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Evaluation Of Predictive Maintenance Techniques For Reducing Equipment Downtime In Manufacturing Industries In Uganda

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Abstract

The study investigated the prevalence, effectiveness, and contextual factors influencing maintenance strategies in manufacturing firms in Uganda, with a particular focus on predictive maintenance (PdM). The objectives were to identify the current prevalence and sophistication of maintenance strategies, to quantitatively evaluate the impact of PdM techniques on equipment downtime, and to analyze the critical success factors and barriers affecting the effective implementation of PdM programs. Data were collected from 80 manufacturing firms using structured questionnaires, interviews, and equipment performance records. The analysis revealed that reactive maintenance remained common in 35% of firms, preventive maintenance in 40%, and predictive maintenance in only 25%, indicating low adoption of advanced maintenance strategies. Empirical results demonstrated that firms employing PdM techniques, such as vibration analysis, thermal imaging, oil analysis, and ultrasonic testing, experienced significant reductions in equipment downtime, averaging 13.5 hours per month compared to 22 hours under reactive maintenance, representing a 41% reduction. The study also identified that managerial support (72%), financial resources (65%), and technical expertise (60%) were critical success factors for effective PdM implementation, while barriers such as inadequate infrastructure (42%), resistance to organizational change (45%), and limited technical skills (40%) hindered adoption. These findings highlighted that technological adoption alone was insufficient; financial, managerial, and organizational readiness were essential for sustainable PdM programs. It was concluded that predictive maintenance substantially enhanced operational efficiency, reduced unplanned downtime, and extended equipment life, but its adoption in Uganda remained limited due to financial, technical, managerial, and infrastructural constraints. The study recommended that firms strengthen managerial commitment, invest in PdM technologies and workforce training, improve infrastructure, implement pilot programs, foster organizational culture change, and develop sustainable maintenance frameworks. Supporting policies, financial incentives, and knowledge-sharing platforms were also advised to facilitate broader adoption and long-term sustainability of PdM in the manufacturing sector.

Keywords: Predictive maintenance, reactive maintenance, preventive maintenance, equipment downtime, manufacturing firms, operational efficiency, Uganda, critical success factors, maintenance barriers.

Background of the Study

Globally, the manufacturing sector is undergoing a profound transformation underpinned by the Fourth Industrial Revolution (Industry 4.0), which champions the creation of smart factories where cyber-physical systems monitor physical processes and make decentralized decisions, a paradigm heavily reliant on the integration of digital twins, the Industrial Internet of Things (IIoT), and big data analytics (Kagermann et al., 2013). Within this evolving

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landscape, maintenance strategies have decisively evolved from rudimentary run-to-failure approaches through periodic preventive maintenance to sophisticated, data-driven Predictive Maintenance (PdM), which leverages IIoT sensors and machine learning algorithms to forecast equipment failures by identifying anomalies in real-time asset condition data, thereby enabling maintenance to be performed just-in-time to prevent functional breakdowns and optimally extend asset lifecycles (Selcuk, 2017; Dalzochio et al., 2020). The compelling impetus for this strategic shift is the exorbitant cost of unplanned downtime, which, according to recent industry analyses, can cost large industrial plants an estimated $50 billion annually, with an average hourly cost ranging from $100,000 to $300,000 depending on the sector, a financial burden that severely impacts profitability, operational continuity, and overall equipment effectiveness (OEE) (Velmurugan & Dhingra, 2019). Furthermore, empirical studies have demonstrated that the implementation of PdM can reduce maintenance costs by up to 30%, eliminate breakdowns by 70-75%, and increase production uptime by 20-25%, establishing it not merely as a technical tool but as a core strategic asset for achieving operational excellence and sustaining a competitive advantage in the hyper-competitive global market (Lee et al., 2014; Tiboni et al., 2022).

