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Cost Effectiveness Analysis of Spare Parts Optimization for Fighter A/C

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Spare part,
Stock,
Maintenance

Abstract: The aim is to analyze the alternative spare part stock level solutions for different operational scenarios and operational tempos for a generic Fighter jet product for different customers. It is aimed to use evidence-based decision-making methods for cost effective life cycle cost starting from design to the end of life for the life cycle sustainability case study. There are different methods for life cycle cost analysis and authors decided to use OPUS decision tools suite for this case study. Various Mean Time Between Failure (MTBF) and Mean Time To Repair (MTTR) values were estimated and how strategic decisions should be made for changing situations were discussed with case studies. OPUS10 cost effectiveness analysis based on different Campaign Scenario alternatives. It has been shown that different cost-effective solutions for life cycle cost starting from design during life cycle can be achieved for stock levels and warehouse levels for different cases. The study was prepared for a generic fighter jet product and is original in terms of providing support to the decision makers for making strategic decisions for the supportability system. Strategic decisions include; stock-levels, depot levels, transportation, supply and maintenance plan.

Savaş Uçağı için Yedek Parça Optimizasyonunun Maliyet Etkinliği Analizi

Anahtar Kelimeler
Kullanıma Hazır Olma,
Simülasyon Modelleme,
Operasyonel senaryo,
Yedek parça,
Stok,
Bakım

Öz: Amaç, bir savaş uçağının farklı müşteriler için farklı operasyonel senaryoları ve operasyonel tempolarına yönelik jenerik savaş uçağı ürünleri için alternatif yedek parça stok seviyesi çözümlerini analiz etmektir. Tasarım sürecinden, sürdürülebilir yaşam döngüsü sonuna kadar maliyet etkin karar, kanıta dayalı karar verme yöntemlerinin kullanılması amaçlanmaktadır. Yaşam döngüsü maliyeti analizi için farklı yöntemler bulunmaktadır ve bu vaka çalışması için OPUS karar araçları paketi kullanılarak çeşitli Ortalama Arıza Yapma Sıklığı (MTBF) ve Ortalama Tamir Zamanı (MTTR) değerleri tahmin edilmiş ve değişen durumlara göre stratejik kararların nasıl alınması gerektiği tartışılmıştır. OPUS10 maliyet etkinliği analizi Farklı Kampanya Senaryo alternatifleri temel alınarak yapılmıştır. Tasarımdan yaşam döngüsüne kadar maliyet etkin çözümlerin stok seviyeleri ve farklı durumlar için depo seviyeleri açısından elde edilebileceği gösterilmiştir. Çalışma jenerik bir savaş uçağı projesi ürünleri için hazırlanmış olup, desteklenebilirlik sistemi için stratejik kararların alınmasına destek sağlaması açısından özgün niteliktedir. Stratejik kararlar; stok seviyeleri, depo seviyeleri, ulaşım, tedarik ve bakım planını içermektedir.

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1. Introduction

Optimization and efficiency are integral concepts that often intersect and complement each other in various domains, including economics, engineering, business, and environmental science. Optimization refers to the process of making something as effective or functional as possible, while efficiency focuses on achieving maximum productivity with minimum wasted effort or expense. This essay explores the relationship between optimization and efficiency, examining how these concepts interplay to enhance performance, reduce costs, and promote sustainable practices across different sectors.

Optimization and efficiency are crucial in the modern world, where resource constraints and competitive pressures necessitate the effective utilization of available assets. Optimization involves finding the best possible solution among a set of feasible alternatives, often using mathematical models and algorithms. Efficiency, on the other hand, emphasizes the prudent use of resources to achieve desired outcomes. Understanding the relationship between these two concepts is vital for improving operational processes, enhancing productivity, and fostering innovation.

Optimization can be defined as the process of making a system, design, or decision as effective as possible within given constraints. It involves selecting the best option from a range of possibilities to achieve the highest level of performance. Optimization techniques include linear programming, integer programming, and dynamic programming, among others. Efficiency is the ability to accomplish a task with the maximum opertaional benefit and with minimum expenditure of resources, including time, money, and labor. It is about maximizing output while minimizing input, ensuring that resources are used in the most effective way possible. Efficiency can be measured through various metrics, such as productivity ratios, cost-benefit analysis, and performance indicators.

