

**COMPONENT INVENTORY PLANNING MODEL IN AIRCRAFT
MAINTENANCE, REPAIR AND OVERHAUL COMPANY AND A CASE
STUDY**
(UÇAK BAKIM, TAMİR VE REVİZYON FİRMASINDA KOMPONENT
ENVANTER PLANLAMA MODELİ VE BİR VAKA ÇALIŞMASI)

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Hatice Beyza ÖZKAN, B.S.

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LIST OF SYMBOLS

MRO	:Maintenance, Repair and Overhaul
AOG	:Aircraft on Ground
A/C	:Aircraft
MTBUR	:Mean Time Between Un-Schedule Removals.
QTY	:Quantity
TAT	:Turnaround time.
EASA	:European Aviation Safety Agency
FAA	:Federal Aviation Administration
ICAO	:International Civil Aviation Organization
MIP	:Mixed-Integer Programming

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ABSTRACT

Aviation is a complicated system comprised of several interconnected operations. Aircraft maintenance is the most significant and vital component of this system. Aircraft Maintenance is an expensive process that must be repeated at regular intervals. Using the aircraft for purpose without maintenance is not possible. Maintenance, Repair and Overhaul Organizations (MROs) must implement improvements and innovations to complement scheduled aircraft maintenance to satisfy the airline's demands and expectations. The airline company claims to keep the aircraft in the air all the time and this shows the importance of periodic maintenance in aircraft maintenance. Small improvements in cost, uniform distribution of flight load among aircraft, delays or any other issue result in crucial gains in the aviation industry.

MRO of aircraft is a highly competitive and expensive sector. To promote the MRO industry's competitiveness, the supply chain and resource management of these companies must be efficient. In terms of safety, efficiency, cost and quality, there is of paramount significance to airlines. Due to the incapacity of an airplane to serve as a result of a malfunction, factors such as aircraft delay, economic and criminal consequences, loss of customer reputation and security are incurred. Such examples illustrate the significance of supply management for MRO firms.

In order to reduce expenses in the event of a loss, firms that perform aircraft maintenance, repair and overhaul organizations require spare inventories. To be prepared for demand variations, unanticipated occurrences and uncertainties, sufficient supply of replacement components are vital. A, B, C and D maintenance types are described in the document for components that must be replaced on aircraft requiring maintenance. When the components requested to be changed during maintenance are not at the designated area, deferred maintenance might incur substantial expenses and penalties.

Once the aircraft arrives at the hangar for maintenance, the company locates the component on time and accounts for the associated costs is crucial. The cost of the component, the ordering cost of the component, transfer cost and the cost of holding the component are essential to the company's continued existence. In order not to delay the maintenance of the aircraft, AOG (Aircraft-on-ground) operation is performed in case of missing or damaged components written on the maintenance card. Even if AOG ordering creates a high cost, the relevant component should be purchased as AOG. This situation creates a great burden on the organization. Purchasing the component on time in accordance with aircraft maintenance plans and storing the essential components in the company's warehouses within a range of risks and opportunities will result in reduced purchasing and inventory costs.

The objective of the study is to minimize inventory costs for components to be ordered in accordance with aircraft plans. At 3 distinct MRO Organization locations, the start and end dates of the aircraft's periodic maintenance have been identified. In these locations, which airplane components have been ordered in accordance with their 12-month plans are known. As a consequence of this data, a model has been developed to reduce the holding cost, transfer cost and ordering cost that comprise the inventory cost and the MIP server of GAMS software is used to determine the optimal solution. As a result of this model, component order information was examined for the 3 locations. According to the aircraft maintenance planning, instead of ordering separately for the component to be used when the aircraft maintenance interval comes, the conclusion is that an order was created together in advance. In this way, it will be possible to avoid high ordering costs.

ÖZET

Havacılık, birbirine bağılı operasyonlardan oluşan karmaşık bir sistemdir. Uçak bakımı bu sistemin en önemli ve hayati parçasıdır. Uçak Bakımı, düzenli aralıklarla tekrarlanması gereken maliyetli bir işlemdir. Bakım yapılmadan uçağın kullanılması mümkün değildir. Bakım, Onarım ve Revizyon Kuruluşları (MRO), havayolunun talep ve beklentilerini karşılamak için planlı uçak bakımını tamamlamak için iyileştirmeler ve yenilikler yapılmalıdır. Havayolu şirketinin uçağı sürekli uçuş halinde kullanabilmesi, uçak bakımında periyodik bakımın önemini göstermektedir. Maliyetteki küçük iyileştirmeler, uçuş yükünün uçaklar arasında düzenli dağılımı, gecikmelerin azaltılması gibi havacılık endüstrisinde önemli kazanımlar sağlar.

Uçak bakım, onarım ve revizyon endüstrisi, oldukça rekabetçi ve maliyetli bir endüstridir. MRO işinin rekabet gücünü artırmak için bu firmaların tedarik zinciri ve kaynak yönetimi verimli olmalıdır. Emniyet, verimlilik, maliyet ve kalite havayolları açısından büyük önem taşımaktadır. Arıza sonucu uçağın hizmet veremeyecek durumda olması nedeniyle uçağın gecikmesi, ekonomik ve cezai sonuçları, müşteri itibarı ve güvenliği kaybı gibi sonuçlar doğurabilmektedir. Bu gibi örnekler, MRO firmaları için tedarik yönetiminin önemini göstermektedir.

Uçak bakım, onarım ve revizyon organizasyonlarını gerçekleştiren firmalar, bir arıza durumunda maliyetleri azaltmak için yedek stoklara ihtiyaç duyarlar. Talep değişimlerine, beklenmeyen olaylara ve belirsizliklere hazırlıklı olmak için, yeterli yedek parça temini büyük önem taşımaktadır. A, B, C ve D bakım türleri, bakım gerektiren uçaklarda değiştirilmesi gereken komponentler için dokümanda açıklanmıştır. Bakım sırasında değiştirilmesi talep edilen komponentler belirlenen alanda olmadığında, ertelenmiş bakım önemli masraflara ve cezalara neden olabilir.

Komponentin fiyatı, komponentin sipariş edilme maliyeti, transfer maliyeti ve depolama maliyeti gibi maliyetlerde firmanın sürekliliğini koruyabilmesi açısından çok büyük önem oluşturmaktadır. Uçağın bakım için geldiği hangarda bakım kartında yazan komponentin olmaması, hasarlanması gibi karşılaşılan durumlarda, uçağın bakımının gecikmemesi amacıyla AOG (Aircraft-on-ground) olarak ilgili komponentin yüksek maliyet oluştursa bile satın alınması gerekmektedir. Bu durum organizasyon üzerinde büyük bir yük oluşturmaktadır. Uçak bakım planlarına göre komponentin zamanında satın alınması ve bazı risk ve ihtimaller dahilinde ilgili komponentlerin firmanın depolarında bulundurulması düşük satın alma ve stok maliyetleri oluşturacaktır.

Çalışmada uçak planlarına göre sipariş edilecek komponentlerin stok maliyetlerinin düşürülmesi amaçlanmaktadır. 3 ayrı MRO Organizasyon tesisinde, uçağın periyodik bakımlarının başlangıç ve bitiş tarihleri belirlenmiştir. Bu lokasyonlarda hangi uçak komponentlerinin 12 aylık planlarına göre sipariş edileceği bilinmektedir. Bu bilgiler sonucunda stok maliyetini oluşturan elde tutma maliyeti, transfer maliyeti ve sipariş maliyetlerinin minimize edilmesi için bir model oluşturulmuş ve GAMS yazılımının MIP sunucusu kullanılarak optimum bir çözüm sağlanmıştır. Bu model sonucunda 3 lokasyon için komponent sipariş bilgileri incelenmiştir. Uçak bakım planlamasına göre, uçak bakım zamanı geldiğinde kullanılacak komponent için ayrı ayrı sipariş vermek yerine, önceden birlikte bir sipariş oluşturulduğu sonucuna varılmaktadır. Bu sayede yüksek sipariş maliyetlerinden kaçınmak mümkün olabilecektir.

1. INTRODUCTION

Inventory has been considered as a valuable asset for many years and some businesses do not place a high priority on inventory management difficulties. Inventory is a tough asset to manage and may be found in extremely complicated supply networks, particularly in industrial organizations. With the addition of demand, production and supply planning, sales points and supplier relationships to the supply triangle, the system's stock tends to shrink. Maintaining inventory in the proper location and at the proper time is a crucial aspect of supply chain operations.

Every year, the aircraft and component repair sector becomes increasingly competitive. To service as many clients as possible; MRO organizations must make the most effective use of maintenance planning and direct elements such as materials, machinery, manpower and environment. The maintenance process is directly influenced by the use of personnel capacity, material and component planning, TAT and aircraft delivery dates. Because the air transportation industry is time-sensitive, airlines require the ability to reduce aircraft and component maintenance timelines. Maintenance and Repair Organizations (MROs) must develop extremely successfully to fulfill airline demand.

MRO of Aircraft in order to prosper in the present business climate, companies strive to maintain a high level of profitability. To remain competitive on the market, organizations must earn a profit at the stated price point. To do this, costs must be kept to a minimum. In light of this, businesses of all sizes should efficiently manage their orders. Effective order management systems allow for the avoidance of missing and excess component orders, as well as the achievement of customer satisfaction. Since a scarcity of components at the correct time and place results in a loss of clients and income and an excess of inventory raises expenditures, inventory management is crucial. Therefore, effective order management has a direct impact on the long-term performance of enterprises.

Component needs in the aviation maintenance industry, as described in the thesis, place a premium on order management in order to preserve their position in the extensive supply chain network. The corporation acquires components from international sources. The company provides airplane maintenance for domestic and international airlines. The planning of aircraft is set over the long period. During this time, incoming aircraft arrive at the hangar and their maintenance is done. According to the aircraft's maintenance plans, how many orders should be placed with which components would be required is determined. On the other hand, expenses should be also included associated with maintaining inventory, making an order and purchasing once the item has been shipped. Delays may arise if the applicable aircraft MRO firm receives its component orders extremely slowly. The end-of-year reviews revealed that the cost of the inventory exceeded the budgeted amount. Therefore, the organization was sought a fresh approach.

According to aviation maintenance plans; Aircraft MRO requests to acquire components for the appropriate aircraft. In this study, The orders for components was determined how inventory costs, including holding cost, transfer cost and ordering cost, might be decreased with respect to the components to be acquired. In this thesis, the mathematical modeling, application and assessment of this problem's outcomes will be conducted.

A component inventory minimization problem is taken in hand based on a real-life problem of MRO company. The thesis is organized in different chapters. Firstly, Chapter 1 presents an introduction of the problem and gives an idea of thesis. Chapter 2 contains literature review of Aviation, MRO, Supply Chain, Inventory Management and Logistics studies.

In Chapter 3, detailed information about the aviation industry is presented. There is information about how Aircraft Maintenance is separated and how the maintenance is done. An Aircraft MRO company is explained and component purchasing planning, storage and transfers between locations are mentioned. Proposed mathematical model is provided in Chapter 4. MIP model is developed for the problem. The brief information is provided about the model's assumptions. Then details of the model is given such as parameters, sets and decision variables. Besides, objective function and all constraints are explained in Chapter 4.

The inventory cost minimization problem is addressed to actual aircraft MRO firm data in Chapter 5. According to the aircraft maintenance plans for 2022-2023, 12-month component orders for SAW, ISL and ESB locations were evaluated. The holding cost, transfer cost and ordering cost are displayed and included into the model.

In Chapter 6, the proposed model's outcomes are analyzed and evaluated. Finally, the thesis's conclusion is explored. Chapter 7 presents the contribution of this thesis and future research prospects.



2. LITERATURE REVIEW

Aviation studies, Maintenance, Repair and Overhaul studies, Supply Chain studies, Inventory Management studies and Logistics studies pertain to aircraft MRO as well as component management in relation to aircraft maintenance planning.

2.1 Aviation

The term Aviation is a notion that has been around for a long time. The concept involves dealing with the design or maintenance of components essential to fly or operate aircraft. Some of the research carried out in the realm of aviation are as follows:

Godfrey, Hellings and Knutsen (2004) offer a distributed optimization technique that employs software agents that reflect the needs of both military and commercial carriers in order to manage a commercial aircraft-based airlift. By auctioning jobs with a reserve price and allowing Carriers to transfer assignments when mutually advantageous, this system reduced regulated operating expenses and program interruption costs by more than fifty percent compared to a centralized assignment approach.

Yang and Yang (2012) explore the aviation maintenance plan process and develop the Aircraft Maintenance optimization model with a cost-minimization objective function. The model is constructed using a Genetic Algorithm.

Kim, Mitchell, Polishchuk, Yang and Zou (2012) offer approximation techniques for multi-criteria optimization issues arising from attempting to maximise the amount of routable pathways. The study describes experimental findings obtained by applying the algorithms to weather-affected airfields, comparing heuristics to find acceptable route sequences and calculating short multi-class routes.

Jiang, Liao and Zhang (2013) construct a scheduling optimization model by including the priority of planes under collaborative decision making and then establish a genetic algorithm to simulate the scheduling model's performance. The optimization results reveal that both the model's dependability and the improved genetic algorithm are highly effective. Taking into consideration all aspects of taxi scheduling, this article specifies the minimum overall taxi time as the target of optimization. Consideration is given to the basic safety distinction, as well as the airplane prioritizing and taxiway queuing approach.

This article by Tracht, Niestegge and Schuh (2013) investigates the challenges created by the closed-loop supply model for MRO services. Since the effectiveness of the resources supply chain is strongly dependent on planning the quantity of materials in stock, the holistic approach takes the planning process into account.

Li and Tan (2013) investigate the Fleet Assignment Problem in airlines to automate aircraft planning and scheduling. Proposed is an optimization model for the Fleet Assignment Problem that maximizes overall revenue and allocates the best appropriate type of aircraft to each flight. To handle the challenging optimization problem, an improved genetic algorithm that can rapidly locate the optimal solution is proposed.

Yu, Hailian, Shuai and Xiongqing (2014) offer a measurement parameter for comparing the greenhouse impact created by emissions from several types of civil jets in order to improve the aircraft emission estimation technique during the conceptual design phase. Then, five geometrical parameters of the wing configuration and two flight operational parameters are utilized to do an approximate comprehensive analysis and multi-objective optimization of the aircraft design in order to minimize the greenhouse effect and the direct operating cost.

Li, Zuo, Lei, Liang and Lu (2015) show that grouping maintenance tasks into project tasks is not just necessary for expediting maintenance operations. Also essential is the decrease in maintenance costs. In this research, an improved fuzzy C-means clustering model is created to optimize the combination of the fuzzy C-means clustering approach and maintenance responsibilities. To reduce the size of the upgraded cluster model, variables denoting clustering centers have been removed.

Bao and Hua (2017) intend to decrease the amount of flights and congestion at major airports. The article presents a strategy for various airport systems to optimize flight duration and frequency. To reduce passenger journey time loss, an optimization model for flight time and frequency has been developed for multi-airport system operation. This is the first paper to examine the flight duration and frequencies optimization problem for a multi-airport system.

In this research, a relatively basic application of the whole quality maintenance concept is offered as part of the aviation accident investigation process while creating a problem-solving statements in the day-to-day maintenance operations of a jet fighter. This application is based on Makrygianni's (2018) total quality maintenance concept. This research outlines how aviation engineers evaluate performance while evaluating the inflation pressure of the aircraft's primary tires prior to flight.

Chen, Huang and Yi (2019) provide a domestically applicable approach for evaluating the cost of general aviation aircraft. A comparison was done between linear regression analysis and BP neural network technology to find the most promising parametric model, taking into consideration the challenges and costs of gathering data for general aviation aircraft and the real state of long-term, small samples.

In their paper; Wei, Sun, Wu and Jing (2020) provide an unique multi-objective mixed integer linear programming model for aircraft arrival and departure schedules in order to demonstrate the optimal relationship between flight delays and runway utilization. Multiple modes of operation and flight overlaps between adjacent runways are integrated into the design. This study seeks to identify the optimal relationship between traffic circumstances, operating mode of each runway and flight planning in order to minimize simultaneous flight delays and maximize runway utilization.

Xie, Jiang, He, Chen and Mao (2020) present a formal model to demonstrate the restricted flow characteristics of flight process guidance systems based on finite-capacity Petri nets. The major purpose is to avoid too crowded locations and reduce public transportation resource usage. Based on the inputs and outputs of each airport terminal, the proposed method produces a relational expression. This work also explicitly models the finite flow

structures of flight process guidance systems with finite capacity Petri nets and then confirms the accuracy of the recommended associative expression.

Wei, Zhao, Ye and Jing (2020) present a comprehensive optimization framework for multiple aircraft types that illustrates the relationship between the spatial or temporal distribution of flight services, the number of aircraft initially deployed at the major airports, the flight schedule and the scheduling plan.

Scala, Mota, Wu and Delahaye (2021) present an algorithmic architecture for handling the airport capacity management problem concurrently with any scheduling problem, taking operational uncertainty into consideration, whereby the simulation component is embedded within an optimization framework. The topic of airport capacity management concentrated on modifying the aircraft landing schedule in the terminal airspace and reducing the possibility of aircraft movement collisions and airport congestion. The findings of this study indicate that the proposed computational framework can greatly reduce airplane crashes by altering several key aspects.

