PROACTIVE FAULT DETECTION AND COMPONENT PLANNING TO SUPPORT HELICOPTER LOGISTIC PROCESSES

Massimo Manzini, Leonardo Helicopter Division, Sesto Calende, Italy
Giulia Romani, Leonardo Helicopter Division, Sesto Calende, Italy
Alessio Pagliarin, Leonardo Helicopter Division, Vergiate, Italy

Abstract

Digitization, process optimization, servitization and customer proximity are key elements for competing in the nowadays aerospace context. Consistent with these directions, the development and delivery of data-driven services, i.e., services based on the exploitation of available data, aimed at improving the level of service offered to customers with the enhancement of helicopter logistic processes and component planning activities. These services promote a paradigm shift in customer support: from being primarily reactive to events that have occurred, reaching the excellence of the current 24/7 FOC service, to a proactive and predictive approach, diagnostics, statistical and prognostic prediction capabilities enabled by the use of data (e.g., in-flight data, transactional data, ground reliability data, *As-Built* and *As-Maintained Configuration*).

More in detail, an ecosystem of digital services described in the following represents an application and industrialization of statistical analytical solutions within the aerospace industry, and the development of prognostic solutions based on ML and AI applied to a cutting-edge context (predicting un-scheduled maintenance events), with limited reference literature.

In this paper, the ecosystem of digital services is discussed in detail, spanning from an approach able to foresee scheduled and un-scheduled removals on the in-service fleet, to a customer-tailored tool supporting the maintenance event scheduling as well as component booking. Potential benefits have been evaluated after an early adoption session resulting in an increase in forecast accuracy and in spare parts availability.

1. INTRODUCTION

Nowadays, the aerospace sector is experiencing a critical era, where an uncertain geopolitical landscape, the urgent imperative for environmental sustainability, and the escalating demand for robust cybersecurity measures contribute to create a complex and fast-paced environment.

Considering such a situation, the resilience of the supply chain emerges as a pivotal factor, holding the key to effectively manage and overcome the entire spectrum of these interconnected challenges. A robust and adaptable supply chain is not merely a logistical convenience; but represents a strategic necessity, enabling the industry to overcome shocks, maintain continuity of operations and accelerate innovation in a rapidly changing global environment.

In addition to this, the progressive digitalization of processes leveraging advanced technologies such as AI and Big Data Analytics, is revolutionizing sectors in which the creation added value from the exploitation of data could be high beneficial.
These advancements offer relevant opportunities to collect, analyze and exploit large volumes of operational data. However, the full realization of this new paradigm necessitates a comprehensive organizational and cultural adaptation. This includes, for instance, the adoption of appropriate tools and the fostering of an integrated vision among operational, logistical, and industrial entities.

Under this light, some of the core topics of Leonardo's vision are represented by the development of capabilities like digitalization, process efficiency, servitization, and customer proximity. Following these strategic directives, the *Predictive 4 Logistics &*

HELIanalytics project, discussed in this document, exemplifies the development and delivery of data-driven services.

These services leverage available data to support business growth and enhance the service level offered to customers. This initiative promotes a paradigm shift in the customer support model: from an essentially reactive approach to operational events, exemplified by the current 24/7 FOC service excellence, to a proactive and predictive methodology. This is achieved by developing business intelligence, diagnostic capabilities, statistical prediction and prognostics, all enabled by the exploitation of several data streams (e.g., in-flight data, on-ground transactional and reliability data, *As-Built* and *As-Maintained Configurations*). Grounding on this, the data collection and its exploitation represent critical enables for the successful switch to the new paradigm.

The innovative aspects of this project can be found in the application and industrialization of statistical analytical solutions. Furthermore, it encompasses the development of Machine Learning and AI-based prognostic solutions applied to an advanced context, specifically the prediction of un-scheduled maintenance events, an area with limited existing literature.

On the other side, the innovation of operational processes within the business functions can benefit from these data-driven services, for which the up-skilling and re-skilling of operational personnel is needed.

Finally, the proposed business model entails the delivery of these services via a dedicated, self-explanatory platform: *HELIanalytics*. This platform is supported by the technological stack provided by the HPC *DaVinci-1*.

Outline: the State of the Art, in which the available works are briefly discussed is included in Section 2, while the solution proposed considering four digital services and the *HELIanalytics* platform are presented in Section 3. In Section 4, the measured, potential benefits of the adoption of such ecosystem are discussed in detail, while conclusions and next steps are included in Section 5.

2. STATE OF THE ART

As discussed in the previous section, the governance and optimization of the supply chain represents a cornerstone, as it is moving beyond historical forecasts to more agile, data-driven methods due to market volatility and supply chain complexity. Digital services are crucial for this evolution.