Optimization and efficiency are inherently connected, as optimization seeks to enhance efficiency by identifying the most effective use of resources. In many cases, optimization is a means to achieve efficiency. For example, in manufacturing, optimizing the production process can lead to greater efficiency by reducing waste, lowering costs, and increasing output.

The OPUS10 software used in this study provides comprehensive decision support for optimizing spare parts inventory and maintenance operations in the aviation industry. By leveraging its advanced analytical capabilities, airlines can make informed strategic decisions that enhance efficiency, reduce costs, and ensure high aircraft availability. The integration of OPUS10 into the maintenance management process offers significant advantages in terms of cost savings, operational reliability, and overall performance.

2. Methodology

In engineering, optimization is used to design systems and structures that perform efficiently under specific conditions. For example, optimizing the design of an aircraft can result in reduced fuel consumption, lower operating costs, and improved performance. Engineers use optimization algorithms to determine the best materials, dimensions, and configurations for achieving maximum efficiency.

Strategic decisions are supported by OPUS10 software in aircraft maintenance studies. OPUS10 is a powerful logistics support analysis software used for optimizing spare parts inventory and support systems. In the context of the aircraft maintenance case study, OPUS10 can facilitate several strategic decisions to enhance operational efficiency and minimize costs [1].

OPUS10 helps in formulating effective stock replenishment policies, including reorder points and quantities. It can simulate different scenarios to determine the most cost-effective replenishment strategy. By ensuring timely replenishment of stock, preventing shortages and overstock situations. Additionally, optimizes inventory turnover, improving cash flow management.

The software enables the definition and monitoring of Service Level Agreements (SLAs) for spare parts availability and maintenance response times. It provides insights into performance metrics and helps in setting realistic and achievable targets. So, it improves reliability and predictability of maintenance operations and enhances customer satisfaction by meeting agreed service levels.

OPUS10 can conduct comprehensive cost-benefit analyses for different inventory strategies. It evaluates the trade-offs between various factors, such as holding costs, ordering costs, and stockout costs. Informs strategic decisions with a clear understanding of financial implications. Helps in identifying the most cost-effective strategies for inventory management.

Life cycle consists of concept, procurement, production, operations support and decommissioning stages. The purpose of analytic Life Cycle Management (LCM) is to ensure and maintain a capability over time by providing analysis methods, models, tools, and strategies.

2.1. Literature review

OPUS10 helps determine the optimal stock levels for spare parts at each maintenance level by analysing historical usage data, failure rates, and lead times. The software uses advanced algorithms to balance the costs of holding inventory against the risks of stockouts. This ensures critical parts are available when needed, reducing aircraft downtime. Also minimizes excess inventory, leading to cost savings in storage and capital investment.
Businesses often use optimization techniques to improve efficiency in their operations. Business management systems can lead to significant reductions in project life cycle costs, improve delivery times, and enhance customer satisfaction. By optimizing supply chains, inventory levels, transportation routes, and supplier relationships, companies can achieve higher efficiency and better overall performance. [2]

The OPUS10 software can assist in deciding the best Depot Location and Allocation for maintenance levels by evaluating various factors such as proximity to flight routes, frequency of maintenance needs, and logistics costs. Strategic placement of depots can reduce transportation costs and lead times for parts delivery. So the number of aircrafts with “Awaiting Part Status” will decrease and Availability Ration will increase. Optimal allocation enhances overall efficiency in the maintenance process by ensuring parts are readily accessible. [3]

A process for extrapolating the Sherbrook Vari-metric optimization model for minimizing backorders to co-optimize parts, manpower, test and support equipment, simultaneously. [4]

Stukes et al. (2021) utilized software tools from the Opus Suite® by Systecon®, specifically OPUS10 and SIMLOX. OPUS10 handles steady-state multi-indenture/multi-echelon (MI/ME) optimization, while SIMLOX conducts discrete-event Monte Carlo simulations. The Opus Data model underpins an analytical method aimed at solving the cost and readiness objective function, which is stochastically validated using a Monte Carlo simulation engine integrated within the Opus Data model. The novel concept of treating manpower and support equipment as backorderable entities that can be optimized is further discussed in this paper. The Opus Data model serves as the basis for an analytical approach to resolve the objective function of cost and readiness and is stochastically verified via a Monte-carlo simulation engine integrated within the Opus Data model. [5]

According to Systecongroup.com (2024), industry leaders globally utilize the Opus Suite throughout all stages of the system life cycle to simulate, assess, and comprehend the effects of key decisions on technical system design and its maintenance and support solutions on costs and performance. [6]

2.2. Approach

In this study OPUS10 is used to integrate predictive maintenance systems and to align inventory management with predictive insights. This ensures that parts are available just in time for anticipated maintenance needs. Reduces unplanned maintenance and enhances aircraft availability. Optimizes the timing of parts replacement, extending the life of components.