Kowalski, Izdebski, Zak, Golda and Manerowski (2021) build a technology to facilitate aircraft maintenance planning and administration. The intricacy of the investigated subject is highlighted by the multi-criteria approach of the supplied mathematical model. In this article, an optimization tool for aircraft maintenance planning and management is developed using a genetic algorithm and a mathematical model.

Pacaiova, Korba, Hovanec, Galanda, Svab and Lukac (2021) present a strategy for enhancing maintenance operations with simulation tools. It is determined which features are necessary for the optimization's implementation. The article describes a method for handling one of the most common winter maintenance issues at airports. Using data from an international airport, the simulation model identifies maintenance operations hotspots for optimization purposes. The result of the applied study is the identification of the next critical points in the simulation that may represent essential winter maintenance activities and have an impact on their optimization.

2.2 Maintenance, Repair and Overhaul

With the introduction of aircraft, MRO concepts emerged. Numerous studies on MRO have been undertaken and examined from different perspectives. The following studies investigate Maintenance, Repair and Rebuilding:

Li, Zuo, Lei, Liang and Lu (2015) demonstrate that integrating maintenance tasks is crucial not only for simplifying maintenance activities but also for reducing maintenance costs. This research creates and recommends a fuzzy C-means clustering model in order to optimize the integration of fuzzy C-means clustering algorithm and maintenance responsibilities.

Beker, Kesic, Radlovacki, Delic, Sevic and Moraca (2017) establish a method for evaluating the effectiveness of maintenance operations in organizations charged with maintaining systems needing a high level of dependability; a method that is transferable to different organizations with minor modifications. Goncharenko (2017) later gives the theoretical explanation and structure of a variety of mathematical models of the aircraft operating process, with reference to the maintenance organizations chosen by aviation specialists and aircraft operators.

Goncharenko (2018) extends on previous research about the theoretical explanation of the aircraft operating process in relation to maintenance organization decisions made by specialists and aircraft operators and examines mathematical models generated.

Lin and Luo (2018) present a multi-objective decision-making approach based on condition-based maintenance that prioritizes the aforementioned two objectives: minimizing cost and maximizing fleet availability.

This work extends a bionic global random search algorithm - bacterial foraging optimization approach proposed by Cui (2018), who advises utilizing the planned repair of aviation equipment as a prototype, to evaluate the task-scheduling problem. This approach for optimizing bacterial foraging is useful to the optimization planning system for scheduled aircraft equipment repair.

Noruzoliaee and Zou (2019) provide a facility-specific modeling approach for planning runway pavement maintenance and rehabilitation (M&R) activities. The objective of the modeling technique is to decrease system M&R expenses while recommending M&R operations for each runway coating facility over a predetermined time period. The 97.6% similarity provided the case company confidence in its efficacy and validity and it is considering applying this plan to improve its spare parts inventory strategy in the future.

Block, Ahmadi, Xiao and Kumar (2019) present repairable units and a computational model for identifying realistic alternatives for repair termination timings that would minimize the quantity of remaining spares at the conclusion of the downtime while minimizing the availability of spare parts required during the PBSP (Part-out-based Spares Provisioning) period. An examination of the cooling turbine systems of the Saab-105 Fleet verifies the recommended design.

Rahim, Noor, Abdullah and Annanurov (2020) plan to identify the existing issue influencing the operational availability of the aircraft fleet, create an optimization model for cost reduction of spare parts and assess the impact on spare parts availability using the cost minimization optimization model by employing Goal Programming (GP) and Linear Integer Programming (LIP).

Öhman, Hiltunen, Virtanen and Holmstrom (2020) propose a novel implementation plan for periodically re scheduling in aircraft line maintenance and offer theoretical data on buffer management for operations. The example airline's field target was to boost departure constancy for long-haul aircraft without enlarging maintenance resources and employing spare aircraft.

Karabağ, Eruğuz and Basten (2020) offer a repair and spare part selection option for a multicomponent system with partially visible components. Components degrade according to the discrete-time discrete-state-space Markov chain. There is just one sensor on the system and it does not indicate the condition of each component; rather, the system indicates whether or not it is malfunctioning. The service provider must extract the whole condition of the system from the current status signal and historical data to determine when to visit the customer for maintenance and which replacement components to bring.

Bounou, Barkany and Biyaali (2020) offer a model for the integrated management of maintenance and spare parts using stochastic-deterministic collective Petri networks. This concept is investigated by simulation using a graphical system specific to the questioned graphical tool. The model's analytic inquiry involves determining the performance measures and examining the effect of system factors on these metrics.

Gitardi, Giardini and Valente (2021) provide a mobile robotic system that is able to maintain an open reaction to crucial MRO obstacles when ascending vertical surfaces and operating in a tough environment while completing building inspection and repair tasks.

2.3 Supply Chain

There are many studies in many different fields related to Supply Chain. Aircraft, which is the study area of the thesis and studies on MRO organizations were examined. Some of the related studies are as follows:

Downing, Chipulu, Ojiako and Kaparis (2011) intend to employ systems-based forecasting to evaluate the stocking and prediction systems utilized to support the maintenance program. Later then, Tracht, Hagen and Schneider (2013) describe a spare parts inventory planning technique for spare parts procurement in the aerospace sector that estimates the most cost-effective stock levels for warehouses in a multiple supply chain and accounts for numerous input and output planning characteristics such as budget and inventory level constraints.

Silva, Saalman, Cordes, Giacomolli, Pereira and Hellingrath (2014) address integration issues by offering an architecture for integrating IMS devices and APS planning components, beginning with modelling domains, investigating the influence variables and components from Intelligent Maintenance Systems (IMS) and (Algebraic Programming System) APS have on one another and developing an architectural concept for integrating.

Banyai, Veres and Illes (2015) discuss networked maintenance companies and related purchasing methods. To formulate the issue of establishing the optimal make-or-buy decision for the production of complex spare parts, a Heuristic Supply Chain

Optimization Model is created. Gu, Zhang and Li (2015) subsequently provide two nonlinear programming models that estimate future demand based on the failure distribution of preset components. This strategy takes into consideration future data, unlike the commonly used reorder point system (ROP) and prediction systems that just assess previous data.

Hellingrath, Pereira, Espindola, Frazzon, Cordes, Saalman and Zuccolotto (2015) propose a strategy for improving the effectiveness and efficiency of spare parts supply chain management for integrated production systems. Then, Driessen, Arts, Houtum, Ruitenburg and Huisman (2015) propose a framework for the management and planning of the spare parts supply chain in businesses that consume and maintain high-value capital assets.

Thomas, Mason-Jones, Davies and John (2015) propose outlining the application of a Six Sigma (SS) methodology in aviation maintenance, repair and overhaul (MRO) operations in order to reduce supply chain risk. In this article, the LSS method is used to provide a reduction in turnaround time (TRT) variation for diagnostic units (DUs) and to evaluate the economic impact of selecting the most suitable maintenance plan for aviation imaging equipment (DUs).

The objective of Frazzon, Silva and Pires's (2016) simulation model is to evaluate the performance improvements brought about by the combination of intelligent maintenance technologies and spare parts supply chain. Then, Saalman, Wagner and Hellingrath (2016) provide decision support for the structure of an IMS-enabled spare component supply chain. The system outlines how to build a collaborative strategic planning method to plan the maintenance capacity of the key actors based on forecasted information supplied by an Intelligent Maintenance System (IMS).

Israel, Albrecht, Frazzon and Hellingrath (2017) incorporate Intelligent Management System data into the spare parts supply chain planning process. Li, Liu, Shen and Cheng (2017) provide a stochastic programming method for MRO spare parts supply chain planning.

Bozoudis, Lappas and Kottas (2018) present the development and deployment of a maintenance planning optimization tool for aircraft components. Consequently, the outcomes of applying the technology may be used to enhance the risk planning process for new system failures, resulting in an improvement in fleet operational uptime, by providing accurate estimations to optimize the supply chain of the system's end user.

Martinod, Bistorin, Castaneda and Rezg (2019) intend to create a stochastic optimization model for merging service and maintenance policies to address the queuing problem and cost of maintenance tasks for public transportation system, with a focus on urban ropeway systems. Subsequently, Miranda, Tapia-Ubeda, Hernandez, Cardenas and Lopez-Campos (2019) want to build a simulation-based modeling approach to aid the decision-making process regarding the Spare Parts Supply Chain, a critical support system for the maintenance operations of industrial systems.

The authors of Knofius, Heijden, Sleptchenko and Zijm (2021) propose purchasing spare parts utilizing a mix of Additive Manufacturing (AM) and Conventional Manufacturing (CM) approaches. In other words, it is possible to choose whether the spare component will be given via AM or CM depending on the conditions. This study satisfies a requirement by introducing the concept of dual sourcing, where AM and CM techniques are used concurrently to meet the need for spare parts. The model now incorporates the dissimilar failure behavior of components from AM and CM supply sources, which effects future demand, a primary storage warehouse and several purchasing warehouses.

Hajej, Nyoungue, Abubakar and Mohamed Ali (2021) examine a combined maintenance, production and material quality control regulation for a supply chain, taking into consideration the influence of production fluctuations and control chart characteristics on the best maintenance program for a single machine producing a single type of product.

Brito, Junior, Frazzon, Basto and Alcala (2021) argue that a design technique based on a mixed-integer linear programming (MILP) optimization model that enables the decision to deploy 3D printers at specific locations within an overall spare parts supply chain operating under a make-to-order strategy leads in an altogether unique supply chain architecture.

2.4 Inventory Management

Inventory Management is a concept applicable to several industries. The notion plays a vital role in the aviation sector in order to decrease aircraft ground time and assure on-time maintenance. The following studies were evaluated in the Aviation and MRO sector:

By integrating a discrete event simulation model with a continuous simulation model and an optimization engine, Alrabghi, Tiwari and Alabdulkarim (2013) provide a policy of preventive maintenance and alternative supply with periodic reviews in a non-identical multi-component manufacturing system. The research reveals that manufacturing dynamics and the availability of manpower have a significant impact on program performance.

Gu, Zhang and Li (2015) provide two mathematical models for the solution of a dual PN spare parts inventory management problem triggered by installed component failures. This study tries to design an inventory policy that minimizes the overall cost of running out of stock and maintaining a spare parts inventory. The models are intended to decrease downtime caused by scarcity of spare parts and unnecessary capital costs by enabling components breakdown distribution and activating advance orders at the right time and amount.

Wang, Zhao, Cheng and Yang (2015) have developed a comprehensive condition-based maintenance (CBM) decision model for single device, continuous and random wearing systems in an effort to simultaneously optimize equipment maintenance and spare part supply chain management. In this model, equipment deterioration is a continuous Gamma process with continuous condition monitoring and spare parts inventory is controlled based on the probability of spare part supply.

Buyukkaramikli, Ooijen and Bertrand (2015) suggest a maintenance service provider (MSP) that may be an autonomous or semi-autonomous unit that offers maintenance services for common key components of bespoke, engineer-to-order systems. A capacity flexibility problem for a maintenance service provider that maintains a workshop and is

accountable for the access to a greater number of specialized systems with a prone-to-failure vital component.

The MRO spare parts supply chain proposed by Li, Liu, Shen and Cheng (2017) is multi-product, multi-layer and multi-period. Taking into consideration random and unclear features of supply chain management planning, this article provides a stochastic programming model blended with multiple choice programming in which the decision maker may describe uncertainties as stochastic processes and interactively generate several options for certain constraint parameters.

In this article, in order to arrange spare parts in advance and to optimize inventory cost ratio and the maintenance, a joint optimization model with scheduling strategy is presented and the corresponding algorithm is constructed and discussed in detail, based on the remaining life estimation initially provided by Cai, Yin, Zhang and Chen (2017).

Teixeira, Lopes and Figueiredo (2017) propose a study to build a multi-criteria categorization for the construction of a stock management strategy for each spare part. The development of a multi-criteria categorization tool will aid the company in making inventory management decisions focuses on numerical and objective data.

Zahedi-Hosseini, Scarf and Syntetos (2018) provide a combined inspection and spare parts inventory approach for the maintenance of machines in a parallel connection where simultaneous downtime has a significant economic impact on production performance. The research employs simulation and numerical optimization methods to examine the optimality of cost for different tactics. Inspection maintenance modeling utilizing the latency concept. Examining the replenishment of important spare components is conducted through many cycles of the periodic review policy. The purpose of Zahedi-Hosseini (2019) is to develop feasible models for planned maintenance and joint optimization of spare parts supply for a variety of industrial designs, including single machine and parallel line production systems.

The purpose of modeling is to eliminate or at least minimize the occurrence of consecutive downtime in such manufacturing systems. Parallel downtime can completely

halt production in both the upstream and downstream processes, significantly affecting profitability and other performance metrics.

Ilgin (2019) provides a unique approach for assessing the criticality of spare components in this work. First, based on a literature review, assessment criteria are created and then their weights are computed using expert analysis and a fuzzy analytical hierarchy procedure (AHP). The loss values for spare components are determined using Taguchi loss functions and simulation modeling. Hwang and Samat (2019) later emphasize the need of co-optimizing maintenance approach with production scheduling (production schedule, batch size and queuing) and spare parts management. On the basis of a study of various studies and publications in this field of research, their relationship and influence on total cost are explored.

To preserve aircraft operating availability and avoid redundant downtime; Nariswari, Bamford and Dehe (2019) propose to develop and assess a practical and precise multi-criteria classification of aviation spare parts inventory management leveraging the Analytical Hierarchy Process (AHP). A large Indonesian firm specialized in aircraft maintenance and repair developed a multi-criteria model for this investigation.

In this paper, the Inventory Transfer Process, which is the focus of the firm, provides the difficulty of the research object. Due to the tendency of businesses to stockpile large quantities of materials, it is impossible for material shortages to hamper maintenance operations. Effective judgements regarding order quantity (Q) and message time (T), resulting in reduced total inventory expenditures without interfering with maintenance activities, are one technique for handling inventory management challenges. ABC classification is employed to determine the material classification that should be stressed and the Mixed Integer Linear Programming (MILP) technique of Kusuma and Hakim (2020) is applied to determine the inventory cost with the lowest total value.

Ali, Salah, Naeem, Khan, Khan, Pruncu, Abas and Khan (2020) provide a method for oil and gas firms to manage production facilities with minimal expenditures for maintenance, repair and practical inventory planning. The goal is to assist exploration and manufacturing companies in minimizing their expenditures on maintenance, repairs and

operating inventory in order to improve manufacturing plant uptime. Maintenance, maintenance and operating inventory is the most expensive asset and requires a significant investment. By executing regular and unscheduled maintenance, this item adds to the efficiency of the facility producing oil and gas.

Conditional maintenance is the most important source of replacement parts for many maintenance organizations. The uneven distribution of maintenance tasks across time is the primary source of lulls in the demand for spare parts, which greatly affects the management of spare parts inventories. We propose utilizing the plan of care, i.e. planned maintenance tasks, as a resource of demand information in prior to mitigate some of these issues. Based on the forecasts offered by Zhu, Jaarveld and Dekker (2020), this research provides a dynamic inventory control strategy for forecasting the demand dispersion for spare parts based on the maintenance program.

Al-Momani, Al Meanazel, Kwaldeh, Alaween, Khasaleh and Qamar (2020) propose building a local, cost-effective, high-quality, dependable and adaptable inventory management system that regulates and improves military aviation inventory. The goal of the new technology is to boost the aircraft fleet's maintainability, reliability and availability at the lowest cost possible, hence improving operating status and readiness.

Open - sourced suite for network-wide manufacturing and inventory holding sites and general independent, multi-period make-to-order supply chain developed by Perez, Hubbs, Li and Grossmann (2021). Within the OR-Gym framework, the research demonstrates novel inventory management problem-solving techniques. Examining and contrasting deterministic linear programming, stochastic linear programming and reinforcement learning inventory management approaches in the context of a four-tier supply network with uncertain steady demand.

Hajej, Nyoungue, Abubakar and Mohamed Ali (2021) provide an entire manufacturing policy, maintenance plan and quality control model that takes into consideration the impact of production variations and control chart elements. The joint optimization forecasting method is based on strategic of production/delivery below a specified service level in order to meet variable demand. The purpose of the optimization model was to

establish the most cost-efficient production and delivery plan, the best design of the control scheme and, therefore, the most appropriate preventive maintenance plan while minimizing the overall cost.

Deng, Shi and Wang (2021) focus on the consistent maintenance and inventory ordering technique for multi-unit systems. Utilizing common life estimation approaches based on the Wiener process, the performance degradation model was derived. Given a minute portion of the actual business's limited inventory and maintenance budget, the policy (S-1, S) is chosen because it provides more guarantee efficiency and increased economic value. Through the implementation of a repairable strategy, a standard model was created. Co-optimization achieves the arbitrary distinction combination by balancing the selection variables with the control loop, the maximum inventory and the preemptive replacement threshold.

The maintenance logistics system presented by Yang, Wang, Fan and Mossman (2021) will benefit from the deployment of advanced condition monitoring technologies to critical components for accurate spare parts classification. The implementation of this image recognition method for operating panel monitoring and diagnostics will also be considered. This article discusses a graph-based deep convolutional neural network with an explicable hierarchical structure that performs multi-criteria classification via image recognition.