A significant area discussed in literature is using AI and ML to boost demand forecasting accuracy.
For example, in Ref. 1 some advanced algorithms exploiting advanced technologies for analyzing complex historical data leading to reduced forecast errors and better inventory management are presented, while in Ref. 2 a use-case dedicated to the aerospace sector is discussed. What emerges from these works is that the best method to be applied depends on the specific use-case addressed and the data to be exploited.

A second point of view considers the application of analytics approaches able to exploit data also coping with configuration and scheduling problems, like discussed in Ref. 3 and 4.

Grounding on this, Predictive Maintenance applications are always taken into account to integrate Supply Chain optimization algorithm and support them with an operative point of view.

By analyzing asset performance data, failures can be predicted, enabling proactive spare parts planning. This reduces unplanned downtime and optimizes critical spare part inventory, transforming reactive material management into a predictive process, as discussed Ref. 3, 4 and 5.

Prognostics and Health Management for Remaining Useful Life estimation is a promising research area for aerospace material planning as discussed in Ref. 6 and 7.

Digital platforms are revolutionizing organizational interaction with data, technology, and stakeholders. These platforms facilitate digital service ecosystems by providing scalable infrastructure. Literature highlights their reliance on microservices, open APIs, and cloud-native technologies for flexibility and interoperability, as discussed in Ref. 8. In industry, these platforms manifest as "Industrial IoT Platforms" or "Digital Twin Platforms," integrating data from sensors, and enterprise systems (like ERP and MES) and contributes to create added value from data.

3. SOLUTION PROPOSED

In order to cope with the challenges and objectives described in Section 1, a digital service ecosystem has been designed, representing the data-drive answer to the business needs identified. A meticulous gap analysis has been conducted, resulting in the *Predictive 4 Logistics* digital service ecosystem briefly depicted in Figure *1*.

More in detail, with the main aim to enhance the component supply chain capability, the ecosystem can be described using two dimensions:

- The target user of the service, that can be either internal (e.g., Material Planning team) or external (e.g., directly the customer willing to plan maintenance actions and material supply).
- Component level addressed, that can be either Part Number (representing the type of component) or Serial Number (representing the specific object installed on a specific helicopter).

Grounding on this, four different digital services have been designed, developed and deployed with data-driven capabilities aimed at:

- More accurately foresee the demand for individual components up to 60 months in advance, thereby streamlining internal forecast generation processes. For this purpose, the digital service identified with number 1 and 2 in Figure *1* have been developed, namely *Component Removal Forecast* and *Material Planning*.
- Predicting potential malfunctions at the Serial Number Helicopter and component level, to enable a proactive support model towards the customer while simultaneously mitigating the impact of the malfunction itself. For this purpose, the digital services identified with number 3 and 4 in Figure *1* have been developed, namely *Component Provisioning and Prepositioning* (dedicated to internal Customer Support) and *Pre-Alert on Maintenance Stop* (dedicated to the customers).

Such a set of digital services is hosted on *HELIanalytics* platform working as a single entry point for the ecosystem, that leverages the technological stack made available by HPC *DaVinci-1*.