The failure rate may be expressed in terms of failures per hours, percent failures per 1000 hours, or failures per million hours. A failure is defined as an instance when the system is not operating within a specified set of parameters. Assuming an exponential distribution, the system mean life the mean time between failure (MTBF) is:

$$MTBF = \frac{1}{\lambda} \qquad [7]$$

(λ : Failure Rate)

The software assists in conducting lifecycle cost analyses for spare parts and maintenance strategies. It evaluates the total cost of ownership, considering acquisition, operation, maintenance, and disposal costs. Supports long-term strategic planning and budgeting. Helps in selecting maintenance strategies that minimize lifecycle costs.

OPUS10 software is used for a comprehensive decision support for optimizing spare parts inventory and maintenance operations in generic fighter jet product. The capabilities and processes of analysis used to calculate system availability process has the following steps:

- Data Collection and Preparation: In this phase, data related to the system's performance is collected and prepared for analysis. This data may include failure history, maintenance records, and usage statistics.

- System Modelling: Using the collected data, a model representing the system's operation and the interactions of its components is created. This model is used to simulate the real-world behaviour of the system.
- Determination of Simulation Parameters: Parameters and scenarios to be used in the simulation process are determined. These parameters are used to evaluate how the system performs under different operating conditions.
- Analysis and Reporting of Results: The simulation results are analysed, and reports related to system availability are generated. These reports provide decision-makers with information about the current state of the system and potential areas for improvement.
- Optimization and "What If" Scenarios: Based on the simulation results, optimization studies are conducted to increase system availability. Additionally, different scenarios (e.g., adding new components, changing maintenance strategies) are analysed to assess their impact on system performance.
- Inputs, activities and outputs of the process are summarized in the following Figure-1.