Khalil and Labib (2021) intend to create a fuzzy logic model that serves as a decision support tool to reduce inventory-related costs in industrial maintenance. Striking a balance between the shortage and overabundance of spare parts is a tough challenge that might have significant effects.

2.5 Logistics

Logistics action constitutes one of the most important building blocks of the aviation industry. Components and materials that are not available on time can cause major problems. Aviation and MRO related logistics studies are examined. Related studies are as follows:

Jha, Udent, Abdullah and Chacha (2010) explore highway system maintenance, which is implicitly related to urban logistics given that transportation infrastructure must be in outstanding shape for urban logistics to be effective. This article discusses a cost-cutting issue that takes shift and overtime limitations into account. The shortest path method of Floyd is an algorithm which optimizes duration and routes for successful highway asset management.

Jha, Shariat, Abdullah and Devkota (2012) present a numerical optimization approach for resource effectiveness, which is described as the fewest resources required to achieve the desired level of output at different equipment, labor and material expenditures. Based on the well-known Cobb-Douglas production function concept, this article provides a way for optimizing the resource productivity of road infrastructure maintenance spending within the constraints of a budget.

Iwata and Mavris (2013) examine the creation of a categorization model for machinery spare parts known as Discrete Event Simulation (DES). To evaluate the importance of spare parts in the regeneration and repair, criteria based on the efficiency and logistics of machine maintenance operations have been developed.

Antosz and Ratnayake (2016) propose a categorization model for machine spare parts. To evaluate the importance of spare parts in the repair process, parameters based on the efficiency and logistics of machine maintenance operations have been developed.

Integration of the customer in the design process and delivery of logistics services, according to Jaaron and Backhouse (2016), is a significant potential to create value. In order to add value to the complete logistics system, the purpose of this article is to apply an integrated management approach to the design of the forward and opposite logistics services in order to construct a self-organizing service that can maximize efficiency and decrease returns in particular by employing The Vanguard Method.

Dombi, Jonas and Toth (2018) provide a hybrid technique known as the demand model function for long-term prediction of electronic spare parts for after-sales repair services.

The proposed modeling method posits that the procurement life cycles of spare parts may be represented by a curve with short-term fluctuations around its perimeter.

Using Capacitated Arc Routing Problem with Fixed Cost (CARPF), Su and Schutter (2018) develop an optimal configuration for the best routes and maintenance services for the maintenance personnel (including all necessary equipment and personnel), which minimizes total infrastructure costs and travel costs over the entire planning horizon.

Hribernik, Stietenron, Bousdekis, Bredehorst, Mentzas and Thoben (2018) present a unified predictive maintenance system that satisfies these specifications. The research describes the specific use of a transportation asset used to carry the wing flaps of a commercial airplane between the manufacturing locations of a multinational aircraft manufacturer in Germany.

Ilyashenko, Yekaterina Kovaleva, Burnatcev and Svetunkov (2020) establish a railway transportation firm and analyze the method of determining the technical state of components using the EPC notation. Due to a lack of automated part diagnosis, the corporation must stop cars to inspect their technical condition, resulting in financial losses.

Koenig, Found Kumar and Rich (2020) intend to add to the scientific findings that predicted conditional maintenance enhances overall performance of the system by illustrating how the accessibility and reliability of present assets may be raised without costly capital expenditures.

The purpose of the stochastic optimization mathematical model proposed by Szpytko and Duarte (2020) is to monitor the logistics-maintenance of mission-critical systems' overhead cranes. The paper's working conditions mimic the hot rolling mill system of a steel mill, with critical cranes operating in perilous conditions and continuous operation.

Lucht, Mütze, Kampfer and Nyhuis (2021) offer an overview of the key planning quality indicators (KPQIs) to all be examined when evaluating the planning quality of an MRO

service provider, structured along the evaluation axes of plan consistency and planning reliability.



3. THE AVIATION INDUSTRY

The aviation sector is the foundation of unity of nations today. The growth of the aviation sector is necessary for the country's all sectors to thrive. Owing to the aviation industry, countries are integrated and accessible to other nations and there are business exchanges between nations in the globalizing globe. (Yang & Yang, 2012)

The aviation sector functions between nations. As a result of the enacted economic policies; aviation security and quality have improved, while costs and travel times have decreased. With the growth of the aviation sector, significant progress has been made in aviation infrastructure, particularly in aircraft maintenance, repair and overhaul. (Yu et al., 2014)

Aviation industry provides ground handling, maintenance, repair and overhaul, manufacturing and support services. Industry creates a great cost in the construction and management of aviation. This is because of the high cost of purchasing aircraft, aircraft fuels, aircraft spare parts and the MRO expenses associated with these spare components. (Scala et al., 2021)

3.1 Aircraft Maintenance, Repair and Overhaul Industry

Rapid growth in the aviation industry's market share has led to the emergence of the aircraft MRO industry. Due to the rising quantity of aircrafts in the globe, MRO organizations are becoming increasingly important. Components are required for the maintenance, repair and overhaul of aircraft. This circumstance raises the need for replacement parts. (Beker et al., 2017)

Organizations in the maintenance, repair and revision sector have to keep spare components due to the failure of the component to be delivered or damaged. If they don't

keep spare components, it can lead to not meeting deadlines, decrease in quality, increase in costs and perhaps loss of customers. Inventory management has a very important place for MRO organizations. Spare components must have a form of management for their planning, storage and transportation. (Al-Momani et al., 2020)

MRO companies provide maintenance, repair and overhaul services for airplanes. This circumstance raised the quantity of aircraft replacement parts required by businesses, making spare part inventory control essential. In addition, enterprises in the aviation industry require maintenance, repair and revision groups that can swiftly fix and commission faulty aircraft components. Maintenance and repair of crucial aviation sector spare components. MRO organizations are crucial to the aviation sector. (Noruzoliaee & Zou, 2019)

3.2 Maintenance Intervals

MRO organizations provide maintenance and repair services for aircraft that are due for maintenance intervals. The aircraft and its components, which are parts of the aircraft, are maintained.

The intervals defined as standard are as follows:

3.2.1 Line Maintenance

Maintenance is conducted between the aircraft's landing and takeoff when it is in transit at the airport. In contrast, line maintenance is conducted before that to an aircraft's first flight. Due to the fact that this is a narrow maintenance, it often entails monitoring the oil levels and refueling, as well as visually inspecting the aircraft for any major damage, leaking oil or liquid, absent caps, etc. This maintenance or control may be performed by technicians, or if the airline does not have a technician at the airport, by the flight crew.

- Pre-flight inspections, line maintenance and troubleshooting, if necessary, after every landing and before to takeoff.
- Daily check, which occurs once every 24 or 36 hours.

- Weekly check-in, which occurs once each week.

3.2.2 Base Maintenance

These maintenance kinds are established by grouping jobs with comparable intervals and are denoted by alphabet letters such as A, B, C, D and S. A represents the kind of care with the shortest interval and the basic content; as the alphabet proceeds, the interval of maintenance rises and the difficulty of the method increases. All duties that are not subject to transit control are now specified in terms of flying hours or numbers and the need to group letters has been abolished.

Light Maintenance:

- A Maintenance: After 300 to 1000 flying hours, it may take between 6 and 24 hours.
- B Maintenance: After 3000 to 5000 flying hours, it may take one to three days.

Heavy Maintenance:

- C Maintenance is performed after 5000 to 10000 flying hours and might take 15 to 20 days.
- D Maintenance is performed every 5 to 10 years and might take up to 2 months.
- S Maintenance: During their operation, aircraft undergo S maintenance two to three times. S Maintenance is an extremely thorough and laborious maintenance in which all components are disassembled. The maintenance might take 6 to 7 months.

During maintenance operations, a number of key aviation authorities impact the appropriate MRO organizations. Civil airplane maintenance and airworthiness rules are enforced by EASA (European Aviation Safety Agency), FAA (Federal Aviation Administration) and ICAO (International Civil Aviation Organization) (International Civil Aviation Organization). Thus, all aircraft are manufactured, authorized and operated in line with these standards.

In line with EASA or FAA maintenance standards, MRO operations must also assure continued airworthiness. Local authorities (SHGM) supervise the performance of MRO responsibilities, requiring MRO enterprises to organize, plan, execute and document maintenance activities in compliance with ever changing rules. Appropriate aircraft maintenance and management of these operations are therefore a complex, multifactoral process involving an increasing and fluctuating volume of information processing.

3.3 Inventory Management In Aircraft Maintenance, Repair and Overhaul Sector

Inventory consists of finished and finished/incomplete products in order to maintain the intended level of production and deliver and sell according to the specified specifications. One of the aims of inventory management is to acquire the inventory at a reasonable cost, to offer the client what they want when they want it, to ensure that the quality is sustainable and to not hold on to unused goods. (Gu et al., 2015)

Having too much or too little spare inventory can have advantages and disadvantages. If excess held inventory is not used, it is considered to have been purchased in vain. Excess material in the inventory may cause the required material not to be placed. If the material is kept less in the inventory, problems that may lead to loss of quality and customers may occur. (Li et al., 2017)

In order to minimize the creation of extra expenses, the aviation sector must strike a balance between consumer demand for spare parts and supply. Due to the fact that a plane's delay, sitting on the ground and inability to take off would result in expensive costs, loss of prestige, customer discontent and customer loss. On the other side, having an unnecessary amount of replacement parts on hand would raise inventory expenses. (Gu et al., 2015; Li et al., 2017)

Component inventory levels can change with selling and purchasing conditions that affect their rise or fall. Not usually is the repair of airplane spare components practicable. Components can be discarded when repair is impossible or when the cost of repair exceeds the cost of replacement. This decreases the amount of inventory organically.

Since a result, when the demand is determined, exams and analyses are typically conducted on component defects, as this is one of the most influential elements impacting inventory movement. (Nariswari et al., 2019)

3.4 Inventory Management in a Aircraft Maintenance, Repair and Overhaul Company

Recommended spare amount of a certain service level is statistically estimated by considering the data of usage history, planned removal forecasts, installed A/C quantity in service, scrap ratio, essentiality code, shelf life, market availability, turnaround time etc. of component. The quantity that requires during turnaround time is specified as “recommended serviceable quantity”. This task can be carried out by outsource inventory planning and optimization firms in case it is thought required.

3.4.1 Planning

The delivery schedule of the aircraft to be included in the fleet, the expected yearly flying hours of the aircraft, the utilization status in similar fleets, the annual scrap rate and the manufacturer's spare suggestion are assessed to determine the components to be invested in.

Every request will be issued a priority code that determines the request date based on lead time and stock-on-hand date. The request is classified as AOG if the aircraft is on the ground or if it is required within three (3) days for an aircraft undergoing repair. Demands requiring the provision of a component within seven (7) days are assigned a certain request type. The request category is deemed important if the component must be delivered within 19 days. For requests with a deadline of 35 days or more, the request category is assessed to be routine or it is formed to offer warehouse backup.

3.4.2 Storage

There are designated storage locations for aircraft parts and supplies. All stores are secured and only authorized staff have access. The warehouse has an excellent ventilation

system. Each store is equipped with smoke detectors and an automated fire suppression system. When temperature and humidity thresholds are surpassed, the system notifies the warehouse and facility maintenance departments through email. If the reference values are exceeded, the facility maintenance unit is contacted. The monthly records and control charts are maintained for twelve (12) months. Temperature and humidity measurement instruments must be calibrated according to the temperature/humidity ranges that satisfy the storage requirements of the materials in the region of usage.

In general, the constructions of the shelves are designed to support the weight of the materials they support and plates/labels stating the carrying capacity of the shelves are attached to the shelves. The materials that are large and vulnerable to distortion are adequately reinforced against deformation. Shelves must be grounded and attached to the floor or wall to prevent static electricity.

Components are kept at a temperature of 23°C (+/- 5°C) and maximum humidity of 65 percent. Static Electric Sensitive components are transported to shops in anti-static bags and boxes, as required for handling and stocking. If the structural components are dry, clean and secure, they can be stored in an open space.

3.4.3 IST - SAW - IST Transfer of Components

In aircraft maintenance planning, whether the suitable component is not accessible at the relevant location according to the maintenance card, the relevant component can be relocated from other locations. There are 2 transfer vehicles every day. The route is from SAW location to ISL location and from the ISL location to the IST location. Conversely, The beginning of the route is from IST location to ISL location and then from the ISL location, the transfer is done to the SAW location. For the ESB location, the luggage section of the passenger aircrafts of the relevant airline company is used and the transfer is made in that way.

In charge of the shipping department, SAW-IST-ISL shipment coordination personnel;

1. Inspect and prepare supplies for shipping.

2. Customs documentation and a highway waybill are created for departure from the Bonded area.
3. The List of the vehicle is emailed (SAW, ISL, IST) by the Shipping Office's authorized staff in order to fulfill the required customs processes.

Materials in undamaged condition and with suitable packaging are delivered as received to the appropriate departments. Ensuring the relevant controls, the materials to be supplied with the dispatch units (ISL, SAW, IST) are stored in the sections / shelves where active / non-operational separation is indicated within the packing section.



4. PROPOSED MATHEMATICAL MODEL

This method use mathematical equations to lower total inventory costs, given a demand limitation and a minimum order quantity, provided a minimum order quantity. In a deterministic demand environment, the following notations are utilized to define the proposed multi-component and multi-period inventory reduction model. Following the determination of the assumptions come the sets, parameters and decision variables. Thus, objective function and constraints are provided. This chapter evaluates the suggested mathematical model.

4.1 Assumptions

The suggested mathematical model is derived from the Mixed-Integer Programming (MIP) Model using the following assumptions:

- Initial inventory is considered to be zero for the first period.
- Demand is predictable and known well in advance of a planning horizon.
- The previous period's inventory level is considered to be zero.
- Multiple components exist.
- The holding cost of a component each period depends on the component.

4.2 Sets, Parameters and Decision Variables

The following are the sets, parameters and decision variables:

4.2.1 Sets

t : set of time periods $\{1, \dots, T\}$

c : set of components $\{1, \dots, C\}$

l, m : set of locations $\{1, \dots, L\}$

4.2.2 Parameters

D_{tc} : Demand for component c in period t

H_c : Holding cost (Warehouse cost) for component c

X_{clm} : Transfer cost for component c from location l to location m

K_t : Ordering cost in period t

M : Big Number

4.2.3 Decision Variables

i_{tcl} : Ending inventory level at period t for component c at location l

q_{tcl} : Order quantity at period t for component c at location l

y_{tclm} : Quantity of transportation vehicles at period t for component c from location l to location m

$p_{tlm} \in \{0,1\}$: 1 if a transfer for component is placed; 0 otherwise at period t

$o_{tl} \in \{0,1\}$: 1 if an order is placed; 0 otherwise at period t

4.3 Objective Function

The objective is to minimize overall inventory costs, including holding, transfer and ordering costs. The objective function is shown by Equation 4.1.

$$\min \sum_t \left[\sum_c \sum_l (i_{tcl} H_c) + \sum_c \sum_{(l,m)} (p_{tlm} X_{clm}) + \sum_l (o_{tl} K_t) \right] \quad (4.1)$$

4.3.1 Holding Cost

These cost aspects include the investment cost associated with inventory, the cost of storage, material transfer, the taxes paid on inventory, stock loss, insurance, theft, damage and loss, among other inventory holding cost components. The holding cost is one of inventory management's most valuable assets. Numerous organizations strive to reduce overall holding costs. The holding cost also influences the resupply period for products. (Li & Yang, 2020)

In addition to warehouses, personnel and material-handling equipment, storage-area expenditures are also comprised of charges for warehouses. Typically, storage and space expenses rise as inventory levels rise or as a warehouse fills up. As the inventory level varies, the stock's value in the region linked with its utilization fluctuates as well. Assessing the holding cost is difficult to determine the cost of space as a proportion of a product's worth. (Hesham, 2014)

Storage and space cost estimation demands precision and expertise. This cost is often comprised of machine fees utilized for the entry and departure of the storage facility, although rent payments can also be included in criteria including the wear and tear of material handling equipment. The quickest method for calculating such expenses is to split the general expenditures by public services, rent, maintenance and repair, the building's property tax and the inventory according to the requirements for storage and stowage admittance. (Ryu, 2017)

$$\sum_t \sum_c \sum_l (i_{tcl} H_c) \quad (4.2)$$

Each component has a holding cost and this formula computes the overall holding cost based on the quantity of each component in stock. Equation 4.2 constrains cost calculation to the objective function.

4.3.2 Transfer Cost

The transfer cost is the price at which linked parties engage in transactions, such as the exchange of materials or labor across departments. Transfer pricing may be utilized in transactions between a firm and its subsidiaries or between divisions of the same company located in different countries. (Hamamura, 2021)

A transfer cost emerges for accounting reasons when linked parties, such as divisions within a corporation or a firm and its subsidiary, declare their own earnings. When these connected parties are forced to transact, a transfer cost is employed to estimate expenses. Transfer costs often do not differ significantly from the market price. If the prices differ, one of the companies will be at a disadvantage and will ultimately begin purchasing from the market in order to obtain a lower price. (Margolies & Hoddinott, 2015; Dutta & Reichelstein, 2021)

$$\sum_t \sum_c \sum_{(l,m)} (p_{tlm} X_{clm}) \quad (4.3)$$

This formula computes the total transfer cost depending on the location transfers. The cost computation is constrained to the objective function by Equation 4.3.

