ENGINEER

international scientific journal

ISSUE 1, 2026 Vol. 4

E-ISSN 3030-3893

ISSN 3060-5172

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A bridge between science and innovation

TOSHKENT DAVLAT TRANSPORT UNIVERSITETI
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ENGINEER

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E-ISSN: 3030-3893

ISSN: 3060-5172

VOLUME 4, ISSUE 1

MARCH, 2026

engineer.tstu.uz

TASHKENT STATE TRANSPORT UNIVERSITY

ENGINEER

INTERNATIONAL SCIENTIFIC JOURNAL
VOLUME 4, ISSUE 1 MARCH, 2026

Founder of the international scientific journal “Engineer” – Tashkent State Transport University, 100167, Republic of Uzbekistan, Tashkent, Temiryo‘lchilar str., 1, office: 465, e-mail: publication@tstu.uz.

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Tashkent State Transport University had the opportunity to publish the international scientific journal “Engineer” based on the **Certificate No. 1183** of the Information and Mass Communications Agency under the Administration of the President of the Republic of Uzbekistan. **E-ISSN: 3030-3893, ISSN: 3060-5172.** Articles in the journal are published in English language.

Smart maintenance scheduling via predictive logistics for post-flight engine maintenance in Central Asia

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Abstract: This paper presents a data-driven approach to post-flight aircraft engine maintenance based on Smart Maintenance Scheduling via Predictive Logistics (SMS-PL). Unlike conventional time- or cycle-based programs, SMS-PL integrates environmental exposure, operational stress indicators, and digital logistics planning to dynamically prioritize inspections and material preparation. The study focuses on Central Asian operations characterized by large temperature excursions, frequent dust exposure, and dispersed maintenance infrastructure. The proposed framework combines environmental monitoring, flight-path analytics, and maintenance history to form a per-flight Maintenance Severity Index (MSI) that supports proactive decisions. Conceptual analysis indicates that predictive logistics can reduce turnaround delays, improve spare-part positioning, and raise effective fleet readiness under regional constraints. The approach aligns maintenance activity with measured operating context, supporting reliability, efficiency, and sustainability goals in arid environments.

Keywords: predictive maintenance, logistics scheduling, Central Asia, post-flight maintenance, aircraft engine, maintenance severity index, environmental impact, data-driven maintenance

1. Introduction

Post-flight maintenance is central to flight safety and operational economics. In Central Asia, aircraft frequently operate in conditions that differ materially from temperate regions: high summer ground temperatures (often +40 to +45 °C), seasonal dust and sand exposure originating from Kyzylkum and Karakum deserts, low ambient humidity, and a geographically dispersed network of airports with uneven maintenance capacity. Conventional schedules based on elapsed time or accumulated cycles ensure regulatory compliance, yet they are not designed to reflect route-specific thermal and particulate loading, altitude effects, or repeated operations from hot and high airfields.

A systems-engineering view suggests complementing fixed intervals with adaptive planning informed by operating context. Engines that repeatedly depart in hot, dusty conditions are likely to experience different fouling and wear trajectories than those serving cooler, cleaner routes of similar duration. Treating both equally in scheduling and logistics can lead to premature attention for relatively healthy units and delayed intervention where stress accumulates faster. In this setting, Smart Maintenance Scheduling via Predictive Logistics (SMS-PL) is considered as an overlay to existing programs, using operational indicators and environmental traces to refine inspection timing and resource placement while maintaining compliance with OEM and authority requirements (e.g., RCM/PHM-aligned practices) [1; 2].

2. Research methodology

Scientific and systems-engineering foundations of SMS-PL

Smart Maintenance Scheduling via Predictive Logistics (SMS-PL) is founded on the principle that post-flight maintenance should evolve from static scheduling to an adaptive, data-informed optimization problem. The system integrates concepts from reliability engineering, prognostics and health management (PHM), and logistics forecasting, treating each flight not as an isolated event but as a measurable increment in the component degradation timeline.

Each flight generates a distinct operational signature defined by its thermal, mechanical, and environmental exposure. Parameters such as exhaust gas temperature (EGT) margin variation, engine vibration amplitude, oil-condition index, ambient air temperature, and aerosol optical depth (AOD) collectively characterize the stress intensity of that flight. Over time, these data form a cumulative stress trajectory for each aircraft tail number. By aggregating such indicators, the system derives a Maintenance Severity Index (MSI) that represents the normalized effect of operational and environmental load on component health.

In a simplified analytical form, the MSI can be conceptualized as a function:

$$MSI_i = f(T_i, V_i, O_i, E_i, D_i) \qquad (1)$$

where T_i denotes thermal exposure, V_i vibration signature, O_i oil-condition score, E_i environmental severity (e.g., dust concentration, humidity), and D_i duration or cycle load of the i-th flight. Although not computed through a deterministic equation in the current stage, this relationship defines the data structure from which statistical and learning models can infer degradation trends.

By translating environmental and operational parameters into quantifiable stress values, SMS-PL enables a relative comparison among aircraft within the same fleet. This approach aligns with the prognostics concept of remaining useful life (RUL) estimation, where degradation is modeled as a stochastic process driven by observed stressors rather than elapsed time. As the dataset expands, regression or

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machine-learning techniques can refine the mapping between MSI evolution and maintenance outcomes, improving prediction accuracy with each operational cycle.[3]

Parallel to the analytical layer, predictive logistics transforms maintenance preparation into a forward-looking optimization task. Traditional logistics respond to maintenance findings with reactive shipments and technician dispatches; SMS-PL predicts where and when these requirements will occur based on MSI trajectories and route plans. This coupling between degradation modeling and logistics forecasting forms a closed loop that connects physical aircraft condition with material and human resources.