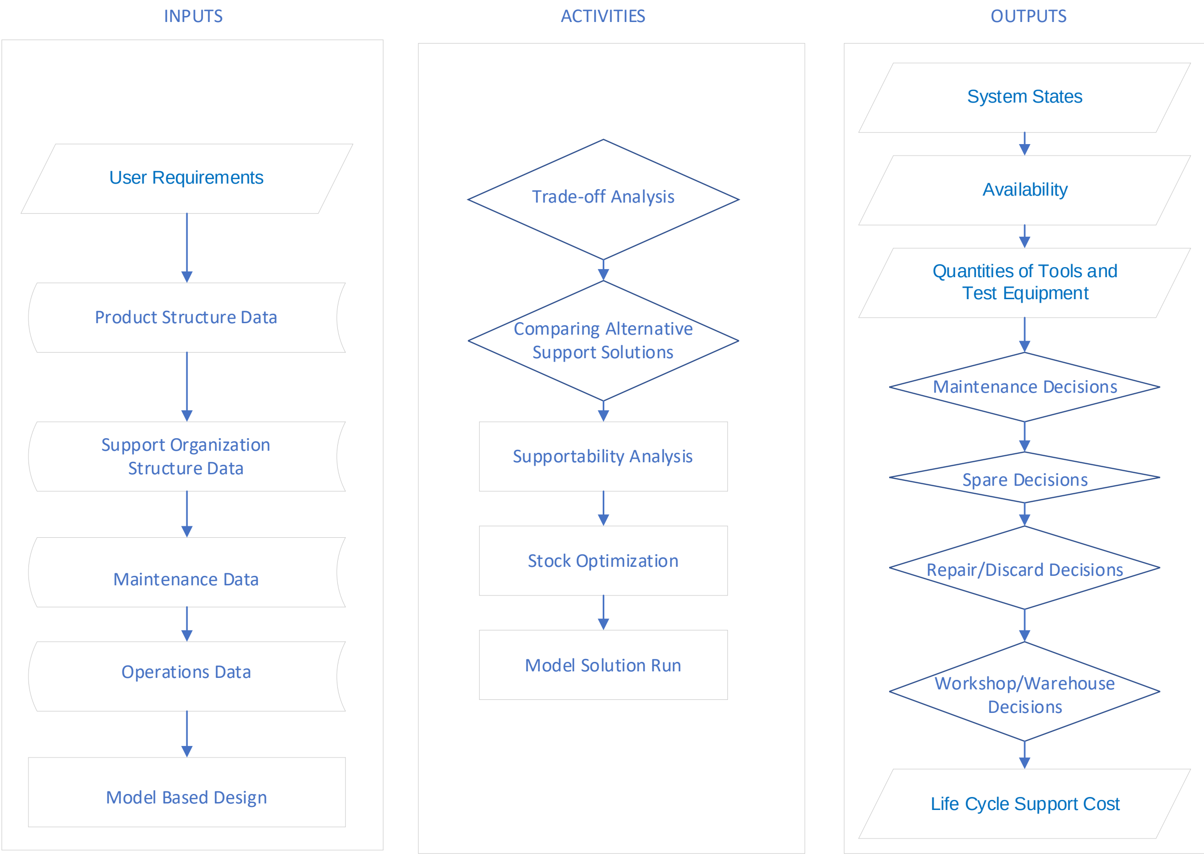

Figure 1. Analysis Process

These processes are critical for maximizing the efficiency and operational availability of the system.

Main steps in data collection and analysis are gathering historical data on maintenance schedules, part usage rates, lead times, and failure rates for each aircraft model and then analysing demand patterns for spare parts to identify high-usage items and critical components. Four main types of data used in supportability modelling analysis for generic fighter jet products are; product structure data, support organization structure data, maintenance data, and operations data.

In inventory classification stage authors categorized engine spare parts based on criticality and usage frequency using an ABC analysis to be able to idenfty the most cost-effective strategies for inventory management.
In this classification A items are; high-value parts with critical usage (e.g., engines, avionics), B items are; moderate-value parts with regular usage (e.g., landing gear components), and C items are low-value parts with occasional usage (e.g., cabin fittings).

3. Analyses and Results

The optimization model developed using linear programming to determine optimal stock levels for each part at each depot considers factors such as:

- Part demand and variability,
- Lead times for replenishment,
- Holding costs and stockout costs,
- Logistics service level operational availability targets (e.g.,90% availability).

Information has been provided regarding the analysis data and calculation methods obtained using OPUS Suite software for the engine producer-company.

The Availability analysis studies started with the identification of the main product (Aircraft) to which the engine system is connected. Then, a detailed description of the product variant was defined.