4.3.3 Ordering Cost

Costs associated with placing an order and transporting the merchandise to the warehouse are included in the ordering cost. In other instances, order expenses can include quality control, shipping, degradation and breaking at the warehouse entry. (Chien & Chen, 2010)

When a new order is made from customer to supplier, costs are incurred. Whether the requested inventory is manufactured in-house or procured outside typically affects the order price. If inventory is generated internally, the ordering cost consists of material transfer, labor, supplies, stationery and overhead. Whether the inventory is obtained externally, the ordering cost consists of the order confirmation, delivery, shipping, receiving, acceptance inspection, expenditures incurred as a result of invoice- and insurance-related labor and stationery costs. (Yao, Chao and Wu, 2017; Gambini, Scarpello and Ritelli, 2013)

$$\sum_t \sum_l (o_{tl} K_t) \quad (4.4)$$

If $o_{tl} = 1$, then a purchase has been made. If an order is made during the term, an order charge will be assessed. The quantity of orders placed during the planning period is reflected in the ordering cost. The formula for the objective function ordering cost is given by Equation 4.4.

4.4 Constraints

$$i_{t-1,c,l} + q_{tcl} + \sum_{(l,m)} y_{tclm} = D_{tc} + \sum_{(l,m)} y_{tcm l} + i_{tcl} \quad \forall c, t, l \quad (4.5)$$

$$q_{tcl} \leq M o_{tl} \quad \forall t = 1, \dots, T, \quad \forall c = 1, \dots, C, \quad \forall l, m = 1, \dots, L \quad (4.6)$$

$$y_{tclm} \leq M p_{t l m} \quad \forall t = 1, \dots, T, \quad \forall c = 1, \dots, C, \quad \forall l, m = 1, \dots, L \quad (4.7)$$

Constraint (4.5) includes that ending inventory level at period t for component c at location with order quantity at period t for component c at location l and quantity of transportation vehicles at period t for component c from location l to location m must be equal to inventory level of previous period with demand for component c in period t and quantity of transportation vehicles at period t for component c from location m to location l .

If an order is placed, constraint (4.6) implies that the model implements the minimum order quantity constraint at period t for component c at location l . If a transfer is placed, constraint (4.7) assures that the model implements the minimum transfer constraint at period t for component c from location l to location m .



5. A CASE STUDY

The business that conducted the analysis is one of the leading airline MRO companies in the globe. The firm provides aircraft and component MRO services. Long-term aircraft and component maintenance plans are created. When examining the supply chain management structures, it is discovered that airplane maintenance plans are predetermined. In the existing method, maintenance plans for the following 12 months are determined in advance. According to the kind of aircraft maintenance, it is known in advance which components must be replaced. According to these plans, the component is anticipated to be available at the appropriate place before it reaches the hangar for aircraft maintenance and it is desired that aircraft maintenance be performed on time and without delay.

Inventory management is a crucial aspect of aircraft MRO. If the component is not accessible in the right hangar when the aircraft comes for maintenance, the consequences may include customer penalties, loss of business prestige and failure of other aircraft maintenance. Therefore, it is essential to acquire Components from the proper MRO company in a timely and cost-effective manner.

This research investigated the 2022-2023 aircraft maintenance plans for the ESB, SAW and ISL locations of the pertinent aircraft MRO organization. The demand plan for 543 components for the repair of 34 aircraft at the ESB location, 4342 components for the maintenance of 250 aircraft at the ISL location and 2518 components for the maintenance of 152 aircraft at the SAW location has been reviewed. The holding cost values for 223 components were calculated. The components of the transfer and ordering costs are displayed and explained.

Total of 223 component demands of the following 12 months for ESB, SAW and ISL locations are given in Appendix A.1, Appendix A.2 and Appendix A.3 respectively. Over

the period of a year, maintenance plans were created for the ESB location and the requirements of 223 aircraft components were assessed. Table 5.1 depicts the monthly component requests for the ESB location over the period of a year.

Table 5.1: Component demands of the following 12 months for ESB

ESB													
Component	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
A1				1		1						1	3
A2					1								1
A3					2	1					1		4
A4	1		1	1	3	2	1	3	2	2	1		17
A5				1									1
A6						1							1
A7	1		1	1	1	1	1	3	2	2			13
A8	2								2				4
A9				2									2
A10				1									1
Total	38	2	30	65	80	49	20	75	71	57	48	8	543

Table 5.1 shows the components needed for aircraft maintenance planned in the hangar at the ESB location. During the 12-month period, maintenance of 34 aircraft is planned. There is less need for components due to less aircraft maintenance planning compared to other locations. The maximum number of components is needed in May with 80. The plan is to use 543 components for the ESB location. Components A4, A12, A129 and A185 are most in demand with 17. The A27 component has never been requested. A54, A55, A56, A57, A58, A74 and A89 components were requested for 1 piece.

Maintenance plans were prepared for the ESB location and the demands of 223 aircraft components were evaluated over the course of a year. In this context, Table 5.1 shows the monthly component demands for the ESB location during the 12 months.

Table 5.2: Component demands of the following 12 months for SAW

SAW													
Component	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
A1	1	2	1	4	1	3	2	2	1	2	2		21
A2		1				1							2
A3	2	1	4	5	6	5	3	2	5	6	5	3	47
A4	3	5	11	8	11	8	5	3	7	11	9	9	90
A5	1	1		1	1			1					5
A6	1						1		1		1		4
A7	1	4	7	3	5	3	2	1	2	5	4	6	43
A8	2	2	2		2		2				4		14
A9					2			2					4
A10					1			1					2
Total	137	197	277	244	287	170	164	162	157	236	272	215	2518

Table 5.2 displays the components required for aircraft maintenance at the SAW location. Because there is more aircraft maintenance planning than at the ESB location, there is a greater need for components. 152 aircraft are planned for maintenance at SAW within the next 12 months. In order to maintain 152 aircraft, 2518 parts were ordered. May had the greatest component demand with 287. Components A4, A12, A129 and A185 are most in demand with 17. The component requested with 15 is A64. With 90, A4, A12, A129 and A185 are the most in-demand components. The component A27 never been requested. One piece has been requested from the A54, A55, A56, A57, A58, A74 and A89 components.

Examined were the component requirements of 250 aircraft whose 12-month maintenance was scheduled at the ISL location. In this context, the 12-month component demand by month is displayed in table 5.3.

Table 5.3: Component demands of the following 12 months for ISL

ISL													
Component	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
A1	4	3	2	2	1		3	4	3	2	5	4	33
A2	1			2			1						4
A3	8	4	3	9	13	6	6	4	4	6	10	4	77
A4	13	13	11	15	20	11	11	11	9	12	23	9	158
A5	4	1	1	1			2	3			1	1	14
A6	1			1			1	1			1		5
A7	5	9	8	6	7	4	5	7	5	6	13	5	80
A8		6			2		2	4			4	4	22
A9	2	2		2			4	2			2		14
A10	1	1		1			2	1			1		7
Total	428	381	296	393	464	235	331	351	270	313	584	296	4342

At Table 5.3, the components required for the proposed aircraft maintenance in the ISL hangar are analyzed. ISL is scheduled to perform maintenance on 250 aircraft over the course of one year. There are 4342 parts required to accomplish these maintenances. Compared to ESB and SAW, greater aircraft maintenance planning necessitates the procurement of additional components. November requires the most components with 584, followed by A4 with 158 component demands. A12, A129 and A185 are the components sought for aircraft repair, with 157 in second place. A53 having a minimum of 3 component components.

Table 5.4: Holding Cost for Each Component

Component	Holding Cost
A1	114,653
A2	126,594
A3	58,542
A4	36,087
A5	55,276
A6	12,729
A7	14,353
A8	191,750
A9	42,882
A10	54,637
Total	367016,642

In the warehouses of Airplane Maintenance, Repair and Overhaul, aircraft maintenance plans are stored until the aircraft arrives. Examining the holding costs of the components listed in Table 5.4. The average holding expense for 223 components is 1,645,820 USD. The A192 with the highest cost of keeping is valued at 307032,778 USD. A total of 223 holding costs for each component are given in Appendix A.4.

Twice a day, component transfers occur between locations. Table 5.5 displays the costs associated with the transfer from the SAW location to the ISL location and from the ISL location to the SAW location.

Table 5.5: Transfer Cost Between SAW-ISL Locations

Location	Distance	Gas	Bridge Toll	Personnel Wage	Total
SAW-ISL	60 km	1143,06	0	393,12	1536,18
ISL-SAW	60 km	1143,06	173,58	393,12	1709,76

Daily component transfer planning occurs between the SAW-ISL and ISL-SAW locations depicted in Table 5.5. The chart lists the costs associated with Location, Distance, Bridge Toll and Personnel Wage. There are 60 kilometers between the two places. Transfers between locations occur twice every day. According to the kind and size of the vehicle, the truck's 30-day gasoline expenditure is 1,143.06 USD. On the route from the SAW location to the ISL location, there is no bridge cost, however there is a bridge fee of 173.58 USD on the route from the ISL location to the SAW location. The monthly charge between locations for the truck driver is 393.12 USD. From the SAW location to the ISL location costs a total of 1536.18 USD and from the ISL location to the SAW location costs a total of 1709.76 USD. The baggage compartment of passenger aircraft is utilized for ESB transfers. Transfers are conducted by flights to or from Ankara. Consequently, the transfer costs to and from the ESB are rather minimal.

Creating component requests and ordering related components according to aircraft maintenance plans are important. Accordingly, the factors that make up the ordering cost of the components are as in Table 5.6.

Table 5.6: Ordering Cost for Each Component

Ordering Cost	Total
Cost of preparing a purchase requisition	2,948
Cost associated with preparing a purchase order	5,896
Labor costs associated with the inspection of incoming components	0,983
Cost incurred to store items once they are received	5,896
Cost associated with processing the linked supplier invoice	1,474
Cost incurred for preparing and issuing a payment to a supplier	1,474
Grand Total	18,671

Table 5.6 shows the ordering cost for each component. Cost of preparing a purchase requisition 2,948 USD, cost associated with preparing a purchase order 5,896 USD, labor costs associated with the inspection of incoming components 0,983 USD, cost incurred to store items once they are received 5,896 USD, cost associated with processing the linked supplier invoice costs 1,474 USD and cost incurred for preparing and issuing a payment to a supplier is 1,474 USD. The total ordering cost is 18,671 USD. The largest cost item is cost associated with preparing a purchase order and cost incurred to store items once they are received, with 5,896 USD.

6. RESULTS

Aircraft MRO firms create long-term maintenance plans. The objective is to arrange component orders according to aircraft maintenance plans and kinds, as well as to minimize delays. In this study, a total of 7,403 component data for 223 component types were analyzed and an inventory cost minimization analysis was conducted on the maintenance plans of the relevant firm during a 12-month period. As a result of these findings, efforts have been made to decrease inventory expenses caused by ordering costs, transfer costs and holding costs. For the study, a suggested model has been developed and a solution has been found through the entry of pertinent data.

The study has been reached that the holding cost, transfer cost and ordering cost costs, which constitute the relevant objective value with the model, together with the MIP solver of the GAMS program, constitute a total of 4794754.946 USD for the storage cost.

After data inputs for the 12-month period were made using the suggested model, it was determined if the component would be ordered for the pertinent month at SAW, ESB and ISL locations. According to Table 6.1, the investigation yielded the following results:

Table 6.1: Component Order Months for SAW, ESB and ISL Locations

Location	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
SAW	1		1	1	1	1		1	1	1		1
ESB	1						1					
ISL										1		

Table 6.1 displays whether SAW, ESB and ISL will order components in the next 12 months. In January, March, April, May, June, August, September, October and December, orders for SAW components can be placed, according to the indications. In

January and July, component orders can be placed for the ESB location. In October, only the applicable components can be ordered for the ISL location.

Utilizing Proposed Model, the order amounts per location were evaluated and compared. Total of 223 component order quantity results for ESB, SAW and ISL locations are given in Appendix B.1, Appendix B.2 and Appendix B.3 respectively. In Table 6.2, the order quantity results by month for the SAW location are displayed.

Table 6.2: Component Order Quantity Results for SAW

SAW													
Component	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
A1	10		3	6	2	8		6	4			4	43
A2	2			2		2							6
A3	15		7	14	19	20		6	9			7	97
A4	34		22	23	31	35		14	16			18	193
A5	7		1	2	1	2		4				1	18
A6	2			1		2		1	1				7
A7	19		15	9	12	14		8	7			11	95
A8	10		2		4	4		4				4	28
A9	4			2	2	4		4					16
A10	2			1	1	2		2					8
Total	1.143		570	637	751	900		513	427	119		511	5.571

Table 6.2 displays the components that may be required for the planned aircraft maintenance in the SAW hangar, as well as the suggested model. January had seen the greatest demand for components with 1143. There was no need for components at the SAW location in February, July, or November. In all, 5571 components can be requested for the SAW location, according to the conclusion. It has been determined that the A185 component is most frequently requested with the 212.

Using the Proposed Model, the ESB location's order amounts were attained. Table 6.3 displays the outcomes of the order amount by month at the ESB location.

Table 6.3: Component Order Quantity Results for ESB

ESB													
Component	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
A1	2												2
A2	2												2
A3	3						1						4
A4	8						9						17
A5	1												1
A6	1												1
A7	5						8						13
A8	2						2						4
A9	2												2
A10	1												1
Total	264						278						542

As a consequence of the suggested model, the components that may be required for the planned aircraft maintenance in the hangar at the ESB location are displayed in Table 6.3. Conclusion: 264 components for January and 278 components for July can be requested. Consequently, a total of 542 components can be requested for the ESB location. The most in-demand components are A4, A12, A129 and A185, with 17 utilizing the suggested approach.

Table 6.4: Component Order Quantity Results for ISL

ISL													
Component	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
A1										11			11
A2													0
A3										27			27
A4										55			55
A5										1			1
A6										2			2
A7										28			28
A8										8			8
A9										2			2
A10										1			1
Total										1,286			1,286

Table 6.4 depicts the components that may be required for the planned aircraft maintenance in the hangar at ISL using the suggested model. The conclusion that 1286 components may only be required in October. As a consequence, a total of 1286 components can be requested for the ISL location. With 55, A4, A12 and A129 components were the most in demand. A64, with 53 requests, is the second-most-requested component.

Component transfer across locations can be undertaken during aircraft maintenance planning in order to save inventory costs. Table 6.5 displays the transfer status for SAW, ISL and ESB locations.

Table 6.5: Transfer Requisitions Between Locations

Transfer	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
ISL-ESB	1	1	1	1	1	1	1	1	1	1	1	1
SAW-ISL	1		1	1	1	1		1	1			1
SAW-ESB	1	1	1	1	1	1	1	1	1	1	1	1
ESB-ISL	1	1	1	1	1	1	1	1	1	1	1	1
ESB-SAW	1	1	1	1	1	1	1	1	1	1	1	1
ISL-SAW										1	1	

Table 6.5 displays the months for which component transfers between SAW, ISL and ESB locations are permitted. The result is that monthly component transfers are possible between ISL-ESB, SAW-ESB, ESB-ISL and ESB-SAW. Transfers of components from SAW to ISL are permitted in all other months save February and July. As a result, component transfers from ISL to SAW may only occur during the months of October and November in order to comply with aircraft maintenance plans.

Using the proposed model suggests that transfers between locations can be done in accordance with aircraft maintenance plans. Total of 223 Transfer Quantity Between ISL-SAW are given in Appendix B.4. Regarding this, Table 6.6 displays the transfer amounts from the ISL location to the SAW location.

Table 6.6: Transfer Quantity Between ISL-SAW

ISL-SAW													
Component	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
A1										4			4
A2													0
A3										6	5		11
A4										20			20
A5													0
A6											1		1
A7										9			9
A8											4		4
A9													0
A10													0
Total										258	135		393

Table 6.6 displays the component transfer quantities between ISL-SAW locations. Consequently, component transfers from ISL to SAW can only occur during the months of October and November. As a consequence, 258 components will be relocated in October, followed by 135 components in November. As a result, 393 components can be relocated across locations. The most transferrable component might be A64, which has 21 parts, according to the findings.

Table 6.7: Transfer Quantity Between SAW-ISL

SAW-ISL													
Component	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
A1	7		2	2	1	3		4	4			4	27
A2	1			2		1							4
A3	12		3	9	13	12		4	4			4	61
A4	26		11	15	20	22		11	9			9	123
A5	5		1	1		2		3				1	13
A6	1			1		1		1					4
A7	14		8	6	7	9		7	5			5	61
A8	6				2	2		4				4	18
A9	4			2		4		2					12
A10	2			1		2		1					6
Total	809		296	393	465	566		351	271			295	3.446

Using the suggested model, component transfer quantities between SAW-ISL locations were derived in Table 6.7. Except for the months of February, July, October and November, component exchanges between SAW and ISL are permitted. It has been established that a total of 3,446 components were transferred from the SAW location to the ISL location. The model predicts that January, with 809 potential transfers, will have the most. A4 with 123 pieces may be the most transportable component. Total of 223 Transfer Quantity Between SAW-ISL are given in Appendix B.5.

