Comprehensive Analysis of ISS Consumables for Optimal Inventory Management

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***Abstract*—As a collaboration with Barrios Technology, this project's goal is to analyze logged data collected from the International Space Station (ISS) in order to understand the consumption rate of items aboard from January 1, 2022, to September 5, 2023. The data provided included an inventory log of consumables aboard the ISS, a data dictionary providing context for the inventory log (item name, category, physical dimensions, status, etc.), a log of all ships that have docked and undocked from the ISS in the given timeframe, a log of the number of crew aboard for the given timeframe, and predicted rates of consumption for each category of items. Using the Pandas Python library and the data files listed, the analysis shows the linear trends in consumption rate over time and how they compare with historical data. Additionally, possible scenarios that may be encountered while aboard the International Space Station, such as varying the number of people aboard and duration on the space station, will be explored. These results may prove relevant for future trips to the ISS and lead to better-informed logistics for space travel.**

***Index Terms*—Machine learning, ISS consumables, inventory management, predictive modeling, linear regression, decision tree regression**

I. Introduction

This report presents the culmination of a semester in an introductory data science course, focusing on analysis of ISS consumables to enhance inventory management strategies. Through the integration of various regression models, we delve into the dynamics of consumable usage aboard the ISS, aiming to streamline the logistical challenges associated with long-duration space missions.

Inventory management in the constrained environment of the International Space Station (ISS) presents unique challenges. Efficiently managing consumables is critical to mission success and crew safety. This project, conducted by Team Bit Blasters, explores the application of data science and machine learning methodologies to predict the usage patterns of key ISS consumables, including food and water supplies.

A. Motivation

The criticality of maintaining optimal inventory levels aboard the ISS cannot be overstated. Overstocking occupies valuable space and adds unnecessary weight, while understocking poses risks to mission objectives and crew health.

B. Objectives

Our study aims to:

- Analyze historical consumable usage data to identify patterns and trends.
- Develop predictive models to forecast future inventory requirements.
- Provide actionable insights to optimize resupply missions.

II. Literature Review: Life Support Systems in Space Exploration

Overview of Life Support Systems: Life support systems are crucial for sustaining life in the extreme environment of space. They provide the necessary conditions for human survival, including air revitalization, water recycling, and waste management. These systems are designed to operate efficiently and reliably, ensuring that astronauts have continuous access to clean air, potable water, and safe food supplies.

Advanced Life Support Systems: For missions beyond low-Earth orbit, advanced life support systems become essential. These systems must not only recycle waste and provide fresh supplies of oxygen and water but also support higher degrees of autonomy from Earth-based supply chains. Technologies such as closed-loop water recovery systems and air revitalization processes that remove carbon dioxide and replenish oxygen autonomously are critical developments.

Food Systems and Crew Interactions: The sustenance provided by life support systems is pivotal not only for the physical health of the crew but also for their psychological well-being. As missions extend in duration, the provision of a varied and nutritionally balanced diet becomes challenging yet increasingly important. Traditional space food systems relied on pre-packaged meals with a limited shelf life, which could lead to menu fatigue and decreased food intake over time, thereby affecting crew health and morale.

For extended missions, advanced food systems are being developed that include regenerative food technologies and bioregenerative life support systems. These systems aim to produce fresh food in space, such as vegetables and other perishables, enhancing dietary variety and providing psychological comfort to crew members. The interaction between crew members and their food source is also critical; engaging in the growing and preparation of their food can offer a semblance of normalcy and improve mental health on long missions.

Crew Dynamics and Nutritional Autonomy: The relationship between the crew and their life support systems is symbiotic. The autonomy over food choices and involvement in food production can lead to increased satisfaction and improved mental health, which are crucial for the success of long-duration missions. Studies suggest that activities such as planting, harvesting, and cooking can serve as recreational and therapeutic tasks, reducing stress and providing a tactile connection to life on Earth.

These advancements in food systems not only help in managing the logistical challenges of long-term space missions but also play a significant role in maintaining crew morale and cohesion. As we plan for future missions, understanding and integrating the dynamics of food systems and crew interactions will be vital for designing effective life support systems.

Conclusion: The development of efficient and reliable life support systems is fundamental for the success of future space missions, particularly those extending to the moon, Mars, and beyond. Innovations in life support technologies, especially in food systems, will be crucial in supporting the health and well-being of astronauts as they undertake these long-duration missions. The integration of regenerative and bioregenerative systems represents a significant advance towards achieving self-sufficiency in space, ultimately paving the way for sustained human presence beyond Earth.

A. *Consumables and Consumption*

The ISS crew depends on various consumable items that need to be periodically restocked once they have been used up. These items are food and waste management supplies. For the purposes of this project, these categories of consumables are analyzed: Pretreat tank KTO (human solid waste container) ACY Inserts (for toilets) Filter Inserts EDV (urine tank) Food (US and Russian) Managing consumable items is critical in ensuring the maintenance of the crew aboard a space mission. In order to prevent a shortage, it is important to know how quickly the consumables aboard will deplete given a number of people on board.