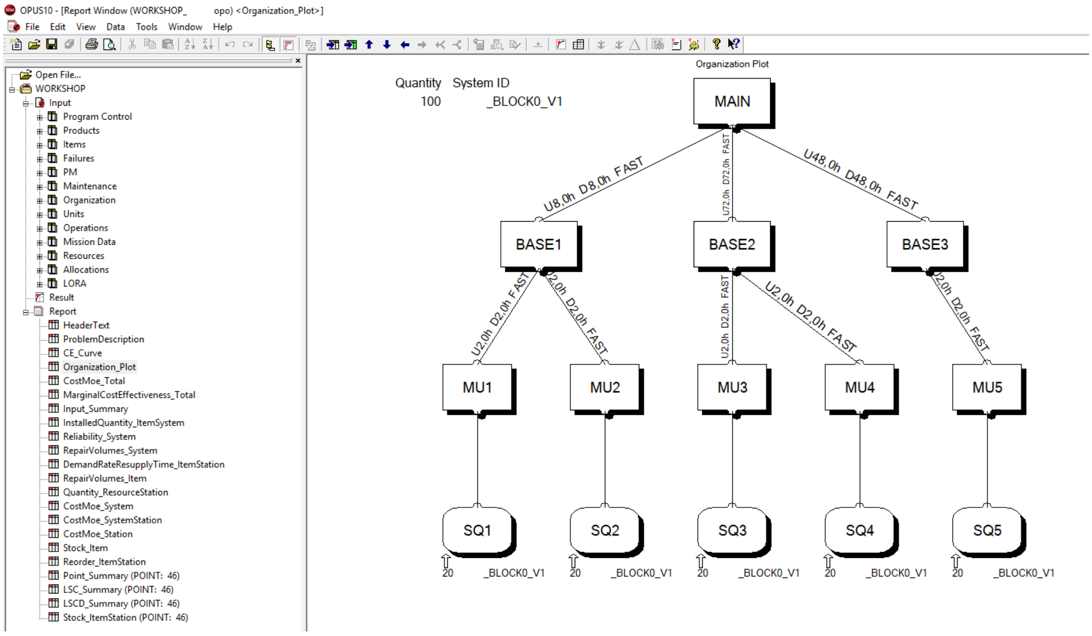

Figure 2. Depot level for a generic fighter jet

First, the number of material items for the engine was determined. The maintenance configuration for the identified 3545 items was created, and catalogue data (NSN, P/N, Price) were reviewed from PUBLOG records. Current price data could not be obtained for 237 items. Subsequently, commercial firms were contacted, and price information was obtained for 2 surplus items. For the remaining 235 items, catalogue data were examined, and the average prices of equivalent items were taken to complete the price data.