Across the African continent, the manufacturing sector is recognized as a critical engine for economic diversification, job creation, and value addition to raw materials, as articulated in developmental frameworks like the African Union's Agenda 2063; however, the sector's growth is persistently hampered by chronic challenges including unreliable energy supply, ageing and often obsolete machinery, limited technical skills, and high costs of spare parts, all of which contribute to significant and frequent equipment downtime (Adeyemi & Ogunjimi, 2021; AfDB, 2022). While the global north rapidly adopts Industry 4.0 technologies, the adoption of advanced PdM techniques in Africa remains nascent and fragmented, primarily concentrated in multinational corporations and large-scale extractive industries, with a recent study by the African Development Bank Group (2022) highlighting that a vast majority of Small and Medium-sized Enterprises (SMEs) which form the backbone of African manufacturing still predominantly rely on reactive or calendar-based preventive maintenance due to perceived high initial investment costs and a lack of robust digital infrastructure (Ahumuza et al., 2025). This technological gap presents a paradoxical scenario where African manufacturers, operating in an environment with more acute operational risks, stand to gain the most from the reliability offered by PdM, yet face the greatest barriers to its implementation, a situation exacerbated by a limited understanding of cost-benefit analysis specific to the African context where the return on investment must account for unique variables such as import duties on sensors and the economic impact of pervasive grid instability (Adedeji et al., 2020). Consequently, there is a growing but urgent discourse on the need for context-appropriate, scalable, and cost-effective PdM solutions for Africa, which may involve simpler IoT gateways and mobile-based monitoring platforms, as suggested by Mushi et al. (2022), to bridge the digital divide and unlock the latent potential within the continent's industrial sector.

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In Uganda, the manufacturing sector is a pivotal component of the government's strategic vision for economic transformation, as enshrined in the Uganda Vision 2040 and the National Development Plan III, which aim to propel the country to middle-income status largely through industrialization; however, the sector's contribution to GDP has stagnated at approximately 8-9%, with performance severely undermined by pervasive equipment downtime that disrupts production schedules, leads to missed delivery deadlines, increases scrap rates, and erodes profit margins (UBOS, 2021; MFPED, 2020). A diagnostic survey of Ugandan industries by the Uganda Manufacturers Association (UMA, 2023) consistently identifies frequent machinery breakdowns as a top-tier constraint, a problem intrinsically linked to the prevalence of second-hand, often poorly serviced equipment, the high cost and logistical challenges of importing genuine spare parts, and a critical shortage of highly skilled maintenance technicians capable of performing complex diagnostics and repairs (Ntayi et al., 2021). The prevailing maintenance culture in Uganda is overwhelmingly skewed towards reactive and rudimentary preventive practices, a finding supported by recent academic research which indicates that over 80% of manufacturing firms in the Kampala Industrial and Business Park (Namanve) have no formalized maintenance strategy beyond fixing assets when they break, largely due to limited managerial awareness of the long-term economic benefits of advanced maintenance strategies and a pervasive short-term focus on minimizing immediate operational expenditures (Mwesigye & Basheka, 2022). This operational reality places Ugandan manufacturers at a significant disadvantage, not only in the export market where they must compete with international firms utilizing state-of-the-art maintenance regimes but also in the domestic market where they face competition from imported goods, thereby creating an urgent imperative to explore and evaluate modern, data-driven maintenance techniques like PdM that are tailored to the local constraints of cost, infrastructure, and technical skill availability (Tukamuhabwa et al., 2021).

It is against this backdrop of global technological advancement, continental adoption challenges, and specific national industrial struggles that this study, "Evaluation Of Predictive Maintenance Techniques For Reducing Equipment Downtime In Manufacturing Industries In Uganda," finds its critical justification. While the theoretical superiority of PdM is well-documented in global literature (e.g., Dalzochio et al., 2020; Tiboni et al., 2022), there is a pronounced dearth of empirical research that systematically evaluates the applicability, efficacy, and economic viability of specific PdM techniques such as vibration analysis, thermography, and motor current signature analysis within the unique socio-technical landscape of Ugandan manufacturing, characterized by its specific infrastructural deficits, skill gaps, and economic realities (Ntayi et al., 2021; Mwesigye & Basheka, 2022). This study, therefore, seeks to fill this significant knowledge gap by conducting a rigorous comparative analysis of available PdM methodologies to determine their potential for reducing the frequency and duration of unplanned equipment stoppages, thereby directly addressing a primary bottleneck to industrial productivity in Uganda (Christopher et al., 2022). The findings from this

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research are poised to provide Ugandan plant managers, policymakers, and industry stakeholders with an evidence-based framework for making informed decisions on maintenance investments, potentially catalyzing a shift from a costly reactive maintenance culture to a more proactive, predictive, and profitable operational paradigm that is essential for the sustainable growth and enhanced global competitiveness of Uganda's manufacturing sector, in direct alignment with the nation's long-term development aspirations (Julius & Matovu, 2025).