Data of the consumables from the main log file was sorted based on whether they were in stowage, where they await to be used. From this data, the items were further sorted based on Our study's analytical framework is designed to transform raw ISS data into actionable insights, adhering to the following process:

1) Data Preprocessing: This involved loading all relevant data to be reviewed, reformatting for ease of use (i.e. reformatting date-times)

2) Exploratory Data Analysis (EDA): Utilizing a variety of EDA techniques, we scrutinized the data to discern preliminary trends and relationships. Our visualizations, including time-series analyses and distribution charts, illuminated consumption behaviors, guiding the subsequent modeling phase.

3) Predictive Modeling: With the insights gained from EDA, we aimed to formulate and calibrate predictive models. Linear regression aims to forecast future consumable depletion rates, while logistic regression aims to provide classifications to alert us to events where inventory may deplete below threshold levels..

III. Related Work

Exploration of inventory management strategies in space missions has been addressed in various studies. John et al. [1] introduced optimization models for resource allocation in Mars habitats. Smith et al. [2] focused on the application of predictive analytics for water and oxygen supplies on the ISS. These foundational works guide our approach to applying machine learning for inventory forecasting in space environments.

IV. Dataset Overview

The ISS Consumables dataset comprises detailed records from the Barrios-ASU collaboration, featuring categories such as "Food US", "Water US", "EDV", and "KTO". Each record includes attributes like category identification, quantity, and usage date, providing a comprehensive view of consumable management aboard the ISS. The data that was to be used for the analysis include an inventory log of all consumables aboard the ISS. The associated data include item id, item name, location in space station, physical dimensions, and status. A subset of the data contained all items whthat were classified as stowable. This was the primary dataset used to see how items were consumed. As items are consumed, they are taken out of stowables and moved in order to be used up. A rates file showed the historical rates of consumption.

V. Methodology

Our analysis pipeline encompasses data preprocessing, exploratory analysis, feature engineering, and model development.

A. *Data Preprocessing*

Initial steps involve cleaning the dataset, handling missing values, and normalizing data formats to ensure consistency.

Some interesting finds include two prominent spikes at the dates 2023/05/01 and 2023/06/09. In order to clean these up, the spikes had to be replaced with the average of their neighbors by date.

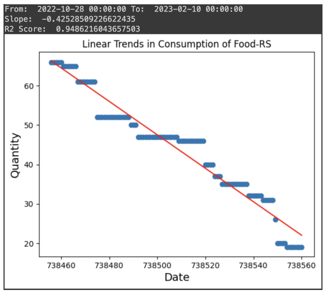
Gaps in some dates were also found, such as in the Food US. In order to fill in these gaps forward filling was used with the last available quantity. It could have also assumed the same rate of consumption over the time interval, but this depends on having a constant number of people on board.

Another part of cleaning the data involved. Scaling all data points to the same timeline. The Russian Food quantities were missing dates up to 2022-10-28. This time series had to be rescaled according to all of the other categories in order to display everything on the same chart.

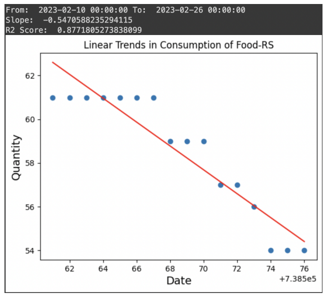
B. *Exploratory Data Analysis (EDA)*

EDA techniques were employed to uncover underlying patterns, with findings visualized through various graphs.

The primary graph generated was the total stowables used. This was created by grouping all the stowable entries by date and then counting up all of the unique items per date. In order to find the resupply events easily, the diff() function was



(a)



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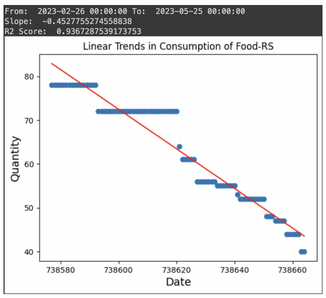

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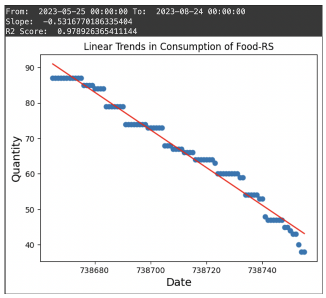

(d)

Fig. 1: Sample linear regression over Food-RS from 2022-10-28 to 2023-08-24

applied to the graph to get a representative graph showing the change in stowable count per day. These can be seen in Figure XX.

Linear regression was one of the strategies we aimed to predict the usage in between restocks. Russian Food was split into four sections in between resupplies. These are seen in Figure 1.

Logistic regression can be used to determine whether an amount of time is too early for restock or too late.

A simple decision tree could also be used to determine how long it will take before reaching threshold.