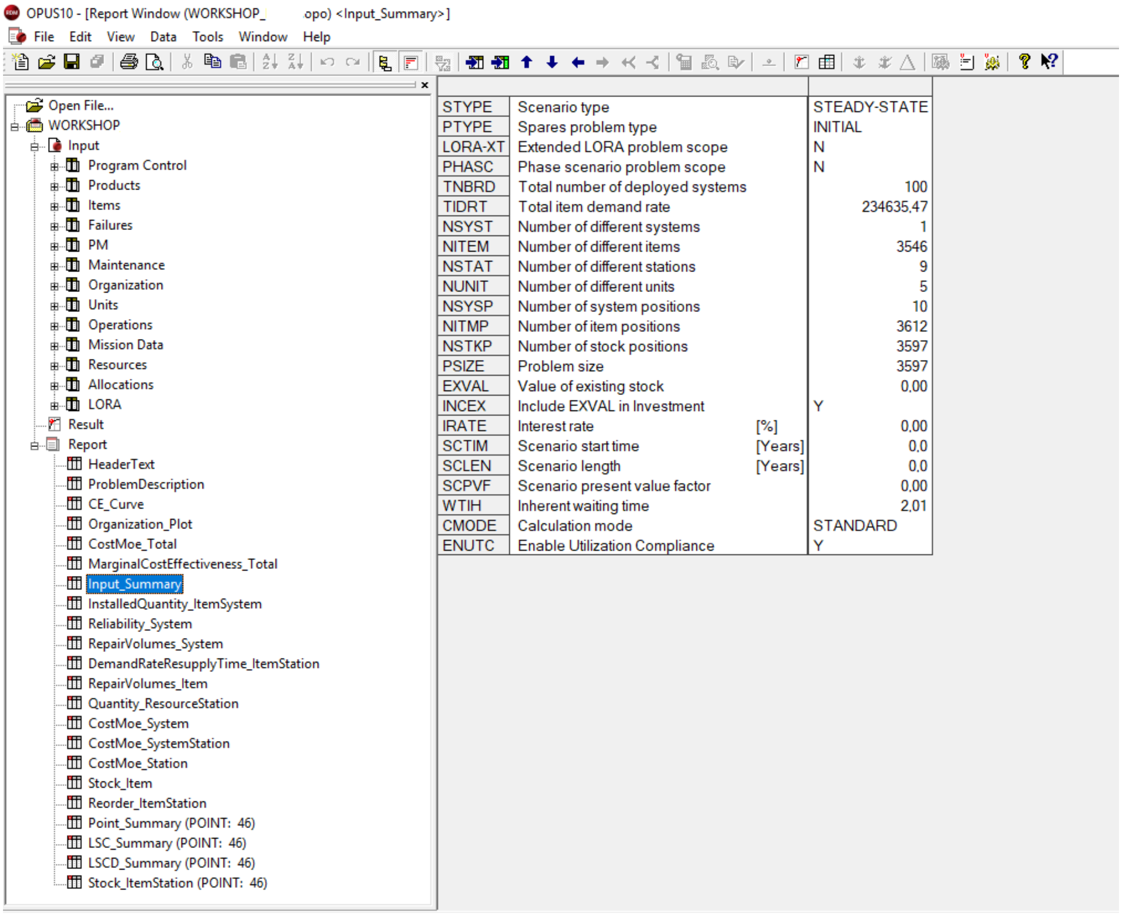

Figure 3. Scenario details for a generic fighter jet

Engine producer provided Inherent Failure Rates (IFRs) for 1491 of the 3545 items in the engine system. Additionally, IFRs for 121 items used in different regions of the engine and having the same P/N but without provided IFRs were determined by taking the arithmetic averages of the IFRs of items with the same P/N given by engine producer. The IFRs for the remaining 1906 items were determined using the "Equal Apportionment Technique" [8].

The repairability/consumability statuses of all items were determined from catalogue data and included in the configuration. Additionally, the LRU and SRU statuses and repair levels of the items were identified from the manufacturer and field data and loaded into the system. Removal and installation times for repairable items were determined by analysing field data.

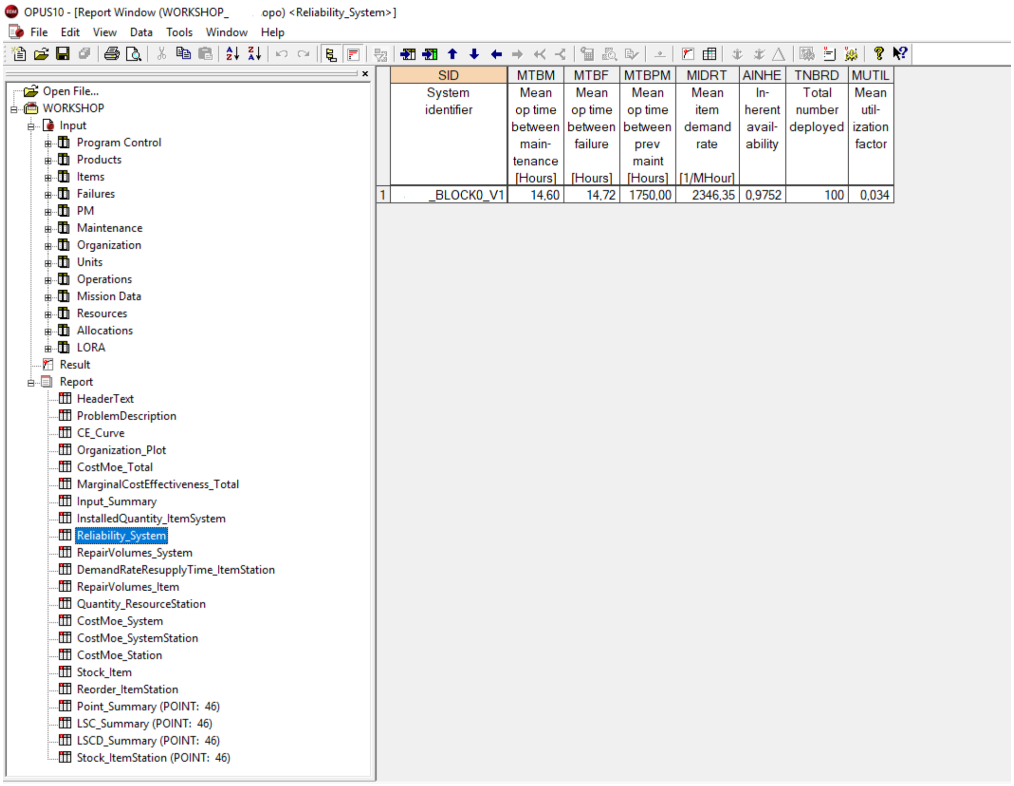

Figure 4. Reliability system for a generic fighter jet

Synthetic data were created by calculating the average time for items whose removal and installation times could not be determined. Moreover, repair times for repairable items were coordinated with relevant centres, and repair cycles (Turnaround time) were defined as 45/60/90 days.

Simulations are run to test the model under various scenarios, including demand fluctuations and supply chain disruptions. Sensitivity analysis is conducted to understand the impact of changes in key parameters (e.g., lead time variability, service level targets) on stock levels and costs. By following this roadmap, authors systematically determined the optimum stock levels for jet engine components, ensuring the required operational availability while minimizing costs.