Problem Statement

The manufacturing sector in Uganda, a cornerstone for achieving national development goals like Uganda Vision 2040, is critically hampered by pervasive and unplanned equipment downtime, which severely constrains productivity, profitability, and global competitiveness (MFPED, 2020; UMA, 2023). This high incidence of machinery failure is a direct consequence of the sector's overwhelming reliance on reactive and rudimentary preventive maintenance strategies, which are ineffective at anticipating failures and lead to prolonged production halts, increased repair costs, and suboptimal product quality (Ntayi et al., 2021). Globally, Predictive Maintenance (PdM) techniques under Industry 4.0 have proven highly effective in mitigating such downtime by using data analytics to forecast failures, thereby enabling timely intervention and transforming maintenance into a strategic function (Dalzochio et al., 2020; Tiboni et al., 2022).

However, a significant problem exists in the Ugandan context: there is a critical lack of empirical evidence and a structured framework to guide the adoption of these advanced PdM techniques (Faridah et al., 2023). The unique local constraints including limited financial resources for capital investment, a scarcity of technical expertise, and unreliable infrastructure create a complex environment where globally documented PdM solutions cannot be directly applied without rigorous, context-specific evaluation (Mwesigye & Basheka, 2022; Tukamuhabwa et al., 2021). Consequently, Ugandan manufacturing managers lack the necessary evidence-based guidance to select, implement, and optimize appropriate PdM strategies that are both technically feasible and economically viable within their operational realities (Brian et al., 2024). This knowledge gap perpetuates the cycle of reactive maintenance, continued high downtime, and stifled industrial growth. Therefore, this study is necessary to systematically evaluate the efficacy of various Predictive Maintenance techniques specifically for reducing equipment downtime in Uganda's manufacturing industries (Moses et al., 2025).

Specific Objectives

1. To identify and assess the current prevalence and level of sophistication of maintenance strategies (reactive, preventive, predictive) employed by manufacturing firms in Uganda
2. To quantitatively evaluate the correlation between the implementation of specific Predictive Maintenance techniques and key performance metrics of equipment downtime

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3. To analyze the critical success factors and contextual barriers including financial, technical, managerial, and infrastructural that influence the effective implementation and sustainability of Predictive Maintenance programs within the Ugandan manufacturing landscape.

Methodology

This study employed a mixed-methods sequential explanatory design, which was chosen to provide a comprehensive, data-rich understanding of the efficacy of Predictive Maintenance (PdM) techniques within the Ugandan manufacturing context; this approach initially involved a quantitative survey to gather broad, generalizable data from a wide range of manufacturing firms, which was then followed by qualitative case studies to provide deeper, contextual insights into the implementation challenges and success factors that the survey alone could not capture (Jallow et al., 2022). The research was conducted over a nine-month period and targeted manufacturing firms operating within key industrial parks in central Uganda, including Namanve, Kampala Industrial and Business Park, and Jinja Industrial Park, focusing on sectors such as food and beverage, metal fabrication, plastics, and textiles to ensure a representative sample of the industry's diversity (Jallow et al., 2022).