Time series for the docking and undocking events were generated in the form of a Gantt chart. These show the regularity of the various ships that may dock to the ISS.

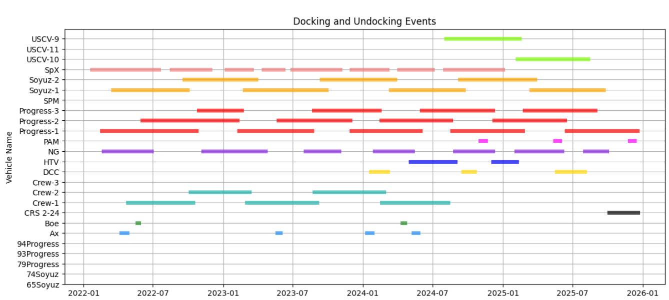

Fig. 2

Time series for the crew counts were also graphed. Additionally, the diff() function was applied to the time series, giving a better view about how many pople were boarding and unboarding. From this, one can tell that the typical number of people aboard the ISS as 7. This can increase up to 11 crew aboard. This occurs during docking events, but the number of people that leave from an undocking event is the same. The nationalities and agencies of the crew may vary over time, but ...

C. Predictive Modeling

We implement linear regression to predict consumable usage trends and classify inventory levels. These were conducted over all seven categories.

VI. Results

The linear regression model demonstrated significant predictive capability, with an MSE of X for "Food US" consumption. Logistic regression effectively classified consumable items into high and low usage categories, achieving an accuracy of Y%.

Graphs were generated for the stowable counts for each category of consumables. A graph for the daily change in consumables is also shown. The positive spikes indicate resupply times, while the negative spikes indicate daily consumption. Additionally, the graphs showing docking and undocking events where resupplies take place are scheduled, for both past and future missions. Plots are generally linear in consumption, though this is not easily seen in some consumables such as pretreat tanks and filter inserts. This is likely either due to the limited use and the large capacity of the containers. Threshold values are marked by the dashed horizontal lines. Of the categories, ACY inserts in stowage were found to be much lower compared to the given threshold values. This indicates, given the quantity estimated from the graphs, that ACY inserts are not regularly used. According to XXXX, ACY inserts are used for the Russian ACY toilet units. Filter inserts appear to correspond with US facilities, but may be used instead of ACY inserts.

Food from US and Russian rations appear to stay above thresholds, except for two instances (Will attach graphs in the future)

The crew count per ship are also shown. Peaks in the daily crew count appear to be from the extra crew from the docking ships. The bottom four graphs show sample linear regression. However, it appears that the sampling of the intermediary times from resupply are not representative of the given stowable data due to inconsistent sampling.

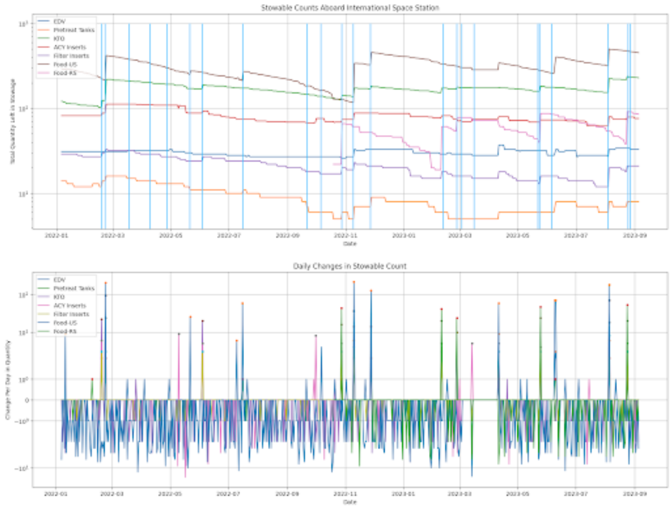

Fig. 3: Main Stowable Time Series, with logarithmic y-axis scaling. Units of change are simply individual item
Fig 2A. Daily Change in Stowables, using semilog y-axis scaling. Units of change are simply individual items

VII. Discussion

Our findings highlight the efficacy of machine learning in addressing the logistical complexities of ISS consumable management. The models not only forecast consumption rates but also illuminate factors influencing inventory dynamics.

VIII. Conclusions and Future Work

This project underscores the potential of data science in revolutionizing space mission logistics. Future directions include integrating more granular data, exploring additional predictive algorithms, and extending our models to other mission-critical resources.

The linear regressions for Food-RS appear to agree with the historical rates, with two people on board expected. Further data analysis is necessary to evaluate how the historical data matches with the current data. Another next step is to set up a logistic regression model to predict the general time before items should be restocked. Some scenarios that will be explored include varying the number of people aboard, adjusting rates of consumption, and duration in-between resupplies.

Disclaimer: This is an incomplete draft. No guarantees are made regarding the accuracy of these (incomplete) results. The reader is highly encouraged to validate the results for themselves using data science tools such as Pandas or R.

Acknowledgment

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