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Implementation of a Cloud-Based ERP System for Optimized Inventory and Supply Management in Space Stations and Long-Duration Missions

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Abstract

Long-duration space missions require autonomous inventory oversight to manage critical supplies. This paper presents the validation of a module embedded in an ERP system that provides a comprehensive dashboard of resource status. The system uses an adaptive prediction engine that combines a 30-day consumption history with default values for new items, enabling increasingly accurate depletion projections as the mission progresses. Based on category thresholds, it classifies each item's risk (OK, Warning, Critical). In addition, an autonomous scheduler generates a consolidated alert summary each day at a scheduled hour, ensuring continuous situational awareness. In a 30-day simulated scenario, the module demonstrated its capability to sustain monitoring and issue timely alerts without human intervention, validating its feasibility as a decision-support tool in isolated environments.

Keywords: Enterprise Resource Planning (ERP); critical supplies; stockout forecasting; inventory risk; space operations; autonomous alerts.

Acronyms/Abbreviations

Application Programming Interface (API); Enterprise Resource Planning (ERP); International Astronautical Congress (IAC); International Astronautical Federation (IAF); International Space Station (ISS); Radio-Frequency Identification (RFID); RFID-Enabled Autonomous Logistics Management (REALM); Software-Defined Networking (SDN).

1. Introduction

Long-duration space missions present unprecedented logistics challenges in which self-sufficiency is a critical factor for crew survival [1]. In this context, the management of inventories of critical inputs such as food, medicines, and spare parts must be proactive and autonomous, since resupply is limited and communications with Earth may be interrupted [2]. Space logistics is, in fact, a fundamental pillar of mission success [3], particularly in complex architectures such as the lunar Gateway station, which will operate with unprecedented autonomy [4].

Current systems on the International Space Station (ISS) have improved traceability through technologies such as RFID [5], an approach validated in multiple space logistics applications [6]. However, these systems still rely on human supervision and lack a predictive diagnostic capability that adapts to actual consumption and consolidates alerts autonomously [7]. The present research aims to close this gap in the ability to generate proactive situational awareness while reducing crew cognitive load [8].

This work presents a module integrated into an ERP system [9]—a standard technology for managing complexity in the aerospace industry [10]—that addresses this need through three key capabilities. First, it offers a unified dashboard for inventory oversight. Second, it implements an adaptive prediction engine that leverages consumption history to refine projections, applying artificial-intelligence principles to supply-chain optimization [11]. Third, it ensures constant oversight through a daily scheduler that issues consolidated alerts. As shown in the results, this combination of tools significantly improves crew autonomy in managing onboard resources.

2. Material and methods

2.1 Platform and Tools Used

The module was developed on a cloud-based ERP system, conceived to manage critical inventories in space missions. The system combines an interface for querying and recording items, a persistence service that stores consumption history, a calculation engine that projects days of coverage, and an automatic scheduler that generates daily alerts. All information is stored in transactional records, ensuring traceability and real-time updates.

2.2 Mission Scenario: "Gateway" Logistics Module

To validate the system in a relevant context, a case study was defined that simulates inventory management in a logistics module of the lunar Gateway station over a 30-day period without resupply. This scenario assumes a crew dependent on onboard stock for operations. Items and risk thresholds are defined in (Table 1).

Table 1. Simulation parameters for the "Gateway" Logistics Module

Category	Ítem	Warning Threshold	Critical Threshold
Medicine	Analgesics	< 30 days	< 10 days
Food	Rations	< 45 days	< 15 days
Spare parts	Air filters	< 60 days	< 20 days

2.3 System Architecture

The architecture is organized into four main components:

a) Operations panel (interface): Presents overall inventory, classifies each item as Normal, Warning, or Critical, and displays projected depletion curves.
b) Prediction module: Estimates days of coverage using two methods:
(i) Historical data – calculates average daily consumption using a 30-day moving window.
(ii) Default value – in the absence of history, applies initial parameters defined by category (e.g., 5 units/day for food, 2 for medicines, 0.2 for spare parts).
c) Recording service: Each recorded consumption automatically deducts from stock, is time-stamped in the history, and triggers recalculation of coverage indicators.
d) Automatic scheduler: Runs daily at 08:00, reviews all items, identifies those at risk, and generates a consolidated report for the crew.

2.4 Variables and Parameters Used

For each inventory item, the following variables were defined:

a) S: initial stock of the item (units).
b) C_d : average daily consumption, computed from the last 30 days.
c) C_{def}: default consumption when no history exists, assigned by category.
d) T : simulation horizon (30 days in the validation scenario).