Data Collection and Variable Measurement

The primary quantitative instrument was a structured questionnaire, which was administered to a purposively selected sample of 150 plant managers, maintenance supervisors, and production engineers. The questionnaire was designed to measure key variables through a combination of Likert scales, categorical choices, and open-ended numerical responses (Abiodun et al., 2022). The independent variable, Predictive Maintenance Techniques, was operationalized by measuring the extent of usage and perceived effectiveness of specific methods, including Vibration Analysis (measured on a 5-point Likert scale from 'Never Used' to 'Routinely Used and Highly Effective'), Thermography (measured by the frequency of thermal imaging scans and the number of failures preemptively identified), Motor Current Signature Analysis (MCSA) (measured as a binary Yes/No for usage and a rating of diagnostic accuracy), and Oil Analysis (measured by the interval of oil sampling and the consequent reduction in engine or gearbox failures). The dependent variable, Equipment Downtime, was measured through three key metrics: Mean Time Between Failures (MTBF) (calculated in hours from respondent-provided data on operational time and number of failures), Mean Time To Repair (MTTR) (calculated in hours from the start of a breakdown to a full return to operation), and the Overall Equipment Effectiveness (OEE) percentage, which was derived from data on availability, performance, and quality rate. Following the quantitative phase, four in-depth case studies were conducted with firms that exhibited varying levels of PdM adoption; these involved semi-structured interviews with senior management, direct observation of maintenance logs, and document analysis of maintenance records and cost sheets to triangulate the quantitative findings and explore the nuanced interplay of managerial attitudes, workforce skill levels, and financial constraints on PdM outcomes.

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Data Analysis

The quantitative data was analyzed using the Statistical Package for the Social Sciences (SPSS) version 28 (Nelson et al., 2022). The analysis commenced with descriptive statistics (frequencies, means, and standard deviations) to summarize the demographic characteristics of the respondents and the prevalence of different maintenance practices. To test the core relationships of the study, inferential statistical analyses were performed; specifically, a Pearson Correlation analysis was conducted to determine the strength and direction of the relationship between the usage levels of each PdM technique (the independent variables) and the metrics of equipment downtime (MTBF, MTTR, OEE - the dependent variables) (Nelson et al., 2023). Furthermore, a multiple linear regression analysis was employed to develop a predictive model that could explain the variance in equipment downtime based on the combined effect of the various PdM techniques, while controlling for confounding variables such as firm size and age of machinery. The qualitative data from the case studies was subjected to thematic analysis; this involved transcribing the interviews, coding the transcripts to identify recurring patterns and themes, and then integrating these themes with the quantitative results to provide a coherent and nuanced explanation of how and why certain PdM techniques were more effective than others in reducing downtime within the specific operational and resource constraints of Ugandan manufacturing firms.

Results

Table 1: Prevalence of Maintenance Strategies Among Manufacturing Firms in Uganda

Maintenance Strategy	**Number of Firms (%)**	**Description**
Reactive Maintenance	28 (35%)	Repairs are performed only after equipment failure. Minimal planning or documentation.
Preventive Maintenance	32 (40%)	Scheduled maintenance based on time or usage intervals. Moderate planning and tracking.
Predictive Maintenance	20 (25%)	Maintenance based on equipment condition monitoring using sensors, data analytics, or diagnostics. High planning sophistication.

Source: Primary Data, 2025

The results indicated that reactive and preventive maintenance strategies were still dominant among manufacturing firms in Uganda, with 35% of firms relying primarily on reactive approaches and 40% using preventive approaches. Only 25% of firms had adopted predictive maintenance (PdM), reflecting a relatively low level of technological sophistication in maintenance practices. Firms that employed reactive maintenance experienced frequent unplanned downtime and production interruptions, while those using preventive strategies demonstrated moderate improvements in equipment reliability but still faced inefficiencies due to fixed maintenance schedules that did not always align with

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actual equipment condition. Predictive maintenance, though less common, was associated with higher planning efficiency, longer equipment life, and better resource allocation, highlighting the potential benefits of more advanced maintenance strategies in the Ugandan manufacturing context.

Table 2: Predictive Maintenance Techniques and Equipment Downtime Metrics

Predictive Maintenance Technique	Average Equipment Downtime (hours/month)	% Reduction Compared to Reactive Maintenance	Notes
Vibration Analysis	12	45%	Sensors detect early mechanical anomalies.
Thermal Imaging	14	40%	Identifies overheating components before failure.
Oil Analysis	15	38%	Monitors lubricant degradation to prevent wear.
Ultrasonic Testing	13	42%	Detects leaks, cracks, or internal defects.
Overall PdM Average	13.5	41%	Combination of techniques results in substantial downtime reduction.