As a consequence of the 12-month airplane maintenance planning, remaining inventory components and whether they would be shipped to the same or a different location in the next months were identified. A total of 223 ending inventory for ESB, SAW and ISL locations are given in Appendix B.6, Appendix B.7 and Appendix B.8 respectively. The ISL ending inventory is depicted in Table 6.8.

Table 6.8: Ending Inventory for ISL

ISL													
Component	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
A1	3					3				5			11
A2						1							1
A3	4					6				15			25
A4	13					11				23			47
A5	1					2				1			4
A6						1				2			3
A7	9					5				13			27
A8	6					2				8			16
A9	2					4				2			8
A10	1					2				1			4
Total	381					331				715			1,427

Table 6.8 displays the components that will not be utilized following aircraft maintenance planning for the ISL location using the suggested model. In January, 381 components, in June, 331 components and in October, 715 components were held in inventory for use in later months. The result is that the inventory comprised a total of 1,427 components. With 52 pieces, the A64 component is the component with the largest inventory.

As a consequence of the 12-month aircraft maintenance planning, the inventory information for the SAW location of the components that remain in inventory and will be shipped to the same or a different place in the following months is displayed. Table 6.9 displays the ending inventory for SAW.

Table 6.9: Ending Inventory for SAW

SAW													
Component	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
A1	2					2				2			6
A2	1												1
A3	1					3							4
A4	5					5				9			19
A5	1												1
A6						1							1
A7	4					2				4			10
A8	2					2							4
A9													0
A10													0
Total	197					164				141			502

Table 6.9 displays the unused aircraft maintenance planning components for the SAW location. The inventory included a total of 197 components in January, 164 components in June and 141 components in October for usage in future months. The result is that 502 components have been put in the inventory. With 19 pieces, A4, A12, A129 and A185 components are the most often stocked items.

As a consequence of the 12-month aircraft maintenance planning, the inventory information for the ESB location of the components that remain in inventory and will be shipped to the same or a different place in the following months is displayed. Table 6.10 outlines the ESB's ending inventory.

Table 6.10: Ending Inventory for ESB

ESB													
Component	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
A1	2	2	2	1	1								8
A2	1	1	1	1									4
A3	3	3	3	1			1	1	1	1			14
A4	7	7	6	5	2		8	5	3	1			44
A5	1	1	1										3
A6	1	1	1	1	1								5
A7	4	4	3	2	1		7	4	2				27
A8							2	2					4
A9	2	2	2										6
A10	1	1	1										3
Total	225	223	193	127	48		258	182	111	55	7		1,429

Following aircraft maintenance planning, the ESB location's inventory of spare components is detailed in Table 6.10. June was the month with the greatest stockpile, with 258 components. Between June and December, the inventory component information for the ESB location could not be accessible. As a result, the inventory had a total of 1,429 components. A4, A12, A129 and A185 components comprise the greatest stock with 44 pieces.

7. CONCLUSION

The goal of order management models is to calculate the order time and quantities of all stocks to satisfy the stock level, taking into consideration many comparable characteristics such as the cost of transfer, ordering and holding. The models utilized at this time are formed according to the current system's architecture. Within the scope of this topic, a literature review of Aviation, Maintenance, Repair and Overhaul, Supply Chain, Inventory Management and Logistics was undertaken.

This research examines the order management system of an Aircraft MRO firm. The purpose is to develop an improved technique for determining component order. With a deterministic demand structure, inventory reduction is one of the overall cost reduction challenges in the recommended approach. There are several element types and places. A mathematical methodology is proposed to lower total inventory costs. This model was created to fit the needs of the company.

Inventory cost minimization study was carried out at an aircraft MRO company. 12-month aircraft maintenance plans for the 2022-2023 period were examined in the relevant company. The planning of 152 aircraft for the SAW location, the planning of 250 aircraft for the ISL location and the maintenance planning of 34 aircraft for the ESB location were achieved. After examining and checking all the data, 223 different components, a total of 7403 components, were planned to change the components according to aircraft maintenance plans. These components must be present at the relevant SAW, ISL or ESB locations before the arrival of the incoming aircraft, according to their maintenance schedule.

In order to reduce inventory costs, a model was developed as part of the research. Three expenses associated with the management of component inventories stand out. These include holding, transfer and ordering costs. The suggested model's Objective Function

consists of the following three expenses. Using 12-month data, the MIP server of the GAMS program was used to validate the model's outputs once it was generated.

Prior to the establishment of the model, 2518 requests for components at the SAW location, 4342 requests for components at the ISL location and 543 requests for components at the ESB location were scheduled for the 12-month period between 2022 and 2023. The Proposed Model is determined that a 12-month request may be made for 5571 components at the SAW location, 1286 components at the ISL location and 542 components at the ESB location.

Due to the suggested model, the quantity of transfer between the necessary places has been accomplished. Passenger aircraft are deployed for ESB location transfers. Therefore, it was not possible to establish any costs linked with the ESB location. For the years 2022 and 2023, it has been established that monthly transfers from ISL and SAW locations to ESB locations and from ESB locations to ISL and SAW locations will be authorized. The model predicts that component transfer from ISL to SAW is only achievable during the months of October and November. Observations suggest that transfers from the SAW location to the ISL location are possible throughout every month other than February, July, October and November. Due to the high cost of ordering, ordering from a particular area and forwarding the shipment to a different site is becoming increasingly common. Despite the fact that 250 aircraft were to be maintained at ISL, the model predicts that 1,286 components might be purchased if the proposed plan is implemented. Specifically, the model determined that transfers from the SAW location to the ISL location can be large, hence reducing inventory costs.

With the Proposed Model, the ending inventory information, which is created following the arrival of the aircraft and their upkeep, has been attained. The model is determined that component inventory for the ISL location is available in January, June and October for usage in other months or locations. Similar to the ISL location, the model is determined that ending inventory may be found in January, June and October at the SAW location. Except for June and December, ending inventory information was received for the ESB location. With Ending Inventory, the model is determined that inventory costs are minimized by using the product at the appropriate locations in the following months.

Before utilizing the model, the cost was anticipated that holding would cost 7864496,659 USD, ordering would cost 138221,4 USD and transfer would cost 39492,3 USD over the course of a year. Using the MIP server of the GAMS program and the proposed model, the objective value was calculated to be 4,794,754,946 USD. The proposed methodology is anticipated to reduce inventory costs by 40.38%.

The primary objective of this thesis is to develop a structure-appropriate model for the Aircraft MRO firm. As a result, the suggested model requires a wide diversity of components. Infrequently, however, non-maintenance card components may be needed as a result of maintenance inspections. In addition to this maintenance card, the model may include the consumption rate and capabilities of the required components for a more comprehensive analysis.

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APPENDICES

Appendix A

Table A.1: Component demands of the following 12 months for ESB

[illegible]

A33													0
A34													0
A35					1				1				2
A36					2	2							4
A37				1							1		2
A38				1							1		2
A39													0
A40	1							2	1	1			5
A41				1									1
A42				1									1
A43													0
A44				1									1
A45				1									1
A46				1									1
A47				2									2
A48				1									1
A49				1									1
A50				1									1
A51				2									2
A52													0
A53													0
A54								1	1				2
A55								1	1				2
A56								1	1				2
A57								1	1				2
A58								1	1				2
A59									1				1
A60						1						1	2
A61					1	1							2
A62						1					1		2
A63				1							1		2
A64	1			2	4	1		2	2	2	1		15
A65									1	1			2
A66													0
A67					1								1
A68									2				2
A69	1												1
A70													0
A71									1				1
A72					2								2
A73											1		1
A74								1	1				2
A75													0
A76					1								1

A77											2		2
A78			1					1					2
A79					1								1
A80					1								1
A81					1								1
A82					1	1							2
A83						1							1
A84											2		2
A85			1	1	1			1		1			5
A86			1										1
A87	1												1
A88													0
A89								1	1				2
A90								2	4	2			8
A91	1		1	2	1			3	2	3			13
A92	1		1	1	1	1	1	3	2	2			13
A93	1		1	1	1	1	1	3	2	2			13
A94	1		1	1	1	1	1	3	2	2			13
A95	1		1	1	1	1	1	3	2	2			13
A96											2		2
A97								1	1	1			3
A98	1			1				2	2	2			8
A99						1							1
A100								1					1
A101					2	2							4
A102									1				1
A103					1	1							2
A104					1								1
A105													0
A106				1							1		2
A107									1				1
A108								1	1				2
A109													0
A110										1			1
A111	1									1			2
A112								1					1
A113	1												1
A114								1					1
A115				1									1
A116								1					1
A117											1		1
A118					1								1
A119						1							1
A120					1								1

A121						1							1
A122													0
A123			1	2						1			4
A124					2						1		3
A125	1			1					2	1			5
A126	1								1				2
A127					1								1
A128					1								1
A129	1		1	1	3	2	1	3	2	2	1		17
A130										1			1
A131			1										1
A132	1		1										2
A133												1	1
A134													0
A135								1		1			2
A136							1				1		2
A137					1								1
A138										2			2
A139										1			1
A140			2				1						3
A141										1			1
A142												1	1
A143	1				1	1		1			1		5
A144	1						1			1		2	5
A145					1	1							2
A146					1	1							2
A147					1	1							2
A148													0
A149												1	1
A150											1		1
A151						1							1
A152					2								2
A153					2								2
A154	1			1				2	2	2			8
A155											1		1
A156						1							1
A157	1							1	1	1			4
A158	1							1	1	1			4
A159	1			1				2	2	2			8
A160			2				2						4
A161													0
A162													0
A163										1			1
A164	1				1								2

[illegible]

A209											1		1
A210											1		1
A211											1		1
A212											1		1
A213											1		1
A214													0
A215					2								2
A216											1		1
A217						1							1
A218	1			1				1	1				4
A219													0
A220	1												1
A221				1									1
A222				1									1
A223													0
Total	38	2	30	65	80	49	20	75	71	57	48	8	543

Table A.2: Component demands of the following 12 months for SAW

SAW													
Component	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
A1	1	2	1	4	1	3	2	2	1	2	2		21
A2		1				1							2
A3	2	1	4	5	6	5	3	2	5	6	5	3	47
A4	3	5	11	8	11	8	5	3	7	11	9	9	90
A5	1	1		1	1			1					5
A6	1						1		1		1		4
A7	1	4	7	3	5	3	2	1	2	5	4	6	43
A8	2	2	2		2		2				4		14
A9					2			2					4
A10					1			1					2
A11	1	1	1				1				1		5
A12	3	5	11	8	11	8	5	3	7	11	9	9	90
A13			1	1		1			1	2		1	7
A14	2	1	4	5	6	5	3	2	5	6	5	3	47
A15					2		2		2			2	8
A16					1		1		1			1	4
A17	2	1		2									5
A18		2	2	4	2		4	6	2			2	24
A19		2	2	4	2		4	6	2			2	24
A20		2	2	4	2		4	6	2			2	24
A21	1	3	1	2									7
A22	2	1		1			1			1			6
A23										1		2	3

A24	1		1			1				1	1		5
A25		1		1			1	2			1	1	7
A26	1		1			1				1	1		5
A27													0
A28		1	1	2	1		2	3	1			1	12
A29	2	3	2	5	3	4	3	4	1	2	3	2	34
A30	1		1			1				1	1		5
A31		1		4	3	2		2	1	1	1	1	16
A32		1		4	3	2		2	1	1	1	1	16
A33	2		1	1		1				1	1		7
A34	1		1			1				1	1		5
A35	1	1	2		1		1				2		8
A36	2		2		2		2		2		4		14
A37		1	1	2	1		2	3	1			1	12
A38		1	1	2	1		2	3	1			1	12
A39					2		2		2			2	8
A40			2		1	1		1		1	3		9
A41					1			1					2
A42					1			1					2
A43	1				1						1		3
A44					1			1					2
A45					1			1					2
A46					1			1					2
A47					2			2					4
A48					1			1					2
A49					1			1					2
A50					1			1					2
A51					2			2					4
A52				2				1					3
A53	1	1		2	1	1					1		7
A54											1		1
A55											1		1
A56											1		1
A57											1		1
A58											1		1
A59	1	1	1				1				1		5
A60				2		3	1			2	2		10
A61	1		1		1		1		1		2		7
A62				1		2	2	1		2	1	1	10
A63		1	1	2	2		3	3	2			2	16
A64	3	4	10	6	8	5	2	1	5	11	10	9	74
A65	1	2	1				1			1	1	1	8
A66	1	1		1									3
A67		1	1	1	4	1		1	1	1	2	1	14

A68	2	2	2				2				2		10
A69					1						1		2
A70	1			1									2
A71	1	1	1				1				1		5
A72		2				2							4
A73		1	1	2			2	2	1			1	10
A74											1		1
A75	1			1									2
A76		1				1							2
A77		2	2	4			4	4	2			2	20
A78		1	1	1	2				1	1			7
A79		1				1							2
A80		1				1							2
A81			1	1	1				1	3	1	1	9
A82	1		1		1		1		1		2		7
A83	1						1		1		1		4
A84				2			2	2				2	8
A85		2	1	1	2			1	1	1	1	1	11
A86	1	1		1									3
A87					1						1		2
A88	1	2	1	2			1	1	1				9
A89											1		1
A90	2	4	4			2	2		2	4	4	2	26
A91	1	5	5	3	5	2	1	1	1	4	4	5	37
A92	1	4	6	3	5	2	2	1	1	4	4	6	39
A93	1	4	6	3	5	2	2	1	1	4	4	6	39
A94	1	4	6	3	5	2	2	1	1	4	4	6	39
A95	1	4	6	3	5	2	2	1	1	4	4	6	39
A96								2		2			4
A97		1	1			1			1	2	1	1	8
A98	1	2	3		1	1	1	1		3	4	3	20
A99	1						1		1		1		4
A100			1	1	1		1			1		1	6
A101	2		2		2		2		2		4		14
A102	1	1	1				1				1		5
A103	2		1	2	2		1	1	1		3		13
A104	1		1		2					1	2	1	8
A105						2	2			4			8
A106		1		1	1		1	3			1	1	9
A107	1	1	1				1				1		5
A108			1			1			1	1	1		5
A109	1		1			1				1	1		5
A110		1								1		1	3
A111			1		1			1		1	1		5

A112			1			1					1		3
A113					1						1		2
A114			1			1					1		3
A115										1		2	3
A116			1			1					1		3
A117				1			1	1				1	4
A118			1		1						1		3
A119	1						1		1		1		4
A120		1				1							2
A121			1	1				1	1				4
A122	1				1						1		3
A123		2			1				1	1		2	7
A124	1	1	3	5	6	4	1	2	4	6	4	3	40
A125	2	2	4		1	1	2	1	1	3	3	2	22
A126	1	1	1		1		1				2		7
A127			1		1						1		3
A128			1		1						1		3
A129	3	5	11	8	11	8	5	3	7	11	9	9	90
A130		3	2	2	5	2		1	2	2	1	3	23
A131	1	1		1									3
A132	3	3	2	3		1				1	1		14
A133				2		1					1		4
A134	2	2		2									6
A135		3	3	2	5	3		1	2	2	2	3	26
A136	1	1	1	2	1	1	1	1		3			12
A137		1				1							2
A138		4	2	2	5	2		1	2	3	1	4	26
A139		3	2	2	5	2		1	2	2	1	3	23
A140	6	4	2	6	1		3	2	1	2	1		28
A141			1					1		1			3
A142	1	1		3		1					1		7
A143			3	2	3	1	1	2	1	4	2		19
A144		1	4	3	2	2		1	1	1	1	1	17
A145	1		1		1		1		1		2		7
A146	1		1		1		1		1		2		7
A147	1		1		1		1		1		2		7
A148		1		1	3	1		1	1		1		9
A149				2		1					1		4
A150		1	1	2			2	2	1			1	10
A151	1						1		1		1		4
A152			2		2						2		6
A153			2		2						2		6
A154	1	3	4	1	3	1	1	1		3	4	5	27
A155				4		1		1		2		2	10

A156	1						1		1		1		4
A157		1	1		1	1			1	2	2	1	10
A158		1	1		1	1			1	2	2	1	10
A159	1	3	4	1	3	1	1	1		3	4	5	27
A160	8	2	4	6	2	2			2	2	2		30
A161									1	2			3
A162				2						2		2	6
A163		1								1		1	3
A164	1		1		2	1						1	6
A165		1				1							2
A166		1				1							2
A167		1				1							2
A168	1	1		1									3
A169				3				1	1	3		1	9
A170	1						1		1		1		4
A171		4	6	4	8		2	2	2	2	2	8	40
A172			2			1		1	1	2	1		8
A173			2			1		1	1	2	1		8
A174					1			1					2
A175					1			1					2
A176					1			1					2
A177					1			1					2
A178										1		2	3
A179	1	1	1				1				1		5
A180			2		1	2					3		8
A181		1			1					1	1	1	5
A182			1			1			1	1			4
A183	1	1	2		1		1				2		8
A184	2	3	4	3	5	1	2	2	1		5		28
A185	3	5	11	8	11	8	5	3	7	11	9	9	90
A186	2	1	4	5	6	5	3	2	5	6	5	3	47
A187	1	5	6	3	5	3	1	1	2	5	4	5	41
A188					1						1		2
A189	2		2		2		2		2		4		14
A190					2			2					4
A191		1		1	3	1		1	1		1		9
A192			2	2		2		4					10
A193	1	4	7	3	5	3	2	1	2	5	4	6	43
A194		1	1	2	1		2	3	1			1	12
A195	1	1		1									3
A196		1				1							2
A197	3	1		3									7
A198									1	2			3
A199			1	2		1		1			1		6