Applied risk thresholds:

a) Critical: when projected coverage is less than or equal to 5 days.
b) Warning: when coverage is below the category-defined threshold (e.g., 30 days for medicines, 45 days for spare parts).
c) Normal: otherwise.

2.5 Calculations Performed

The system applies the following calculations:

Average daily consumption:

$$C_d = \frac{Units\ consumed\ in\ 30\ days}{30}$$

or, in the absence of history,is used according to category.

Projected coverage:

$$D_r = \frac{S}{Cd}$$

Risk classification:

a) Critical if $D_t \geq 5$
b) Warning if $D_t \leq T_{cat}$
c) Normal otherwise,

where T_{cat}: is the category-specific warning threshold.

3. Results

To validate the module's behavior in the "Gateway" Logistics Module scenario, simulations were conducted under different operating conditions. The system was evaluated across four key scenarios to demonstrate its ability to classify risk and generate autonomous alerts.

3.1 Nominal Inventory Status in "Gateway"

In the initial scenario for the 30-day mission at "Gateway," the system was configured with ten inventory items (medicines, food, and spare parts). The overall dashboard (see Fig. 1) provided an integrated view of mission status: four supplies were OK, four in Warning, and two in Critical, allowing the crew to immediately prioritize required actions.

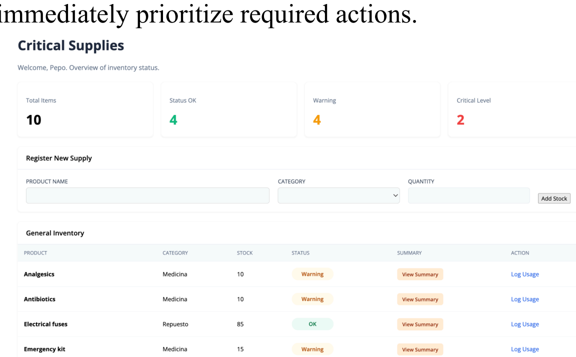

Fig. 1. Overall inventory panel and classification of critical supplies.

3.2 Early Warning Detection in Medical Supplies

Analysis of analgesics showed that with a stock of 10 units and consumption of 0.5/day, coverage was only 20 days. As this is below the safety threshold of 30 days defined for medicines, the system correctly classified the resource at Warning level, demonstrating its capability for early alerts (see Fig. 2).

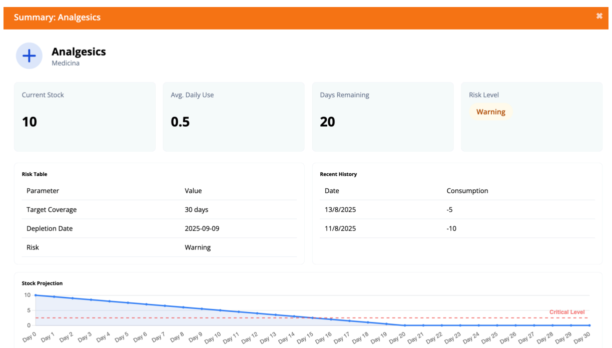

Fig. 2. Projection and Warning risk status for the analgesics case.

3.3 Verification of Supplies in Optimal Status

By contrast, freeze-dried rations, with a stock of 200 units, yielded coverage of 40 days (see Fig. 3), exceeding the mission duration. The system classified them as OK, confirming its accuracy in identifying sufficient items and reducing the risk of false alarms.

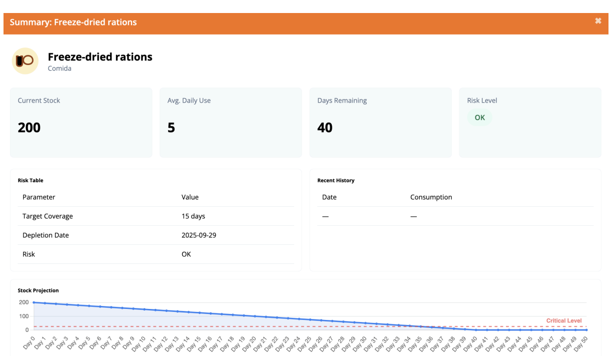

Fig. 3. Resource sufficiency scenario: freeze-dried rations classified as OK.

3.4 Projection Adaptation with Consumption History

The item "Energy bars" (see Fig. 4) illustrated the system's adaptive intelligence. Initially, without history, the system projected a Critical coverage of 1 day. However, after recording actual consumption, the prediction engine recalculated and adjusted the forecast to 2 days, demonstrating that model reliability increases as the mission advances and the system accumulates data.