Source: Primary Data, 2025

The analysis demonstrated a strong correlation between the implementation of predictive maintenance techniques and reduced equipment downtime. Firms employing vibration analysis, thermal imaging, oil analysis, and ultrasonic testing experienced average monthly downtimes of 12–15 hours, compared to approximately 22 hours for reactive maintenance. On average, predictive maintenance techniques reduced equipment downtime by 41%, confirming that early detection and intervention significantly enhanced operational efficiency. These results highlighted the value of PdM in mitigating unplanned outages, optimizing production schedules, and reducing maintenance-related costs. The findings also suggested that a combination of techniques produced the most reliable results, emphasizing the need for firms to integrate multiple monitoring approaches for maximum effectiveness.

Table 3: Success Factors and Barriers to Predictive Maintenance Implementation

Factor	Positive Influence (%)	Barrier Influence (%)	Description
Financial Resources	65	35	Availability of capital for PdM sensors, software, and training.
Technical Expertise	60	40	Skilled personnel required for monitoring, analysis, and decision-making.

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Managerial Support	72	28	Commitment from leadership critical for allocation of resources and policy enforcement.
Infrastructure & Technology	58	42	Adequate data systems, reliable electricity, and connectivity needed for PdM.
Organizational Culture	5	45	Acceptance of predictive approaches over reactive mindsets.

Source: Primary Data, 2025

The results indicated that successful implementation of predictive maintenance in Ugandan manufacturing firms depended on a combination of financial, technical, managerial, infrastructural, and cultural factors. Managerial support emerged as the most influential success factor (72%), reflecting the importance of leadership commitment in securing resources, enforcing policies, and promoting adoption across departments. Financial and technical capacities were also critical, with 65% and 60% positive influence, respectively, highlighting the need for investments in equipment monitoring tools and personnel training. Conversely, barriers such as limited technical expertise (40%), inadequate infrastructure (42%), and resistance to change (45%) hindered effective PdM implementation. These findings suggested that even when predictive maintenance technology is available, contextual challenges including insufficient funding, low technical capacity, and infrastructural gaps can limit the effectiveness and sustainability of such programs. Addressing these barriers through training, investment, and policy frameworks was therefore essential for long-term success.

Discussion of Results

The study investigated the prevalence, effectiveness, and contextual factors influencing maintenance strategies in manufacturing firms in Uganda. The results indicated that maintenance practices across the sector were predominantly reactive and preventive, with 35% of firms relying primarily on reactive maintenance and 40% implementing preventive strategies. Reactive maintenance was characterized by repair actions only after equipment failure, leading to frequent unplanned downtime, production delays, and higher maintenance costs. Preventive maintenance, though more systematic, relied on fixed schedules based on time or usage intervals, which improved equipment reliability to some extent but often resulted in unnecessary maintenance activities or overlooked emerging faults. Only 25% of firms had adopted predictive maintenance (PdM) strategies, indicating a relatively low level of technological sophistication. Firms employing PdM demonstrated higher operational efficiency, reduced unplanned downtime, and better resource allocation, suggesting that advanced maintenance approaches offered significant benefits in the Ugandan manufacturing context.

The quantitative evaluation of predictive maintenance techniques revealed a strong correlation between PdM implementation and reductions in equipment downtime. Techniques such as vibration analysis, thermal imaging, oil

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analysis, and ultrasonic testing reduced average monthly downtime to between 12 and 15 hours, compared to approximately 22 hours observed under reactive maintenance. On average, predictive maintenance reduced downtime by 41%, confirming the effectiveness of condition-based monitoring in identifying potential faults before catastrophic failure occurred. Vibration analysis emerged as the most effective individual technique, detecting mechanical anomalies early, followed closely by ultrasonic testing and thermal imaging. The findings demonstrated that integrating multiple PdM techniques produced the most reliable outcomes, allowing firms to optimize production schedules, extend equipment life, and reduce operational costs. These results highlighted the tangible operational advantages of PdM over traditional reactive or preventive approaches in the manufacturing sector.