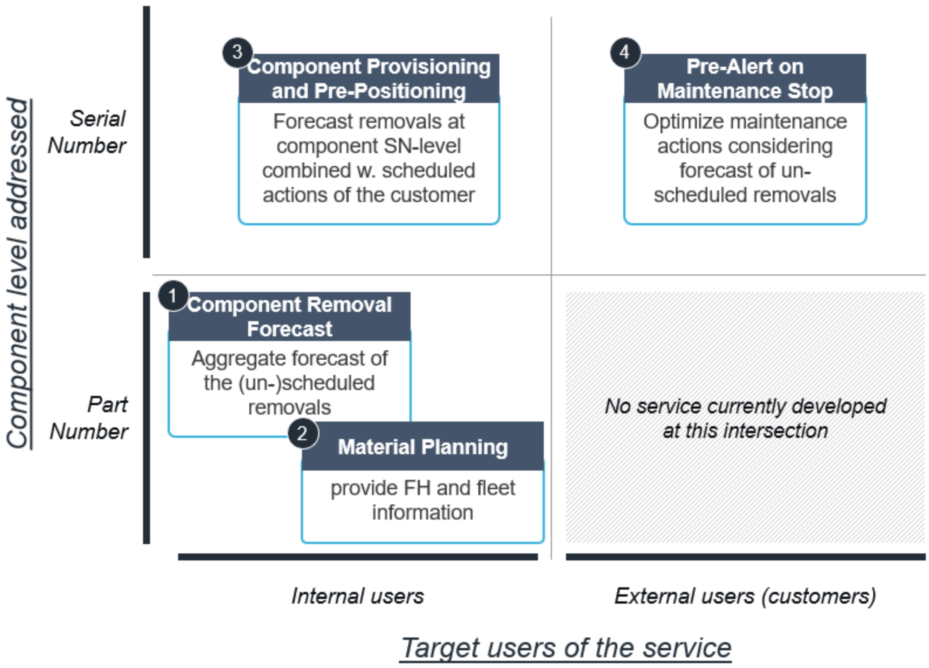

Figure 1: *Predictive 4 Logistics* digital service ecosystem framework. Four different services are clustered considering two dimensions: *Target users of the service* and *Component level addressed*.

3.1. **Component Removal Forecast**

The first digital service to be described is the *Component Removal Forecast*, that is able to generate a forecast of component removals due to both scheduled events (reaching life limits) and un-scheduled events (failures or malfunctions). The scope of applicability is at the component Part Number level, working with an aggregated approach across the monitored fleet, encompassing the entire range of components present in the parts catalog.

This service is able to perform statistical evaluations based on the concept and measurement of component reliability. A screenshot of the service is provided in Figure *2*. Specifically, it consists of two modules:

- *Failure Probability Distribution Generator*: able to generate a component Part Number level failure probability distribution by fitting the distribution based on the analysis of historical failures tracked by the company, and weighting it considering the Mean Time Between Un-scheduled Removals (MTBUR) value, one of the main reliability indicators.
- *Removal Simulator*: able to simulate the life of a component using a Monte Carlo methodology and the actual configuration of the in-fleet helicopters (namely the *As-Maintained Configuration*), predicting a removal in case of reaching life limits (e.g., component overhaul or retirement limit) or failure/malfunction.

The output of such a service is the forecast, at Part Number level, of the needed components for a 12 to 60-months horizon, useful to support the activities of Material Planning team.

Figure 2: Component Removal Forecast user interface. The forecast of the need of a component at Part Number level is presented considering the prediction of both scheduled (e.g., overhaul time or retirement life) or un-scheduled (e.g., malfunction or failure) events represented adopting different colours. The name and technical detail of the PN component have been blurred.

3.2. Material Planning

The second digital service to be discussed is the *Material Planning*. It is able to organize data and information in terms of fleet monitoring, Flight Hours (FH), projections of fleet evolution and reliability data, with the main aim to represent the unique source of such type of information and support the activities of the Material Planning team compliant to internal data governance rules.

More in detail, the service relies on the use of data verified and validated by the business and on automated data submission pipelines that are able to collect and elaborate data coming from multiple sources and provide in output a single FH projection. Such a project grounds on a ML-based algorithm able to learn from past fleet behaviour and generate a forecast considering parameters like mission type and helicopter platform.

The added value of the digital services grounds on the possibility, for the operator, to retrieve validated data and a reliable FH projection to be used in the generation of component Part Number level future demand.

3.3. Component Previsioning and Pre-Positioning

With the third digital service under discussion, the point of view can be changed by considering component as Serial Number level, thus, as already presented, the specific object installed on a specific helicopter.

The *Component Provisioning and Pre-Positioning* service is able to translate the predictions generated by the *Component Removal Forecast* to the component Serial Number level and present them in a dashboard to facilitate proactive customer support.

Mandatory enabler for adopting such a point of view is represented by the list of components installed on the helicopter under study, their status and their history such as date of installation and hours flew, also called *As-Maintained Configuration*. The *As-Maintained Configuration* information, collected automatically via APIs connected to operator fleet management software, allows the monitoring of the status of the helicopter configuration at a specific point in time, including the utilization status of the components installed on it.

This capability, combined with analytics and ML-based capabilities enables the development of a prediction module able to foresee both scheduled removals at the component Serial Number level (e.g., reaching Life Limit or the Overhaul Time) and unscheduled events such as malfunctions and failures.

From a business perspective, the objective of the *Component Previsioning and Pre-Positioning* service is to enable a proactive support model towards the customer (e.g., pre-positioning components in proximity warehouses and proposing the synchronization of corrective aircraft groundings with already scheduled maintenance), while simultaneously mitigating the impact of the malfunction itself.

3.4. Pre-Alert on Maintenance Stop

The fourth and last digital service discussed in this paper is represented by the *Pre-Alert on Maintenance Stop*, dedicated to external customers, capable of processing the same information as *Component Provisioning and Pre-Positioning*, but providing it with a proactive focus towards the operator to reduce the operational impact of un-scheduled events on their fleet.

