that primarily track the needs of executors, the proposed model enables equal collaboration between clients and service companies through a unified platform. Integration of business processes, automated report generation, and the incorporation of analytical and predictive functionalities provide transparent and accurate tracking of work orders while reducing paperwork and duplicate records.

The results confirm that the system delivers clear benefits: it shortens the time required to resolve failures, optimises the use of human and material resources, and increases the quality of service provided. More precise planning of maintenance activities and reduction of unnecessary field visits allow for rationalisation of logistic costs and a

***Slika 4** Isječak analitičkih prikaza*

***Figure 4** Sample analytical dashboards* shorter overall service process. The introduction of a machine learning module further enhances preventive maintenance and enables hospitals to plan interventions more effectively. Thus, the system positions itself not only as a technical solution but also as a strategic tool for managing maintenance processes in healthcare.

Future development may include expanding integration capabilities with the national healthcare system and adapting the model for other sectors where maintenance of critical equipment is essential to business operations.

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6. REFERENCES

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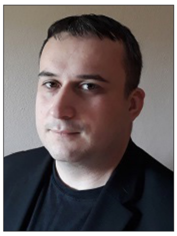

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