According to the model results the required 0,90 availability threshold is achieved at 31786572 USD estimated life cycle cost point. The optimum point can be seen at the following "Figure. 5 Availability vs cost for a generic fighter engine".

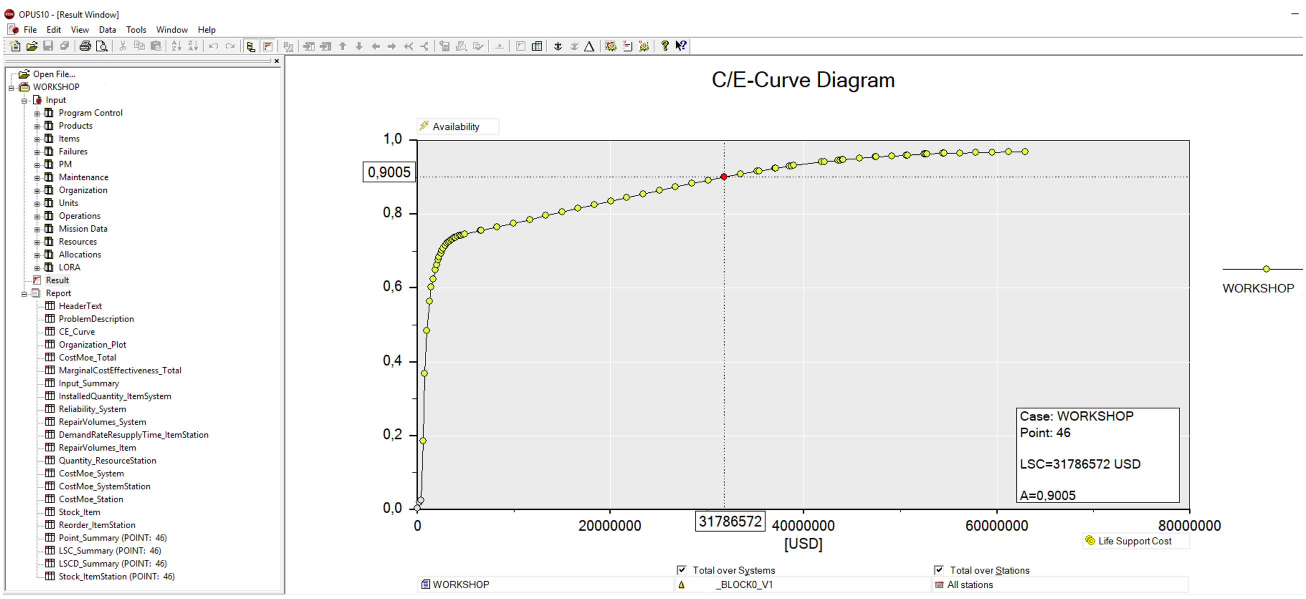

Figure 5. Availability vs cost for a generic fighter engine

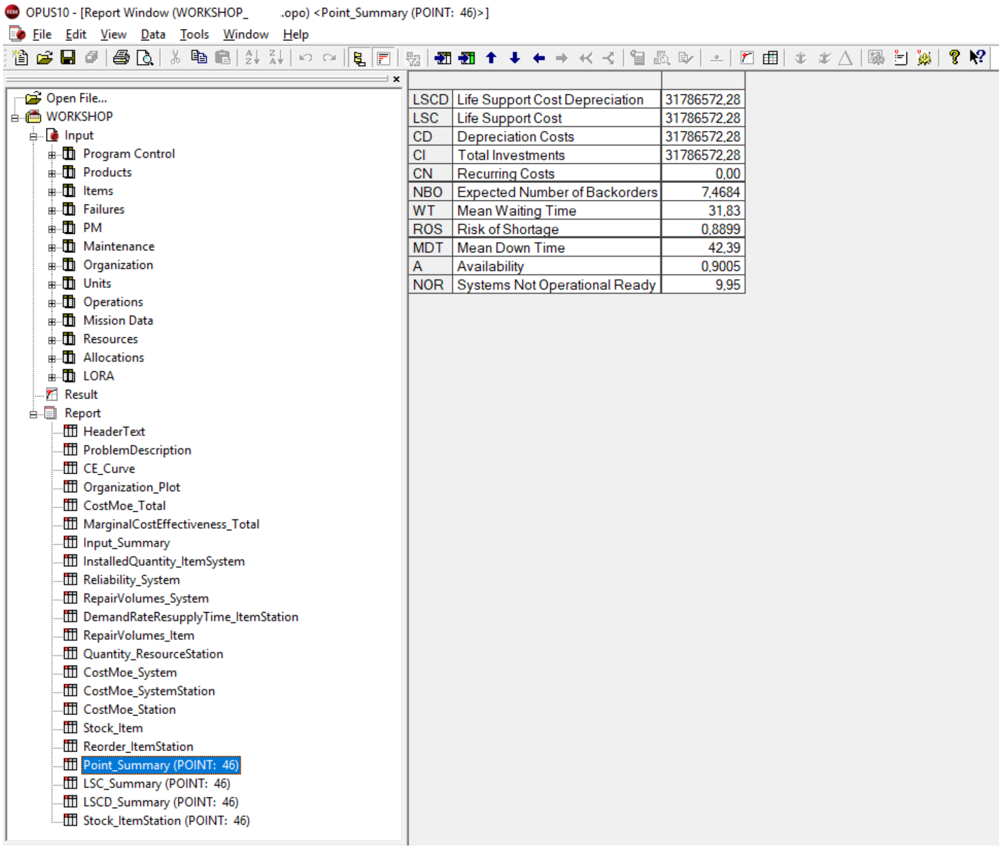

Figure 6. Point summary for the optimum alternative

The optimization model recommends different stock levels for each depot based on the demand patterns and criticality of parts. Implementing the optimized stock levels results in significant cost savings, primarily from reduced holding costs and minimized stockouts. The airline achieves an estimated 15% reduction in overall inventory costs while maintaining high service levels. Aircraft availability improves due to the timely availability of critical spare parts. The optimized inventory system reduces the average downtime per aircraft by 10%, enhancing operational efficiency.

4. Discussion, Conclusion and Future Recommendations

Optimization and efficiency are interdependent concepts that play a critical role in improving performance and resource utilization across various domains. By leveraging optimization techniques, organizations can enhance efficiency, reduce costs, and promote sustainable practices. However, achieving optimal efficiency requires a balanced approach that considers the broader implications of optimization efforts. As the global landscape continues to evolve, the relationship between optimization and efficiency will remain vital for addressing complex challenges and driving progress in diverse fields.

Optimizing depot levels and stock levels for aircraft maintenance is essential for maintaining high operational efficiency and reducing costs in the aviation industry. By leveraging historical data, advanced analytics, and optimization models, the airline successfully balances the availability of spare parts with inventory costs. The case study demonstrates the importance of a strategic approach to inventory management, ensuring that aircraft are ready for operation with minimal downtime and optimized resource utilization.