In this case, the business perspective is dual with respect to the *Component Previsioning and Pre-Positioning* service, if the one is dedicated to the optimization of the supply chain and the management of materials from the OEM side, the other supports the planning of material supply and the scheduling of maintenance action from the operator side.

More in detail, the idea is to support the operator in coordinating the maintenance actions and the incipient occurrence of an un-scheduled event such as the malfunction of a component on the helicopter. For example, consider the incoming malfunction of a component installed on the helicopter under study and the scheduling of a maintenance action in few FH. The information given by the *Pre-Alert on Maintenance Stop* service can eventually support the anticipation of the maintenance action in order to cope with the incoming malfunction and, thus, increase the operational availability of the helicopter

3.5. HELIanalytics

The data-driven services described above, along with a further portfolio of digital services currently in delivery or under development, are provided through a dedicated platform named *HELIanalytics*. This platform has been designed to meet the necessity of delivering data-driven services to both Leonardo customers and internal company users. A screenshot of the platform is provided in Figure *3*.

With a distinctive visual identity and an optimized user experience, *HELIanalytics* represents the foundation for the provision of high value-added digital services. From Figure *3*, it is possible to see several clusters of digital services Leonardo has been able to develop and deploy for internal and external customers.

Such clusters mirror the different scenarios and situation in which a data-driven approach can be beneficial for the business (or for the customer) spanning from the *Predictive 4 Logistics* ecosystem focused on supporting Material Planning and Customer Support related activities, to the in-flight analysis, to the training activities.

The *HELIanalytics* platform and the whole digital services ecosystem leverage the technological stack represented by HPC *DaVinci-1* ensuring the supply of enough computation power to support complex data-driven services and algorithm, and the respect of data governance rules.

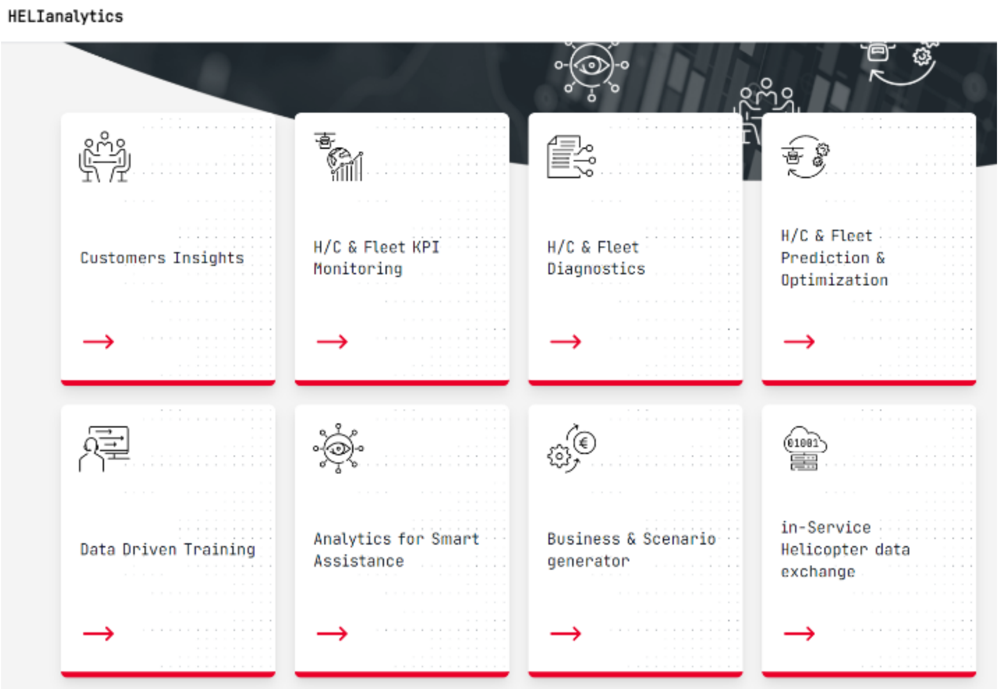

Figure 3: *HELIanalytics* platform representing the single point of access for the digital services ecosystem included but not limited to *Predictive 4 Logistics*.

4. PROCESSES AND BENEFITS

The parallel adoption of the *Component Removal Forecast* and the *Material Planning* digital tools by the Material Planning team of the Customer Support Function enables the planning of component procurement by leveraging an alternative forecast generation method (reliability-based) compared to the standard planning mode based solely on historical demand.