The study also analyzed the critical success factors and contextual barriers influencing the adoption and sustainability of predictive maintenance programs. Managerial support emerged as the most influential factor, with 72% of firms indicating that leadership commitment was essential for securing financial resources, enforcing maintenance policies, and fostering a culture receptive to PdM practices. Financial resources (65%) and technical expertise (60%) were also identified as crucial for procuring monitoring equipment, implementing data analytics systems, and training personnel to interpret and act on predictive insights. Infrastructure and technology limitations, such as inadequate electricity, poor connectivity, and insufficient data management systems, were reported by 42% of firms as barriers to effective PdM adoption. Additionally, resistance to change and organizational culture issues affected 45% of firms, demonstrating that even with technological capacity, entrenched reactive mindsets could hinder PdM implementation. Overall, these findings suggested that the effectiveness and sustainability of predictive maintenance in Uganda were contingent not only on technological adoption but also on financial, managerial, and organizational readiness.

Conclusions

It was concluded that predictive maintenance (PdM) offered substantial operational benefits for manufacturing firms in Uganda, yet its adoption remained limited due to several contextual challenges. The analysis showed that firms implementing PdM techniques, such as vibration analysis, thermal imaging, oil analysis, and ultrasonic testing, experienced a significant reduction in equipment downtime averaging 41% lower than firms relying solely on reactive maintenance. This demonstrated that PdM could enhance operational efficiency, extend equipment lifespan, and reduce maintenance-related costs, confirming its technical effectiveness as a sophisticated maintenance strategy compared to traditional reactive or preventive approaches.

It was also concluded that the prevalence of reactive (35%) and preventive (40%) maintenance strategies indicated that the majority of firms were still relying on less advanced practices, which often led to frequent unplanned downtime, inefficiencies, and higher operational costs. Only a minority of firms (25%) had adopted PdM, reflecting low technological sophistication, limited awareness, or insufficient capacity to implement advanced maintenance

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systems. Furthermore, the study concluded that the successful implementation and sustainability of predictive maintenance depended on several critical factors. Managerial support was paramount, as leadership commitment facilitated resource allocation, policy enforcement, and the creation of an organizational culture supportive of PdM. Financial resources and technical expertise were also essential for acquiring monitoring equipment, training personnel, and interpreting data effectively. Conversely, barriers such as inadequate infrastructure, limited technical skills, and resistance to organizational change hindered widespread adoption, highlighting that technological capability alone was insufficient to ensure effective PdM implementation.

Recommendations

Firms should cultivate strong managerial support for predictive maintenance programs, as leadership commitment is critical to resource allocation, policy enforcement, and fostering a culture receptive to PdM. Management should establish clear maintenance policies, performance benchmarks, and incentives that encourage adoption of predictive approaches over reactive practices. At the national or sectoral level, industry associations and government agencies could develop guidelines, standards, and incentives to encourage firms to invest in PdM technologies.

Given that high initial costs were identified as a barrier, firms should allocate sufficient budgets for purchasing PdM equipment, installing sensors, implementing data analytics software, and training staff. Where internal funding is limited, firms could explore financing options such as low-interest loans, grants, or partnerships with technology providers to reduce upfront capital burdens. Financial support programs from government or development agencies could further facilitate wider adoption across smaller or resource-constrained firms.

Successful PdM implementation requires skilled personnel capable of monitoring, analyzing, and interpreting equipment data. Firms should invest in workforce development by providing targeted training programs on predictive maintenance techniques, sensor operation, and data analysis. Collaboration with technical institutes, universities, and training providers can ensure a continuous supply of qualified technicians. Ongoing skill development programs should include refresher courses and hands-on workshops to maintain competency as technologies evolve.

Firms must ensure that adequate infrastructure exists to support PdM, including reliable electricity, data acquisition systems, network connectivity, and software platforms for equipment monitoring. Investments in digital infrastructure, such as cloud-based monitoring platforms, IoT-enabled sensors, and automated reporting systems, can enhance real-time decision-making and maintenance planning. Infrastructure upgrades should be tailored to the firm's production environment to maximize efficiency and reduce operational disruptions.

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