Calculating the costs that will arise from the design phase to the end of the life cycle of any product will guide the selection of the most cost-effective (cost vs generic fighter jet aircraft operational availability) alternative. It is important to analyse and optimize costs by considering the entire life cycle.

In this study, an engine case study was examined and it was concluded that the optimization of a complex system can be achieved through a system of systems analysis. When analyses are evaluated and combined on the complex system from a holistic perspective, the optimal result is obtained. This optimization includes stock-levels, depot levels, transportation, supply and maintenance plan, leading us to the optimal cost outcome.

While optimization and efficiency are closely related, achieving both can present challenges. Optimization often involves complex mathematical modelling and data analysis, requiring specialized knowledge and skills. Additionally, the pursuit of efficiency must be balanced with other considerations, such as quality, safety, and sustainability. In some cases, optimizing for efficiency in one area may lead to inefficiencies in another optimizing production processes to reduce costs may result in lower product quality or increased environmental impact. Therefore, a holistic approach is necessary to ensure that optimization efforts lead to overall efficiency without compromising other important factors.

Continuous Monitoring and Adjustment is needed to regularly review and adjust stock levels based on changing demand patterns and operational needs. Implement real-time monitoring systems to track part usage and inventory levels dynamically. Integrate the inventory management system with predictive maintenance tools to forecast part failures and maintenance needs accurately. Use machine learning algorithms to enhance demand forecasting and optimize stock levels further. Strengthen collaboration with suppliers to ensure reliable and timely replenishment of spare parts. Explore vendor-managed inventory (VMI) programs to offload some inventory management responsibilities to suppliers, reducing holding costs.

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