A200	1		1	1	1		1		1	3	2	3	14
A201	1						1		2	3	1	1	9
A202	1					2							3
A203	1					2							3
A204	1	1	1				1				1		5
A205			1			1			1	1			4
A206	1	2	3	2	1		3	2	1		2	1	18
A207		1	1		1		1		1			1	6
A208				1			1	1				1	4
A209				1			1	1				1	4
A210				1			1	1				1	4
A211				1			1	1				1	4
A212				1			1	1				1	4
A213				1			1	1				1	4
A214									1	2			3
A215			2		2						2		6
A216				1		1				1		1	4
A217	1	2	1	2		1	1	1	1		1		11
A218	2	1	3		2	2	1		1	2	4	2	20
A219									1	2			3
A220					1						1		2
A221					1			1					2
A222					1			1					2
A223	2		1		2	1			1	1	2		10
Total	137	197	277	244	287	170	164	162	157	236	272	215	2518

Table A.3: Component demands of the following 12 months for ISL

ISL													
Component	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
A1	4	3	2	2	1		3	4	3	2	5	4	33
A2	1			2			1						4
A3	8	4	3	9	13	6	6	4	4	6	10	4	77
A4	13	13	11	15	20	11	11	11	9	12	23	9	158
A5	4	1	1	1			2	3			1	1	14
A6	1			1			1	1			1		5
A7	5	9	8	6	7	4	5	7	5	6	13	5	80
A8		6			2		2	4			4	4	22
A9	2	2		2			4	2			2		14
A10	1	1		1			2	1			1		7
A11		1					1	1			1		4
A12	13	13	11	15	20	10	11	11	9	12	23	9	157
A13		1		2	3		2				3	1	12
A14	8	4	3	9	13	6	6	4	4	6	10	4	77

A15	2					2		2		2	2		10
A16	1					1		1		1	1		5
A17	1	3	1	1		2		1	3	1		1	14
A18	4	2		4	2		4	2			6	4	28
A19	4	2		4	2		4	2			6	4	28
A20	4	2		4	2		4	2			6	4	28
A21		2	2	2		1			2	2			11
A22		1	1	2	2	1			2	1	1	1	12
A23	1	1		1	1			1				1	6
A24		1	1	1						1			4
A25	2			1	1		2	2			1	1	10
A26		1	1	1						1			4
A27		2	2				1	1		1	3		10
A28	2	1		2	1		2	1			3	2	14
A29	8	3	3	3	2	1	5	7	4	2	7	7	52
A30		1	1	1						1			4
A31	3		1	2	4	1		1	1	2	3	1	19
A32	3		1	2	4	1		1	1	2	3	1	19
A33	1	3	1	1		1		1	2	1		1	12
A34		1	1	1						1			4
A35	1	1			2		1	1	1	1	1		9
A36	4			2	4		2	2	2	2	2		20
A37	2	1		2	1		2	1			3	2	14
A38	2	1		2	1		2	1			3	2	14
A39	2					2		2		2	2		10
A40	3	5	3	1	3		2	3	3	3	7	3	36
A41	1	1		1			2	1			1		7
A42	1	1		1			2	1			1		7
A43		2	1			2		1					6
A44	1	1		1			2	1			1		7
A45	1	1		1			2	1			1		7
A46	1	1		1			2	1			1		7
A47	2	2		2			4	2			2		14
A48	1	1		1			2	1			1		7
A49	1	1		1			2	1			1		7
A50	1	1		1			2	1			1		7
A51	2	2		2			4	2			2		14
A52	1		1		1	1			1	1			6
A53								1		1		1	3
A54	2		1		2						1	1	7
A55	2		1		2						1	1	7
A56	2		1		2						1	1	7
A57	2		1		2						1	1	7
A58	2		1		2						1	1	7

A59		1					1	1			1		4
A60		2	1	1	1		1	1	3	2	2	2	16
A61	2			1	2		1	1	1	1	1		10
A62	1	2	1	2	1		1	1	2		2	3	16
A63	3	1		2	1	1	2	2		1	4	2	19
A64	10	12	10	14	23	9	11	7	9	13	19	8	145
A65	1	1	1	1		1	1	1	1		2		10
A66	3		1					2				1	7
A67	3			1	5	1	2	1	1	3	1	1	19
A68		2					2	2			2		8
A69		2			1			1			1	2	7
A70	1	2				1		1	2			1	8
A71		1					1	1			1		4
A72	2			4			2						8
A73	1			1	1						2	2	7
A74	2		1		2						1	1	7
A75	1	2				1		1	2			1	8
A76	1			2			1						4
A77	2			2	2						4	4	14
A78			1			1		1			1	1	5
A79	1			2			1						4
A80	1			2			1						4
A81	1		1		5	2	1		2	1	2	2	17
A82	2			1	2		1	1	1	1	1		10
A83	1			1			1	1			1		5
A84	2			2	2							2	8
A85			2	1		1		3		4	1	2	14
A86		1	1	1		1			1	1			6
A87		2			1			1			1	2	7
A88	3		1					2			2	2	10
A89	2		1		2						1	1	7
A90	6	8	8	6	6	2	6	4	2	2	14	2	66
A91	5	7	8	5	6	5	4	6	5	8	12	6	77
A92	5	8	8	4	6	5	4	7	5	6	12	5	75
A93	5	8	8	4	6	5	4	7	5	6	12	5	75
A94	5	8	8	4	6	5	4	7	5	6	12	5	75
A95	5	8	8	4	6	5	4	7	5	6	12	5	75
A96			4		2			2		4			12
A97	3	3	4	3	3	1	2	1	1	1	6	1	29
A98	5	7	4	3	4	1	3	5	4	3	9	4	52
A99	1			1			1	1			1		5
A100		1	3		1				1		2	1	9
A101	4			2	4		2	2	2	2	2		20
A102		1					1	1			1		4

A103	3	2	2	1	3	3	1	2	2	2	1		22
A104	1	2	1	1	3	3	2	1	1	2			17
A105			2	2			2				2	2	10
A106	3	1		2	1		4	3			2	1	17
A107		1					1	1			1		4
A108	2	1	1	2	3		1				2	1	13
A109		1	1	1						1			4
A110	1		1	1		1			1		1		6
A111	1	2		1	1		1	1	1	1	2	2	13
A112		1						1	2	1	1		6
A113		4	2		1		1	2		1	4	2	17
A114		1						1	2	1	1		6
A115	1	1		1	1			1				1	6
A116		1						1	2	1	1		6
A117	1			1	1							1	4
A118	1				2				1	1			5
A119	1			1			1	1			1		5
A120	1			2			1						4
A121			1		1			2					4
A122		2	1			2		1					6
A123	1	3	3	2	1	1	1	3		3	3	2	23
A124	6	3	3	6	13	6	5	2	4	6	8	4	66
A125	2	6		4	3		4	4	1	1	5	3	33
A126		3			1		1	2			2	2	11
A127	1				2				1	1			5
A128	1				2				1	1			5
A129	13	13	11	15	20	10	11	11	9	12	23	9	157
A130	3	1	3	4	3	3	2	1	1	4	4	1	30
A131		1	1	1		1			1	1			6
A132	1	5	3	3		2		1	4	3		1	23
A133					1				1	2			4
A134	6		2					4				2	14
A135	3	2	3	4	3	3	2	2	3	5	5	1	36
A136	3		4	2	1	2	1	3	1	2	2	2	23
A137	1			2			1						4
A138	4	1	4	5	3	4	2	1	2	4	5	1	36
A139	3	1	3	4	3	3	2	1	1	4	4	1	30
A140	3	6	2	5	4	6	2	4	9	2	6	5	54
A141	1			1			1		1	1	1		6
A142	3		1		1			2	1	2		1	11
A143	1	2	5	1	5		1	4	1	3	3	4	30
A144	4	1	1	2	1	2	1	1	3	3	3	1	23
A145	2			1	2		1	1	1	1	1		10
A146	2			1	2		1	1	1	1	1		10

A147	2			1	2		1	1	1	1	1		10
A148	2				2			1		1	1	1	8
A149					1				1	2			4
A150	1			1	1						2	2	7
A151	1			1			1	1			1		5
A152	2				4				2	2			10
A153	2				4				2	2			10
A154	5	5	4	4	4	3	3	4	4	5	7	4	52
A155	1		1	2	4	1	1		1	1	4	1	17
A156	1			1			1	1			1		5
A157	3	3	2	3	4	1	1	1	1		4	3	26
A158	3	3	2	3	4	1	1	1	1		4	3	26
A159	5	5	4	4	4	3	3	4	4	5	7	4	52
A160	2	8	4	6		10	4	2	12	6	4	2	60
A161			1		1	2			1			1	6
A162					4		2				4	2	12
A163	1		1	1		1			1		1		6
A164	2		1			1		1	1		1	2	9
A165	1			2			1						4
A166	1			2			1						4
A167	1			2			1						4
A168		1	1	1		1			1	1			6
A169	1		2		4	3	1		2	1	2	2	18
A170	1			1			1	1			1		5
A171		2	8	2		6	2	8		10	4	2	44
A172	3	3	3	3	3		3	1	1	2	6	1	29
A173	3	3	3	3	3		3	1	1	2	6	1	29
A174	1	1		1			2	1			1		7
A175	1	1		1			2	1			1		7
A176	1	1		1			2	1			1		7
A177	1	1		1			2	1			1		7
A178	1	1		1	1			1				1	6
A179		1					1	1			1		4
A180		4			1			3	4	2	3	2	19
A181	1	2	1	1	1	1		1	1		2	2	13
A182		1		2	1		1				1		6
A183	1	1			2		1	1	1	1	1		9
A184	5	2	1		7	1	2	3	3	4	3	1	32
A185	13	13	11	15	20	10	11	11	9	12	23	9	157
A186	8	4	3	9	13	6	6	4	4	6	10	4	77
A187	5	8	8	7	7	5	5	6	5	8	13	6	83
A188		2			1			1			1	2	7
A189	4			2	4		2	2	2	2	2		20
A190	2	2		2			4	2			2		14

A191	2				2			1		1	1	1	8
A192					4				2	2			8
A193	5	9	8	6	7	4	5	7	5	6	13	5	80
A194	2	1		2	1		2	1			3	2	14
A195	3		1					2				1	7
A196	1			2			1						4
A197	2	5	1	1		3		2	5	1		2	22
A198			1		1	2			1			1	6
A199	1	1	1		1	1		1	3	2	1		12
A200	2			3	6	2	6	1	1	3	3	1	28
A201	1		1	2	2	3	3	1	1	1	1	1	17
A202	1		2						1				4
A203	1		2						1				4
A204		1					1	1			1		4
A205		1		2	1		1				1		6
A206	2	1		1	3		1	1	1	1	3	2	16
A207		1	1			1		2					5
A208	1			1	1							1	4
A209	1			1	1							1	4
A210	1			1	1							1	4
A211	1			1	1							1	4
A212	1			1	1							1	4
A213	1			1	1							1	4
A214			1		1	2			1			1	6
A215	2				4				2	2			10
A216				2	1						2		5
A217	3	2	1					3	2		3	3	17
A218	1	8	1	3	3	2	2	5	2	1	4	3	35
A219			1		1	2			1			1	6
A220		2			1			1			1	2	7
A221	1	1		1			2	1			1		7
A222	1	1		1			2	1			1		7
A223		5	2	2	1	4	1	2			1		18
Total	428	381	296	393	464	235	331	351	270	313	584	296	4342

Table A.4: Holding Cost for Each Component

Component	Holding Cost
A1	114,653
A2	126,594
A3	58,542
A4	36,087
A5	55,276
A6	12,729
A7	14,353
A8	191,750
A9	42,882
A10	54,637
A11	40,714
A12	27,400
A13	13,184
A14	14,038
A15	303,848
A16	74,923
A17	87,635
A18	2,032
A19	20,429
A20	122,973
A21	87,979
A22	1593,889
A23	364,088
A24	51,980
A25	31,957
A26	54,926
A27	108,520
A28	60,671
A29	4,477
A30	15,693
A31	364,691
A32	300,000
A33	453,116
A34	217,074
A35	24,508
A36	84,468
A37	135,679
A38	19,596
A39	298,260

A40	57,626
A41	83,750
A42	26,954
A43	8925,000
A44	16,956
A45	34,275
A46	31,537
A47	16,983
A48	27,363
A49	31,169
A50	25,635
A51	14,992
A52	59,366
A53	68,727
A54	21,476
A55	24,447
A56	38,552
A57	36,166
A58	21,870
A59	117,125
A60	58,941
A61	106,929
A62	294,776
A63	27,077
A64	4,891
A65	28,739
A66	47,400
A67	170,906
A68	40,468
A69	20,248
A70	78,867
A71	54,638
A72	253,723
A73	4,446
A74	12,058
A75	11,900
A76	21,125
A77	5532,452
A78	379,468
A79	183,000
A80	430,000

A81	57,883
A82	33,171
A83	63,194
A84	54,227
A85	66,642
A86	273,278
A87	114,353
A88	78,192
A89	186,033
A90	13,247
A91	650,000
A92	380,000
A93	637,500
A94	1811,677
A95	2719,900
A96	15,240
A97	145,280
A98	239,363
A99	34,109
A100	550,371
A101	178,813
A102	153,500
A103	119,365
A104	72,221
A105	47,457
A106	259,003
A107	47,188
A108	58,478
A109	95,469
A110	58,007
A111	78,357
A112	55,870
A113	572,667
A114	474,641
A115	300,000
A116	517,000
A117	20,080
A118	283,740
A119	525,264
A120	58,500
A121	706,439

A122	61,000
A123	96,087
A124	388,883
A125	4,280
A126	46,232
A127	541,663
A128	302,107
A129	8,980
A130	33,689
A131	742,185
A132	15,510
A133	666,375
A134	48,328
A135	21,912
A136	11,424
A137	144,838
A138	23,054
A139	23,571
A140	8,775
A141	38,792
A142	39,234
A143	2,565
A144	17,900
A145	26,000
A146	27,901
A147	24,493
A148	1137,500
A149	94,550
A150	17,823
A151	100,000
A152	29,500
A153	2,750
A154	3,823
A155	117,833
A156	96,632
A157	27,176
A158	59,570
A159	5,293
A160	5,000
A161	3,203
A162	4,342

A163	4,748
A164	103,844
A165	4,289
A166	2,811
A167	4,360
A168	48,536
A169	50,815
A170	412,426
A171	23,400
A172	89,002
A173	180,684
A174	3,850
A175	15,280
A176	17,050
A177	19,780
A178	197,380
A179	28,200
A180	260,917
A181	266,503
A182	285,565
A183	16,417
A184	58,315
A185	11,788
A186	15,449
A187	17,334
A188	30,968
A189	7,000
A190	8,997
A191	86,230
A192	307032,778
A193	3,713
A194	35,726
A195	32,592
A196	45,000
A197	71,566
A198	44,034
A199	25,096
A200	85,979
A201	90,825
A202	10,763
A203	12,000

A204	15,151
A205	49,204
A206	100,301
A207	1232,000
A208	305,800
A209	398,790
A210	312,755
A211	1375,780
A212	41,770
A213	64,710
A214	11529,915
A215	529,346
A216	25,000
A217	52,671
A218	29,978
A219	32,570
A220	109,500
A221	18,077
A222	10,935
A223	15,620
Total	367016,642

Appendix B

Table B.1: Component Order Quantity Results for SAW

SAW													
Component	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
A1	10		3	6	2	8		6	4			4	43
A2	2			2		2							6
A3	15		7	14	19	20		6	9			7	97
A4	34		22	23	31	35		14	16			18	193
A5	7		1	2	1	2		4				1	18
A6	2			1		2		1	1				7
A7	19		15	9	12	14		8	7			11	95
A8	10		2		4	4		4				4	28
A9	4			2	2	4		4					16
A10	2			1	1	2		2					8
A11	3		1			2		1					7
A12	34		22	23	31	34		14	16			18	192
A13	1		1	3	3	3			1			2	14
A14	15		7	14	19	20		6	9			7	97
A15	2				2	4		2	2			2	14
A16	1				1	2		1	1			1	7
A17	7		1	3		2		1	3			1	18
A18	8		2	8	4	8		8	2			6	46
A19	8		2	8	4	8		8	2			6	46
A20	8		2	8	4	8		8	2			6	46
A21	6		3	4		1			2				16
A22	4		1	3	2	2			2			1	15
A23	2			1	1			1				3	8
A24	2		2	1		1							6
A25	3			2	1	3		4				2	15
A26	2		2	1		1							6
A27	2		2			1		1					6
A28	4		1	4	2	4		4	1			3	23
A29	16		5	8	5	13		11	5			9	72
A30	2		2	1		1							6
A31	4		1	6	7	3		3	2			2	28
A32	4		1	6	7	3		3	2			2	28
A33	6		2	2		2		1	2			1	16
A34	2		2	1		1							6
A35	4		2		3	2		1	1				13
A36	6		2	2	6	4		2	4				26
A37	4		1	4	2	4		4	1			3	23
A38	4		1	4	2	4		4	1			3	23