A comparative analysis of these two information sets allows for improved material planning accuracy through the implementation of appropriate alert mechanisms integrated into the monthly operational process cycle of the Material Planning team.

It is estimated that this new capability can yield the following benefits:

- An increase in forecast accuracy
- An increase in spare parts availability
- An overall potential saving in overstock yearly.

The adoption of the output from this service within the operational processes of the function involved a training activity for the planning team, as well as recurrent debugging and retraining sessions aimed at the continuous improvement of both the process and the service.

On the other side, the benefits of the adoption of the *Pre-Alert on Maintenance Stop* by an operator, and the contextual performances of the digital service have been estimated during a six-months Early Adoption campaign with several, selected, customers.

More in detail, such a campaign has been conducted on a pool of almost 100 helicopters and more than 50 components at Part Number level, resulting in the following potential benefits:

- Alert of incoming un-scheduled events of about 100 FH in advance, on average, with respect to the actual event (considering only the True Positive results).
- Positive impact on operational availability of the customer's helicopter.

5. CONCLUSIONS

This paper presented Leonardo Helicopter Division's *Predictive 4 Logistics & HELIanalytics* initiative, which the main aim is to support the customer support activities shifting from reactive to proactive and predictive.

Four digital services have been presented and their potential added value discussed, together with the *HELIanalytics* platform and the contribution of the HPC *DaVinci-1*. These services leverage operational data to optimize component demand planning, predict malfunctions, and enhance helicopter operational availability. The innovative application of statistical, Machine Learning, and AI solutions for un-scheduled maintenance prediction is particularly impactful.

Benefits include improved forecast accuracy, increased spare parts availability and yearly savings from reduced overstock. Early adoption of *Pre-Alert on Maintenance Stop* service demonstrated an average 100 Flight Hour advance warning for un-scheduled events, significantly boosting operational availability.

Among the next step, the massive exploitation of the presented services with a well-defined go-to-market strategy is considered a priority, as well as the service portfolio extension by coping with additional business cases.

6. ACKNOWLEDGMENTS

This project relates to one of the macro-streams of the Helicopter Division's Digital Transformation. The *Predictive 4 Logistics* data-driven services package and the *HELIanalytics* platform are part of Leonardo Helicopters' digital strategy for the development of its digital services portfolio.

7. REFERENCES

1. Mediavilla, M., Dietrich, F., Palm, D., *Review and analysis of artificial intelligence methods for demand forecasting in supply chain management*, Procedia CIRP, Volume 107, 1126-1131, 2022
2. Dodin, P., Xiao, J., Adulyasak, Y.,Etebari Alamdari, N., Gauthier, L., Grangier, P., Lemaitre, P., Hamilton, W. L., *Bombardier Aftermarket Demand Forecast with Machine Learning*, INFORMS Journal on Applied Analytics 53(6):425-445, 2023.
3. Manzini, M., Unglert, J., Gyulai, D., Colledani, M., Jauregui-Becker J. M., Monostori, L., Urgo, M., *An integrated framework for design, management and operation of reconfigurable assembly systems*, Omega, Volume 78, 69-84, 2018.
4. Manzini, M., Demeulemeester, E., Urgo, M., *A predictive–reactive approach for the sequencing of assembly operations in an automated assembly line*, Robotics and Computer-Integrated Manufacturing, Volume 73, 2022.
5. Mobley, R. K., *An Introduction to Predictive Maintenance*. Butterworth-Heinemann, 2017.
6. Zonta, T., da Costa, C., A., da Rosa Righi, R., de Lima, M. J., da Trindade, E. S., Li, G., P., *Predictive maintenance in the Industry 4.0: A systematic literature review*, Computers & Industrial Engineering, Volume 150, 2020.
7. Nunes, P., Santos, J., Rocha, E., *Challenges in predictive maintenance – A review*, CIRP Journal of Manufacturing Science and Technology, Volume 40, 53-67, 2023.
8. Ozkat, E. C., Bektas, O., Nielsen, M. J., la Cour-Harbo, A., *A data-driven predictive maintenance model to estimate RUL in a multi-rotor UAS*. International Journal of Micro Air Vehicles, 15, 2023.
9. Mitici, M., de Pater, I., Barros, A., Zeng, Z., *Dynamic predictive maintenance for multiple components using data-driven probabilistic RUL prognostics: The case of turbofan engines*, Reliability Engineering & System Safety, Volume 234, 2023.
10. Popova, P. E., Popov, V., Marinova, K., Petrova, M., *The Role of Digital Platforms and Big Data Analytics as a Base for Digital Service*

Innovation, 4th International Conference on Communications, Information, Electronic and Energy Systems, 1-8, 2023