The relevance of this framework becomes evident in the Central Asian context, where aircraft routinely operate in highly variable climates and across long geographical distances between maintenance hubs. Variations in environmental stress — such as elevated dust concentrations during summer operations in Navoi or high thermal loads at Ashgabat — influence not only the rate of engine wear but also the spatial distribution of maintenance demand. Predictive logistics mitigates such variability by pre-positioning critical components and qualified personnel at locations where maintenance probability is rising, thereby reducing unscheduled downtime and optimizing transport cost.[4]

SMS-PL thus constitutes a hybrid engineering model — combining empirical observation, environmental analytics, and logistic planning — that augments existing OEM-based maintenance frameworks. It preserves regulatory compliance while embedding adaptability through data feedback. This synthesis of reliability theory and predictive resource allocation represents a foundational step toward regionally contextualized, performance-based maintenance systems in modern aviation.

Methodology and implementation of smart maintenance scheduling via predictive logistics

The SMS-PL workflow integrates three streams: (i) operational and condition data captured post-flight (e.g., EGT trends, thrust settings, accelerometer-based vibration tendencies, oil status where available), (ii) environmental context from meteorological and satellite sources (e.g., local METAR, reanalysis temperature fields, aerosol/dust indices), and (iii) maintenance history. After landing, the aircraft data package is ingested into a maintenance data hub and contextualized with the environmental feed matched to the actual flight path and time

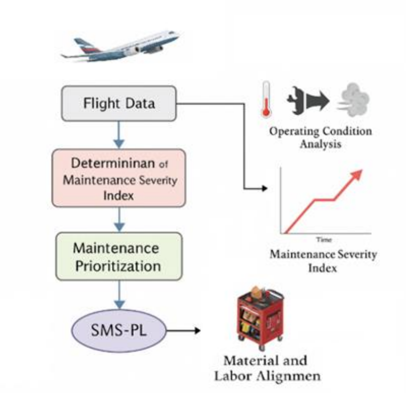

Fig.1. Workflow of the smart maintenance scheduling

• The conceptual workflow of the proposed Smart maintenance scheduling model is illustrated in Fig. 1. It shows the transition from raw flight and environmental data to maintenance prioritization and predictive logistics planning.

A predictive analytics service evaluates each flight record against the aircraft's history and fleet comparators to update a cumulative MSI. Rather than a fixed formula, MSI is treated as a structured data object that reflects relative stress accumulation for that tail under observed conditions. Planning thresholds are set within the airline's approved program and are reviewed periodically; when an MSI trajectory indicates elevated priority, the system proposes an earlier post-flight inspection window or targeted tasks (e.g., borescope on specific modules, oil sampling), still within compliant limits.

The logistics module consumes those proposals together with the forward schedule to forecast parts and skills demand by station. Inventory movements (e.g., filters, seals, borescope kits, balance weights) and short-term technician assignments are generated to place resources at likely event locations (for example, Navoi or Turkmenabat) ahead of aircraft arrival. A planner dashboard provides transparency: aircraft are ranked by MSI trend and proximity to suggested actions; the traceability of decisions is preserved for internal quality review and regulatory oversight. After any maintenance, actual findings (wear evidence, contamination levels, post-action vibration changes) are fed back to improve future recommendations.[5]

Observations and practical assessment

A review of publicly available materials, technical publications, and informal observations of regional workflows suggests that Central Asian operators predominantly apply time- and cycle-based scheduling. This ensures safety and consistency but may not differentiate sufficiently between aircraft exposed to frequent hot-and-dusty departures and those serving cooler routes. Discussions with practitioners and document reviews indicate that inspection timing, spare-parts provisioning, and technician allocation are often organized by calendar and fleet-level averages rather than measured operating context.

Within that reality, SMS-PL appears suitable as a practical enhancement. Using per-flight operational and environmental traces to inform inspection priority can help identify aircraft that warrant earlier attention, while others remain on standard intervals. Coupling prioritization with predictive logistics offers a path to reduce reactive shipments and to align material and staff with anticipated needs at secondary stations. These observations are not the outcome of controlled field trials; they reflect a reasoned assessment that an evidence-supported overlay could improve planning precision under regional conditions without altering regulatory obligations.

3. Results and discussion

The Introducing SMS-PL would shift portions of maintenance planning from strictly procedural scheduling toward analytical decision-making supported by recorded operational context. Even modest data integration—such as tracking repeated dust exposure or frequent high-temperature departures—could refine the order in which aircraft are inspected and the stations at which materials and skills are staged. The concept fits within current reliability-centered and performance-based maintenance trends, provided decisions remain auditable and inside approved limits. Adoption would depend on collaboration among airlines, MROs, and authorities, beginning with pilot deployments that evaluate outcomes under actual Central Asian operating conditions.

4. Conclusion

The study evaluated Smart Maintenance Scheduling via Predictive Logistics as a complementary framework for post-flight engine maintenance in Central Asia. Treating each flight as a source of operational and environmental evidence enables a cumulative profile of stress that can inform inspection priority and material positioning. The approach maintains compliance while adding a data-driven perspective to reduce avoidable delays and improve resource usage across dispersed stations. Further work should focus on structured data collection, targeted pilots with local operators, and measurement of impacts on turnaround time, parts logistics, and dispatch reliability.

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