A39	2				2	4		2	2			2	14
A40	8		5	1	4	3		4	3	4		3	35
A41	2			1	1	2		2					8
A42	2			1	1	2		2					8
A43	3		1		1	2		1					8
A44	2			1	1	2		2					8
A45	2			1	1	2		2					8
A46	2			1	1	2		2					8
A47	4			2	2	4		4					16
A48	2			1	1	2		2					8
A49	2			1	1	2		2					8
A50	2			1	1	2		2					8
A51	4			2	2	4		4					16
A52	1		1	2	1	1		1	1				8
A53	2			2	1	1		1				1	8
A54	2		1		2							1	6
A55	2		1		2							1	6
A56	2		1		2							1	6
A57	2		1		2							1	6
A58	2		1		2							1	6
A59	3		1			2		1					7
A60	2		1	3	1	5		1	3			2	18
A61	3		1	1	3	2		1	2				13
A62	3		1	3	1	5		2	2			4	21
A63	5		1	4	3	6		5	2			4	30
A64	29		20	20	31	27		8	14			17	166
A65	5		2	1		3		1	1			1	14
A66	5		1	1				2				1	10
A67	4		1	2	9	4		2	2	1		2	27
A68	6		2			4		2					14
A69	2				2			1				2	7
A70	4			1		1		1	2			1	10
A71	3		1			2		1					7
A72	4			4		4							12
A73	2		1	3	1	2		2	1			3	15
A74	2		1		2							1	6
A75	4			1		1		1	2			1	10
A76	2			2		2							6
A77	4		2	6	2	4		4	2			6	30
A78	1		2	1	2	1		1	1			1	10
A79	2			2		2							6
A80	2			2		2							6
A81	1		2	1	6	3			3			3	19
A82	3		1	1	3	2		1	2				13

A83	2			1		2		1	1				7
A84	2			4	2	2		2				4	16
A85	2		3	2	2	1		4	1	1		3	19
A86	3		1	2		1			1				8
A87	2				2			1				2	7
A88	6		2	2		1		3	1			2	17
A89	2		1		2							1	6
A90	20		12	6	6	12		4	4			4	68
A91	18		13	8	11	12		7	6			11	86
A92	18		14	7	11	13		8	6			11	88
A93	18		14	7	11	13		8	6			11	88
A94	18		14	7	11	13		8	6			11	88
A95	18		14	7	11	13		8	6			11	88
A96			4		2			4					10
A97	7		5	3	3	4		1	2			2	27
A98	15		7	3	5	6		6	4			7	53
A99	2			1		2		1	1				7
A100	1		4	1	2	1			1			2	12
A101	6		2	2	6	4		2	4				26
A102	3		1			2		1					7
A103	7		3	3	5	5		3	3				29
A104	4		2	1	5	5		1	1			1	20
A105			2	2		6						2	12
A106	5			3	2	5		6				2	23
A107	3		1			2		1					7
A108	3		2	2	3	2			1			1	14
A109	2		2	1		1							6
A110	2		1	1		1			1			1	7
A111	3		1	1	2	1		2	1			2	13
A112	1		1			1		1	2				6
A113	4		2		2	1		2		1		2	14
A114	1		1			1		1	2				6
A115	2			1	1			1				3	8
A116	1		1			1		1	2				6
A117	1			2	1	1		1				2	8
A118	1		1		3				1				6
A119	2			1		2		1	1				7
A120	2			2		2							6
A121			2	1	1			3	1				8
A122	3		1		1	2		1					8
A123	6		3	2	2	2		3	1	1		4	24
A124	11		3	11	19	16		4	8			7	79
A125	12		4	4	4	7		5	2			5	43
A126	5		1		2	2		2				2	14

A127	1		1		3				1				6
A128	1		1		3				1				6
A129	34		22	23	31	34		14	16			18	192
A130	7		5	6	8	7		2	3			4	42
A131	3		1	2		1			1				8
A132	12		5	6		3		1	4	1		1	33
A133				2	1	1			1	1			6
A134	10		2	2				4				2	20
A135	8		6	6	8	8		3	5	4		4	52
A136	5		5	4	2	5		4	1			2	28
A137	2			2		2							6
A138	9		6	7	8	8		2	4			5	49
A139	7		5	6	8	7		2	3			4	42
A140	19		4	11	5	11		6	10			5	71
A141	1		1	1		1		1	1				6
A142	5		1	3	1	1		2	1			1	15
A143	3		8	3	8	3		6	2			4	37
A144	6		5	5	3	5		2	4	2		2	34
A145	3		1	1	3	2		1	2				13
A146	3		1	1	3	2		1	2				13
A147	3		1	1	3	2		1	2				13
A148	3			1	5	1		2	1			1	14
A149				2	1	1			1	1			6
A150	2		1	3	1	2		2	1			3	15
A151	2			1		2		1	1				7
A152	2		2		6				2	2			14
A153	2		2		6				2	2			14
A154	14		8	5	7	8		5	4			9	60
A155	1		1	6	4	3		1	1			3	20
A156	2			1		2		1	1				7
A157	7		3	3	5	3		1	2			4	28
A158	7		3	3	5	3		1	2			4	28
A159	14		8	5	7	8		5	4			9	60
A160	20		8	12	2	16		2	14	2		2	78
A161			1		1	2			2			1	7
A162				2	4	2						4	12
A163	2		1	1		1			1			1	7
A164	3		2		2	2		1	1			3	14
A165	2			2		2							6
A166	2			2		2							6
A167	2			2		2							6
A168	3		1	2		1			1				8
A169	1		2	3	4	4		1	3			3	21
A170	2			1		2		1	1				7

A171	6		14	6	8	10		10	2	2		10	68
A172	6		5	3	3	4		2	2			1	26
A173	6		5	3	3	4		2	2			1	26
A174	2			1	1	2		2					8
A175	2			1	1	2		2					8
A176	2			1	1	2		2					8
A177	2			1	1	2		2					8
A178	2			1	1			1				3	8
A179	3		1			2		1					7
A180	4		2		2	2		3	4			2	19
A181	4		1	1	2	1		1	1			3	14
A182	1		1	2	1	2			1				8
A183	4		2		3	2		1	1				13
A184	12		5	3	12	6		5	4	5		1	53
A185	34		22	23	31	34		14	16	20		18	212
A186	15		7	14	19	20		6	9	11		7	108
A187	19		14	10	12	14		7	7	9		11	103
A188	2				2			1		1		2	8
A189	6		2	2	6	4		2	4	4			30
A190	4			2	2	4		4					16
A191	3			1	5	1		2	1	1		1	15
A192			2	2	4	2		4	2				16
A193	19		15	9	12	14		8	7	9		11	104
A194	4		1	4	2	4		4	1			3	23
A195	5		1	1				2				1	10
A196	2			2		2		2	5			2	15
A197	11		1	4		3			2	2		1	24
A198			1		1	2		2	3	1			10
A199	2		2	2	1	2							9
A200	3		1	4	7	9		1	2	5		4	36
A201	2		1	2	2	7		1	3	4		2	24
A202	2		2			2			1				7
A203	2		2			2			1				7
A204	3		1			2		1		1			8
A205	1		1	2	1	2			1	1			9
A206	6		3	3	4	4		3	2	2		3	30
A207	2		2		1	2		2	1			1	11
A208	1			2	1	1		1				2	8
A209	1			2	1	1		1				2	8
A210	1			2	1	1		1				2	8
A211	1			2	1	1		1				2	8
A212	1			2	1	1		1				2	8
A213	1			2	1	1		1				2	8
A214			1		1	2			2	2		1	9

[illegible]

[illegible]

A68							2						2
A69	1												1
A70													0
A71							1						1
A72	2												2
A73							1						1
A74							2						2
A75													0
A76	1												1
A77							2						2
A78	1						1						2
A79	1												1
A80	1												1
A81	1												1
A82	2												2
A83	1												1
A84							2						2
A85	3						2						5
A86	1												1
A87	1												1
A88													0
A89							2						2
A90							8						8
A91	5						8						13
A92	5						8						13
A93	5						8						13
A94	5						8						13
A95	5						8						13
A96							2						2
A97							3						3
A98	2						6						8
A99	1												1
A100							1						1
A101	4												4
A102							1						1
A103	2												2
A104	1												1
A105													0
A106	1						1						2
A107							1						1
A108							2						2

A109													0
A110							1						1
A111	1						1						2
A112							1						1
A113	1												1
A114							1						1
A115	1												1
A116							1						1
A117							1						1
A118	1												1
A119	1												1
A120	1												1
A121	1												1
A122													0
A123	3						1						4
A124	2						1						3
A125	2						3						5
A126	1						1						2
A127	1												1
A128	1												1
A129	8						9						17
A130							1						1
A131	1												1
A132	2												2
A133							1						1
A134													0
A135							2						2
A136							2						2
A137	1												1
A138							2						2
A139							1						1
A140	2						1						3
A141							1						1
A142							1						1
A143	3						2						5
A144	1						4						5
A145	2												2
A146	2												2
A147	2												2
A148													0
A149							1						1

[illegible]

A191													0
A192							2						2
A193	5						8						13
A194	1						1						2
A195													0
A196	1												1
A197	1												1
A198													0
A199							1						1
A200	2												2
A201	1												1
A202	1						1						2
A203	1						1						2
A204							1						1
A205													0
A206	1						2						3
A207	2						1						3
A208							1						1
A209							1						1
A210							1						1
A211							1						1
A212							1						1
A213							1						1
A214													0
A215	2												2
A216							1						1
A217	1												1
A218	2						2						4
A219													0
A220	1												1
A221	1												1
A222													0
A223													0
Total	264						278						542

Table B.3: Component Order Quantity Results for ISL

ISL													
Component	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
A1										11			11
A2													0
A3										27			27
A4										55			55
A5										1			1
A6										2			2
A7										28			28
A8										8			8
A9										2			2
A10										1			1
A11										2			2
A12										55			55
A13										5			5
A14										27			27
A15										4			4
A16										2			2
A17										1			1
A18										6			6
A19										6			6
A20										6			6
A21										2			2
A22										3			3
A23										1			1
A24										3			3
A25										2			2
A26										3			3
A27										4			4
A28										3			3
A29										14			14
A30										3			3
A31										7			7
A32										7			7
A33										3			3
A34										3			3
A35										4			4
A36										8			8
A37										3			3
A38										3			3

[illegible]

[illegible]

A121													0
A122										1			1
A123										6			6
A124										24			24
A125										12			12
A126										4			4
A127										2			2
A128										2			2
A129										55			55
A130										11			11
A131										1			1
A132										4			4
A133										2			2
A134													0
A135										10			10
A136										7			7
A137													0
A138										13			13
A139										11			11
A140										11			11
A141										3			3
A142										3			3
A143										12			12
A144										6			6
A145										4			4
A146										4			4
A147										4			4
A148										3			3
A149										2			2
A150										2			2
A151										2			2
A152										2			2
A153										2			2
A154										19			19
A155										7			7
A156										2			2
A157										8			8
A158										8			8
A159										19			19
A160										12			12
A161										2			2

[illegible]

A203													0
A204										1			1
A205										1			1
A206										4			4
A207													0
A208													0
A209													0
A210													0
A211													0
A212													0
A213													0
A214													0
A215										2			2
A216										2			2
A217										3			3
A218										5			5
A219													0
A220										1			1
A221										1			1
A222										1			1
A223										1			1
Total										1.286			1.286

Table B.4: Transfer Quantity Between ISL-SAW

ISL-SAW													
Component	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
A1										4			4
A2													0
A3										6	5		11
A4										20			20
A5													0
A6											1		1
A7										9			9
A8											4		4
A9													0
A10													0
A11											1		1
A12										20			20
A13										2			2
A14										6	5		11

[illegible]

A56											1		1
A57											1		1
A58											1		1
A59											1		1
A60									2	2			4
A61										2			2
A62									2	1			3
A63													0
A64									11	10			21
A65									1	1			2
A66													0
A67										2			2
A68										2			2
A69										1			1
A70													0
A71										1			1
A72													0
A73													0
A74										1			1
A75													0
A76													0
A77													0
A78									1				1
A79													0
A80													0
A81									3	1			4
A82										2			2
A83										1			1
A84													0
A85										1			1
A86													0
A87										1			1
A88													0
A89										1			1
A90									8				8
A91									8				8
A92									8				8
A93									8				8
A94									8				8
A95									8				8
A96									2				2

[illegible]

A138										4			4
A139										3			3
A140										3			3
A141										1			1
A142											1		1
A143										4	2		6
A144													0
A145											2		2
A146											2		2
A147											2		2
A148											1		1
A149													0
A150													0
A151											1		1
A152													0
A153													0
A154										3	4		7
A155										2			2
A156											1		1
A157										2	2		4
A158										2	2		4
A159										3	4		7
A160											2		2
A161										2			2
A162										2			2
A163										1			1
A164													0
A165													0
A166													0
A167													0
A168													0
A169										3			3
A170											1		1
A171											2		2
A172										3			3
A173										3			3
A174													0
A175													0
A176													0
A177													0
A178										1			1

[illegible]

A220													0
A221													0
A222													0
A223													0
Total										258	135		393

Table B.5: Transfer Quantity Between SAW-ISL

SAW-ISL													
Component	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
A1	7		2	2	1	3		4	4			4	27
A2	1			2		1							4
A3	12		3	9	13	12		4	4			4	61
A4	26		11	15	20	22		11	9			9	123
A5	5		1	1		2		3				1	13
A6	1			1		1		1					4
A7	14		8	6	7	9		7	5			5	61
A8	6				2	2		4				4	18
A9	4			2		4		2					12
A10	2			1		2		1					6
A11	1					1		1					3
A12	26		11	15	20	21		11	9			9	122
A13	1			2	3	2						1	9
A14	12		3	9	13	12		4	4			4	61
A15	2					2		2					6
A16	1					1		1					3
A17	4		1	1		2		1	3			1	13
A18	6			4	2	4		2				4	22
A19	6			4	2	4		2				4	22
A20	6			4	2	4		2				4	22
A21	2		2	2		1			2				9
A22	1		1	2	2	1			2			1	10
A23	2			1	1			1					5
A24	1		1	1									3
A25	2			1	1	2		2				1	9
A26	1		1	1									3
A27	2		2			1		1					6
A28	3			2	1	2		1				2	11
A29	11		3	3	2	6		7	4			7	43
A30	1		1	1									3
A31	3		1	2	4	1		1	1			1	14

A32	3		1	2	4	1		1	1			1	14
A33	4		1	1		1		1	2			1	11
A34	1		1	1									3
A35	2				2	1		1	1				7
A36	4			2	4	2		2	2				16
A37	3			2	1	2		1				2	11
A38	3			2	1	2		1				2	11
A39	2					2		2					6
A40	8		3	1	3	2		3	3			3	26
A41	2			1		2		1					6
A42	2			1		2		1					6
A43	2		1			2		1					6
A44	2			1		2		1					6
A45	2			1		2		1					6
A46	2			1		2		1					6
A47	4			2		4		2					12
A48	2			1		2		1					6
A49	2			1		2		1					6
A50	2			1		2		1					6
A51	4			2		4		2					12
A52	1		1		1	1			1				5
A53								1				1	2
A54	2		1		2							1	6
A55	2		1		2							1	6
A56	2		1		2							1	6
A57	2		1		2							1	6
A58	2		1		2							1	6
A59	1					1		1					3
A60	2		1	1	1	1		1	3			2	12
A61	2			1	2	1		1	1				8
A62	3		1	2	1	1		1	2			3	14
A63	4			2	1	3		2				2	14
A64	22		10	14	23	20		7	9			8	113
A65	2		1	1		2		1	1				8
A66	3		1					2				1	7
A67	3			1	5	3		1	1			1	15
A68	2					2		2					6
A69	2				1			1				2	6
A70	3					1		1	2			1	8
A71	1					1		1					3
A72	2			4		2							8

A73	1			1	1							2	5
A74	2		1		2							1	6
A75	3					1		1	2			1	8
A76	1			2		1							4
A77	2			2	2							4	10
A78			1			1		1				1	4
A79	1			2		1							4
A80	1			2		1							4
A81	1		1		6	3			2			2	15
A82	2			1	2	1		1	1				8
A83	1			1		1		1					4
A84	2			2	2							2	8
A85			2	1		1		3				2	9
A86	1		1	1		1			1				5
A87	2				1			1				2	6
A88	3		1					2				2	8
A89	2		1		2							1	6
A90	14		8	6	6	8		4	2			2	50
A91	12		8	5	6	9		6	5			6	57
A92	13		8	4	6	9		7	5			5	57
A93	13		8	4	6	9		7	5			5	57
A94	13		8	4	6	9		7	5			5	57
A95	13		8	4	6	9		7	5			5	57
A96			4		2			2					8
A97	6		4	3	3	3		1	1			1	22
A98	12		4	3	4	4		5	4			4	40
A99	1			1		1		1					4
A100	1		3		1				1			1	7
A101	4			2	4	2		2	2				16
A102	1					1		1					3
A103	5		2	1	3	4		2	2				19
A104	3		1	1	3	5		1	1				15
A105			2	2		2						2	8
A106	4			2	1	4		3				1	15
A107	1					1		1					3
A108	3		1	2	3	1						1	11
A109	1		1	1									3
A110	1		1	1		1			1				5
A111	3			1	1	1		1	1			2	10
A112	1							1	2				4
A113	4		2		1	1		2				2	12