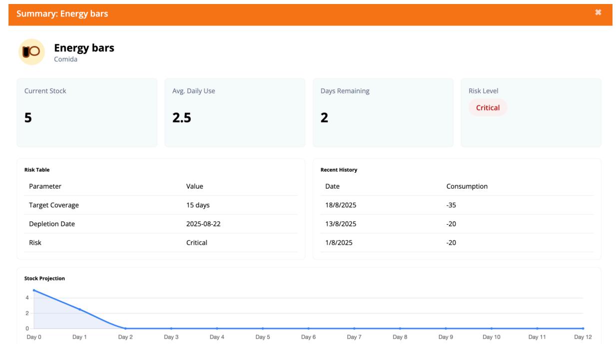

Fig. 4. Item panel for Energy bars showing the critical projection with consumption history and adjusted depletion date.

3.5 Scheduled Autonomous Alert Issuance

Finally, the daily scheduler was validated. Configured to run at 08:00 (see Fig. 6), the system generated and sent a consolidated alert (see Fig. 5) summarizing all items in Critical and Warning status, validating its ability to maintain crew situational awareness autonomously and with minimal intervention.

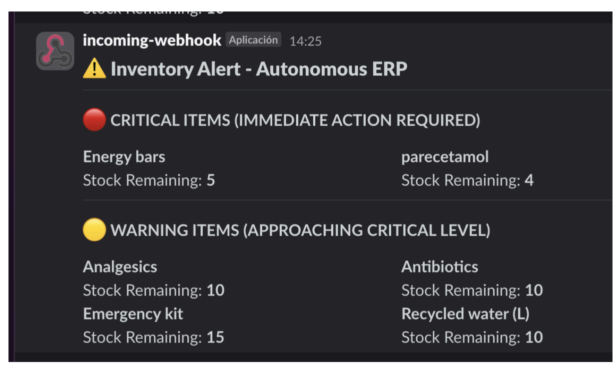

Fig. 5. Autonomous alert sent to the crew listing resources at risk.

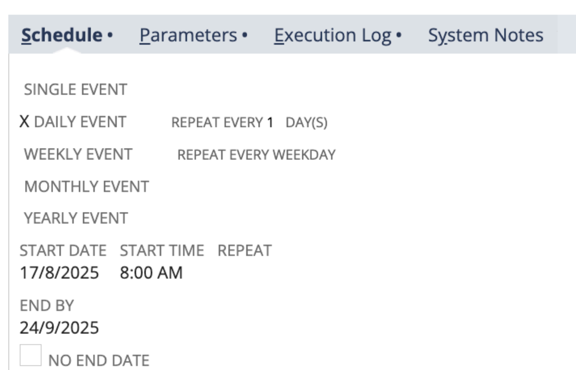

Fig. 6. System configuration for daily scheduled execution at 08:00.

4. Discussion

The simulation results for the "Gateway" Logistics Module demonstrate the system's ability to detect depletion risks autonomously. Unlike traditional approaches that rely on manual reviews [12], the module integrates autonomous calculation and dynamic updating—an important improvement for missions in which communication with Earth is intermittent and suffers from high latency [13].

Validation of the overall panel (Section 3.1) confirms that it provides a consolidated view enabling the "Gateway" crew to prioritize attention on items in Critical or Warning status. Particularly relevant is the scenario with history (Section 3.4), which showed that model reliability increases as the system accumulates data—consistent with principles of progressive learning and predictive analytics [14]. Finally, the daily scheduler's capability (Section 3.5) to issue consolidated notifications is an effective mechanism to reduce crew cognitive load, moving the system toward an intelligent decision-support assistant.

It is important to acknowledge an inherent limitation of the current proof-of-concept implementation: its dependence on a cloud architecture. While ideal for validation, an operational version for "Gateway" would require an on-edge architecture within the spacecraft systems to ensure full autonomy and resilience to connectivity failures [15]. Future work should focus on a local module that periodically synchronizes with an Earth-based ERP through a lightweight, resilient API, ensuring data integrity even with intermittent links—a key strategy in software-defined space networks (SDN) [16]. A future implementation should also incorporate more complex consumption variations, such as periods of high demand or adjustments under extreme conditions.

5. Conclusions

This work demonstrated the feasibility of integrating a predictive simulation module into an ERP platform as a decision-support tool for inventory management in space missions. Validation via the “Gateway” Logistics Module case study confirmed the system’s ability to autonomously classify supply risk (Normal, Warning, and Critical) using a prediction engine that adapts to consumption history.

The integration of a daily autonomous scheduler proved to be an effective mechanism for reducing crew cognitive load and improving situational awareness without relying on communications with Earth. Although validated as a cloud-based proof of concept, this approach represents a fundamental first step toward intelligent, autonomous logistics systems. Developing a local (on-edge) version with a resilient synchronization API would consolidate this tool as a robust solution for self-sufficiency on extraplanetary platforms.

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