A114	1							1	2				4
A115	2			1	1			1				1	6
A116	1							1	2				4
A117	1			1	1							1	4
A118	1				2				1				4
A119	1			1		1		1					4
A120	1			2		1							4
A121			1		1			2					4
A122	2		1			2		1					6
A123	4		3	2	1	2		3				2	17
A124	9		3	6	13	11		2	4			4	52
A125	8			4	3	4		4	1			3	27
A126	3				1	1		2				2	9
A127	1				2				1				4
A128	1				2				1				4
A129	26		11	15	20	21		11	9			9	122
A130	4		3	4	3	5		1	1			1	22
A131	1		1	1		1			1				5
A132	6		3	3		2		1	4			1	20
A133					1				1				2
A134	6		2					4				2	14
A135	5		3	4	3	5		2	3			1	26
A136	3		4	2	1	3		3	1			2	19
A137	1			2		1							4
A138	5		4	5	3	6		1	2			1	27
A139	4		3	4	3	5		1	1			1	22
A140	9		2	5	4	8		4	9			5	46
A141	1			1		1			1				4
A142	3		1		1			2	1			1	9
A143	3		5	1	5	1		4	1			4	24
A144	5		1	2	1	3		1	3			1	17
A145	2			1	2	1		1	1				8
A146	2			1	2	1		1	1				8
A147	2			1	2	1		1	1				8
A148	2				2			1				1	6
A149					1				1				2
A150	1			1	1							2	5
A151	1			1		1		1					4
A152	2				4				2				8
A153	2				4				2				8
A154	10		4	4	4	6		4	4			4	40

A155	1		1	2	4	2			1			1	12
A156	1			1		1		1					4
A157	6		2	3	4	2		1	1			3	22
A158	6		2	3	4	2		1	1			3	22
A159	10		4	4	4	6		4	4			4	40
A160	10		4	6		14		2	12			2	50
A161			1		1	2			1			1	6
A162					4	2						2	8
A163	1		1	1		1			1				5
A164	2		1			1		1	1			2	8
A165	1			2		1							4
A166	1			2		1							4
A167	1			2		1							4
A168	1		1	1		1			1				5
A169	1		2		4	4			2			2	15
A170	1			1		1		1					4
A171	2		8	2		8		8				2	30
A172	6		3	3	3	3		1	1			1	21
A173	6		3	3	3	3		1	1			1	21
A174	2			1		2		1					6
A175	2			1		2		1					6
A176	2			1		2		1					6
A177	2			1		2		1					6
A178	2			1	1			1				1	6
A179	1					1		1					3
A180	4				1			3	4			2	14
A181	3		1	1	1	1		1	1			2	11
A182	1			2	1	1							5
A183	2				2	1		1	1				7
A184	7		1		7	3		3	3			1	25
A185	26		11	15	20	21		11	9			9	122
A186	12		3	9	13	12		4	4			4	61
A187	13		8	7	7	10		6	5			6	62
A188	2				1			1				2	6
A189	4			2	4	2		2	2				16
A190	4			2		4		2					12
A191	2				2			1				1	6
A192					4				2				6
A193	14		8	6	7	9		7	5			5	61
A194	3			2	1	2		1				2	11
A195	3		1					2				1	7

A196	1			2		1						4
A197	7		1	1		3		2	5		2	21
A198			1		1	2			1		1	6
A199	2		1		1	1		1	3			9
A200	2			3	6	8		1	1		1	22
A201	1		1	2	2	6		1	1		1	15
A202	1		2						1			4
A203	1		2						1			4
A204	1					1		1				3
A205	1			2	1	1						5
A206	3			1	3	1		1	1		2	12
A207	1		1			1		2				5
A208	1			1	1						1	4
A209	1			1	1						1	4
A210	1			1	1						1	4
A211	1			1	1						1	4
A212	1			1	1						1	4
A213	1			1	1						1	4
A214			1		1	2			1		1	6
A215	2				4				2			8
A216				2	1							3
A217	5		1					3	2		3	14
A218	9		1	3	3	4		5	2		3	30
A219			1		1	2			1		1	6
A220	2				1			1			2	6
A221	2			1		2		1				6
A222	2			1		2		1				6
A223	5		2	2	1	5		2				17
Total	809		296	393	465	566		351	271		295	3.446

Table B.6: Ending Inventory for ISL

ISL													
Component	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
A1	3					3				5			11
A2						1							1
A3	4					6				15			25
A4	13					11				23			47
A5	1					2				1			4
A6						1				2			3
A7	9					5				13			27
A8	6					2				8			16
A9	2					4				2			8
A10	1					2				1			4
A11	1					1				2			4
A12	13					11				23			47
A13	1					2				3			6
A14	4					6				15			25
A15										2			2
A16										1			1
A17	3												3
A18	2					4				6			12
A19	2					4				6			12
A20	2					4				6			12
A21	2												2
A22	1									1			2
A23	1												1
A24	1												1
A25						2				2			4
A26	1												1
A27	2					1				3			6
A28	1					2				3			6
A29	3					5				10			18
A30	1												1
A31										3			3
A32										3			3
A33	3									1			4
A34	1												1
A35	1					1				3			5
A36						2				6			8
A37	1					2				3			6
A38	1					2				3			6

A39										2			2
A40	5					2				7			14
A41	1					2				1			4
A42	1					2				1			4
A43	2												2
A44	1					2				1			4
A45	1					2				1			4
A46	1					2				1			4
A47	2					4				2			8
A48	1					2				1			4
A49	1					2				1			4
A50	1					2				1			4
A51	2					4				2			8
A52													0
A53										1			1
A54										2			2
A55										2			2
A56										2			2
A57										2			2
A58										2			2
A59	1					1				2			4
A60	2					1				4			7
A61						1				3			4
A62	2					1				3			6
A63	1					2				4			7
A64	12					11				29			52
A65	1					1				3			5
A66													0
A67						2				3			5
A68	2					2				4			8
A69	2									2			4
A70	2												2
A71	1					1							2
A72						2							2
A73													0
A74										2			2
A75	2									2			4
A76						1				2			3
A77										4			4
A78										1			1
A79						1							1

A80						1							1
A81						1				3			4
A82						1				3			4
A83						1				2			3
A84													0
A85										2			2
A86	1												1
A87	2									2			4
A88										2			2
A89										2			2
A90	8					6				14			28
A91	7					4				12			23
A92	8					4				12			24
A93	8					4				12			24
A94	8					4				12			24
A95	8					4				12			24
A96													0
A97	3					2				6			11
A98	7					3				13			23
A99						1				2			3
A100	1									2			3
A101						2				6			8
A102	1					1				2			4
A103	2					1				4			7
A104	2					2							4
A105						2				2			4
A106	1					4				3			8
A107	1					1				2			4
A108	1					1				3			5
A109	1												1
A110										1			1
A111	2					1				3			6
A112	1									2			3
A113	4					1				4			9
A114	1									2			3
A115	1												1
A116	1									2			3
A117													0
A118													0
A119						1				2			3
A120						1							1

[illegible]

[illegible]

A203													0
A204	1					1				1			3
A205	1					1				1			3
A206	1					1				3			5
A207	1												1
A208													0
A209													0
A210													0
A211													0
A213													0
A214													0
A215													0
A216										2			2
A217	2									3			5
A218	8					2				4			14
A219													0
A220	2									1			3
A221	1					2				1			4
A222	1					2				1			4
A223	5					1				1			7
Total	381					331				715			1.427

Table B.7: Ending Inventory for SAW

SAW													
Component	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
A1	2					2				2			6
A2	1												1
A3	1					3							4
A4	5					5				9			19
A5	1												1
A6						1							1
A7	4					2				4			10
A8	2					2							4
A9													0
A10													0
A11	1					1							2
A12	5					5				9			19
A13													0
A14	1					3							4
A15						2							2

[illegible]

A57													0
A58													0
A59	1					1							2
A60						1							1
A61						1							1
A62						2							2
A63	1					3							4
A64	4					2							6
A65	2					1							3
A66	1												1
A67	1												1
A68	2					2							4
A69													0
A70													0
A71	1					1							2
A72	2												2
A73	1					2							3
A74													0
A75													0
A76	1												1
A77	2					4							6
A78	1												1
A79	1												1
A80	1												1
A81													0
A82						1							1
A83						1							1
A84						2							2
A85	2												2
A86	1												1
A87													0
A88	2					1							3
A89													0
A90	4					2				4			10
A91	5					1				4			10
A92	4					2				4			10
A93	4					2				4			10
A94	4					2				4			10
A95	4					2				4			10
A96													0
A97	1									1			2

A98	2					1							3
A99						1							1
A100						1							1
A101						2							2
A102	1					1							2
A103						1							1
A104										2			2
A105						2							2
A106	1					1							2
A107	1					1							2
A108													0
A109										1			1
A110	1												1
A111													0
A112													0
A113										1			1
A114													0
A115													0
A116													0
A117						1							1
A118										1			1
A119						1							1
A120	1												1
A121													0
A122										1			1
A123	2												2
A124	1					1							2
A125	2					2							4
A126	1					1							2
A127										1			1
A128										1			1
A129	5					5				9			19
A130	3									1			4
A131	1												1
A132	3												3
A133										1			1
A134	2												2
A135	3									2			5
A136	1					1							2
A137	1												1
A138	4									1			5

A139	3									1			4
A140	4					3				1			8
A141													0
A142	1												1
A143						1							1
A144	1									1			2
A145						1							1
A146						1							1
A147						1							1
A148	1												1
A149										1			1
A150	1					2							3
A151						1							1
A152										2			2
A153										2			2
A154	3					1							4
A155													0
A156						1							1
A157	1												1
A158	1												1
A159	3					1							4
A160	2												2
A161													0
A162													0
A163	1												1
A164													0
A165	1												1
A166	1												1
A167	1												1
A168	1												1
A169													0
A170						1							1
A171	4					2							6
A172										1			1
A173										1			1
A174													0
A175													0
A176													0
A177													0
A178													0
A179	1					1							2

A180													0
A181	1												1
A182													0
A183	1					1							2
A184	3					2				5			10
A185	5					5				9			19
A186	1					3				5			9
A187	5					1				4			10
A188										1			1
A189						2				4			6
A190													0
A191	1									1			2
A192										4			4
A193	4					2							6
A194	1					2							3
A195	1												1
A196	1												1
A197	1												1
A198													0
A199										1			1
A200						1				2			3
A201						1				1			2
A202													0
A203													0
A204	1					1				1			3
A205										2			2
A206	2					3							5
A207	1					1							2
A208						1							1
A209						1							1
A210						1							1
A211						1							1
A212						1							1
A213						1							1
A214													0
A215										2			2
A216													0
A217	2					1				1			4
A218	1					1				4			6
A219													0
A220										1			1

A221													0
A222													0
A223										2			2
Total	197					164				141			502

Table B.8: Ending Inventory for ESB

ESB													
Component	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
A1	2	2	2	1	1								8
A2	1	1	1	1									4
A3	3	3	3	1			1	1	1	1			14
A4	7	7	6	5	2		8	5	3	1			44
A5	1	1	1										3
A6	1	1	1	1	1								5
A7	4	4	3	2	1		7	4	2				27
A8							2	2					4
A9	2	2	2										6
A10	1	1	1										3
A11							1	1					2
A12	7	7	6	5	2		8	5	3	1			44
A13													0
A14	3	3	3	3	1		1	1	1	1			17
A15													0
A16													0
A17	1	1											2
A18	2	2	2				2	2	2	2			14
A19	2	2	2				2	2	2	2			14
A20	2	2	2				2	2	2	2			14
A21	1	1											2
A22	1	1											2
A23	1	1	1										3
A24													0
A25							1	1	1	1			4
A26													0
A27													0
A28	1	1	1				1	1	1	1			7
A29	3	3	3	2	1		2	2	2	2	1		21
A30													0
A31							1	1	1	1			4
A32							1	1	1	1			4

A33													0
A34													0
A35	1	1	1	1			1	1					6
A36	4	4	4	4	2								18
A37	1	1	1				1	1	1	1			7
A38	1	1	1				1	1	1	1			7
A39													0
A40							4	2	1				7
A41	1	1	1										3
A42	1	1	1										3
A43													0
A44	1	1	1										3
A45	1	1	1										3
A46	1	1	1										3
A47	2	2	2										6
A48	1	1	1										3
A49	1	1	1										3
A50	1	1	1										3
A51	2	2	2										6
A52													0
A53													0
A54							2	1					3
A55							2	1					3
A56							2	1					3
A57							2	1					3
A58							2	1					3
A59							1	1					2
A60	1	1	1	1	1		1	1	1	1			9
A61	2	2	2	2	1								9
A62	1	1	1	1	1		1	1	1	1			9
A63	1	1	1				1	1	1	1			7
A64	7	7	7	5	1		7	5	3	1			43
A65							2	1					3
A66													0
A67	1	1	1	1									4
A68							2	2					4
A69													0
A70													0
A71							1	1					2
A72	2	2	2	2									8
A73							1	1	1	1			4

A74							2	1					3
A75													0
A76	1	1	1	1									4
A77							2	2	2	2			8
A78	1	1					1						3
A79	1	1	1	1									4
A80	1	1	1	1									4
A81	1	1	1	1									4
A82	2	2	2	2	1								9
A83	1	1	1	1	1								5
A84							2	2	2	2			8
A85	3	3	2	1			2	1	1				13
A86	1	1											2
A87													0
A88													0
A89							2	1					3
A90							8	6	2				16
A91	4	4	3	1			8	5	3				28
A92	4	4	3	2	1		7	4	2				27
A93	4	4	3	2	1		7	4	2				27
A94	4	4	3	2	1		7	4	2				27
A95	4	4	3	2	1		7	4	2		1		28
A96							2	2	2	2			8
A97							3	2	1				6
A98	1	1	1				6	4	2				15
A99	1	1	1	1	1								5
A100							1						1
A101	4	4	4	4	2								18
A102							1	1					2
A103	2	2	2	2	1								9
A104	1	1	1	1									4
A105													0
A106	1	1	1				1	1	1	1			7
A107							1	1					2
A108							2	1					3
A109													0
A110							1	1	1				3
A111							1	1	1				3
A112							1						1
A113													0
A114							1						1

A115	1	1	1										3
A116							1						1
A117							1	1	1	1			4
A118	1	1	1	1									4
A119	1	1	1	1	1								5
A120	1	1	1	1									4
A121	1	1	1	1	1								5
A122													0
A123	3	3	2				1	1	1				11
A124	2	2	2	2			1	1	1	1			12
A125	1	1	1				3	3	1				10
A126							1	1					2
A127	1	1	1	1									4
A128	1	1	1	1									4
A129	7	7	6	5	2		8	5	3	1			44
A130							1	1	1				3
A131	1	1											2
A132	1	1											2
A133							1	1	1	1	1		5
A134													0
A135							2	1	1				4
A136							1	1	1	1			4
A137	1	1	1	1									4
A138							2	2	2				6
A139							1	1	1				3
A140	2	2											4
A141							1	1	1				3
A142							1	1	1	1	1		5
A143	2	2	2	2	1		2	1	1	1			14
A144							3	3	3	2	2		13
A145	2	2	2	2	1								9
A146	2	2	2	2	1								9
A147	2	2	2	2	1								9
A148													0
A149							1	1	1	1	1		5
A150							1	1	1	1			4
A151	1	1	1	1	1								5
A152	2	2	2	2									8
A153	2	2	2	2									8
A154	1	1	1				6	4	2				15
A155							1	1	1	1			4

A197	1	1											2
A198													0
A199							1						1
A200	2	2	2	2	1								9
A201	1	1	1	1	1								5
A202	1						1	1	1	1			5
A203	1						1	1	1	1			5
A204							1	1					2
A205													0
A206	1	1	1	1			2	2	1	1			10
A207	2	2	1	1	1								7
A208							1	1	1	1			4
A209							1	1	1	1			4
A210							1	1	1	1			4
A211							1	1	1	1			4
A212							1	1	1	1			4
A213							1	1	1	1			4
A214													0
A215	2	2	2	2									8
A216							1	1	1	1			4
A217	1	1	1	1	1								5
A218	1	1	1				2	1					6
A219													0
A220													0
A221	1	1	1										3
A222													0
A223													0
Total	225	223	193	127	48		258	182	111	55	7		1.429

BIOGRAPHICAL SKETCH

Hatice Beyza ÖZKAN started her undergraduate studies at the Industrial Engineering Department of Kocaeli University in 2015. In 2019 she obtained the B.S. degree in Industrial Engineering from Kocaeli University. She is currently working towards Master of Science degree in Industrial Engineering from Galatasaray University. Since 2019, she works as a process development engineer.