Avrasya Sosyal ve Ekonomi Araştırmaları Dergisi (ASEAD)
Eurasian Journal of Social and Economic Research (EJSER)
ISSN:2148-9963 www.asead.com

OPTIMIZATION OF INVENTORY COSTS OF AIRCRAFT SPARE PARTS WITH MIXED INTEGER PROGRAMMING[1]

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ABSTRACT

The rapid growth in the aviation sector has highlighted the importance of inventory management in aircraft maintenance and repair. Effective inventory control is crucial for airlines to ensure profitability and continuity. Companies aim to minimize stock costs while maximizing service levels. Linear Programming helps achieve these goals. This study, conducted in Turkey's largest aircraft maintenance center, identified 192 components with inventory shortages for narrow-body aircraft as of December 2022. Using mixed integer programming, it determined the necessary spare parts investment to achieve a 96% service level. Poisson distribution was used to calculate service levels for various spare part quantities in 10 scenarios. In the application part, the current number of spare parts for A320 type narrow body aircraft spare parts in the aviation maintenance and repair sector shows the number of spare parts we have as of the end of 2022. The application problem has been solved with Linear Programming. IBM CPLEX Optimization Studio 12.8 application has been used to minimize inventory cost. In this study; company 3. while reaching the service level that the party undertakes to its customers and ensuring customer satisfaction, on the other hand, it has realized inventory optimization by reducing inventory costs. The replacement order costs incurred according to the consultant firm's proposed replacement numbers for the year 2023 and the replacement order costs incurred as a result of solving the optimization problem that provides the desired level of service were compared with each other.

Keywords: Inventory Management, Component Management, Poisson Distribution, Mixed Integer Programming, Optimization.

[1] This article was produced from the master's thesis presented at Istanbul University Department of Business Administration/Numerical Methods, on 14.12.2023.

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UÇAK YEDEK PARÇALARININ STOK MALİYETLERİNİN KARIŞIK TAM SAYILI PROGRAMLAMA İLE OPTİMİZASYONU

ÖZET

Günümüzde havacılık sektöründe meydana gelen hızlı gelişmeler ve sektöre yönelik artan ilgi, uçak bakım-onarım sektöründe kullanılan envanterin yönetimi konusunu önemli hale getirmiştir. Havayolu firmaları için envanter kontrolü ve yönetimi; karlılık ve sürekliliğin sağlanması açısından kritik bir öneme sahiptir. Firmalar hem stok maliyetlerini minimum yapma hem de müşterilerine sundukları hizmet seviyelerini maksimize etme isteğindedirler. Bu iki durumun gerçekleşmesini sağlayan yöntem ise Doğrusal Programlamadır. Şirket minimum düzeyde stok bulundurma maliyetiyle maksimum düzeyde müşteri hizmet düzeylerine ulaşmayı amaçlamaktadır. Yapılan çalışmada, dar gövde uçaklarında 3. parti müşterilere yedek parça hizmeti sunulan müşteriler için 2022 yılı aralık sonu itibariyle envanter eksiği bulunan 192 komponent ele alınmış ve %96 hizmet seviyesi ortalamasını gerçekleştirmek için 192 adet komponentten her birisi için ne kadar yedek yatırımı yapılması gerektiği karışık tamsayılı programlama tekniği ile çözülmüştür. Çeşitli yedek miktarlarında ne kadar hizmet seviyesine ulaşıldığı 10 farklı senaryo için Poisson istatistiksel dağılımıyla hesaplanmıştır. Çalışma, Türkiye'nin en büyük hava araçları bakım onarım merkezinde gerçekleştirilmiştir. Uygulama kısmında havacılık bakım onarım sektöründe A320 tipi dar gövde uçak yedek parçalarının mevcut yedek sayısı 2022 yılının sonu itibariyle elimizdeki yedek sayısını göstermektedir. Uygulama problemi Doğrusal Programlama ile çözülmüştür. Stok maliyetinin minimize edilmesinde CPLEX Optimization Studio 12.8 uygulaması kullanılmıştır. Bu çalışmada; şirket 3. parti müşterilerine taahhüt ettiği servis seviyesine ulaşıp müşteri memnuniyetini sağlarken diğer bir yandan da envanter maliyetlerini düşürerek stok optimizasyonunu gerçekleştirmiş olmaktadır. Danışman firmanın 2023 yılı için önerdiği yedek sayılarına göre ortaya çıkan yedek sipariş maliyeti ile istenilen hizmet seviyesini sağlayan optimizasyon probleminin çözülmesi sonucunda ortaya çıkan yedek sipariş maliyetleri birbirleriyle karşılaştırılmıştır.

Anahtar Kelimeler: Envanter Yönetimi, Komponent Yönetimi, Poisson Dağılımı, Karışık Tam Sayılı Programlama, Optimizasyon.

INTRODUCTION

For businesses to use their resources rationally, efficiently, and effectively, they need to benefit from scientific data rather than experience. Optimality is extremely important in business processes. Rapid developments and increasing interest in the aviation sector, and the increasing number of aircraft and flight operations have made inventory control utilized in aircraft maintenance and repair sector important. Airline companies want to both minimize inventory costs and maximize the service levels they offer to their customers. Because ensuring customer satisfaction and reducing costs are important goals in the sector (Arıkan & Ahipaşaoğlu, 2006).

For this reason, a problem related to the minimization of inventory costs of a business offering upkeep and repair services for aircraft components and operates in the aircraft maintenance and repair sector is discussed plus the results are shared by making an application. In the maintenance and repair of repairable aircraft parts (components), tracking and control of inventory is of utmost importance. In the aviation maintenance and repair sector in our country, tens of thousands of aircraft components undergo repair cycles annually and are certified by authorized repair stations and made ready for use (operational) knowing how many of these pieces are required are in stock and how many of them should be kept in stock and to process the components accordingly. Because arbitrary processing, testing, and repairing of components without considering stock levels is not a suitable situation for the maintenance and repair center. There is a need for systematic and rational inventory control and minimization of inventory costs.

In a globalized and technology-based world that has become a small market, inventory control in the aviation industry is closely related to cost. If an airplane is grounded due to the need for parts, it is not only a huge cost for the airline company, but also means loss of passengers and prestige with decreased customer satisfaction. However, it is also a luxury to keep a spare part in stock unnecessarily and this situation shows that inventory management is not rational and will have an increasing effect on inventory cost. Therefore, the main objective of inventory control is to keep the amount of spare parts to be kept in stock so as not to disrupt flight operations and to keep them at an optimum level so as not to increase the inventory cost by keeping more spare parts than necessary. The subject of the study is repairable aircraft parts. In other words, components. Aircraft parts are called components. Components are aircraft parts that are constantly activated and move in a certain cycle. In other words, they are parts that are repaired in maintenance and repair workshops and brought back into stock rather than being scrapped when they fail. Factors that cause an increase or decrease in the inventory levels of components are sales or purchasing activities. In some cases, it is not possible to repair aircraft spare parts. In such cases, the components may be scrapped, resulting in a decrease in the number of inventories. Since the main factor causing inventory movement is component failure, demand calculations are usually based on failure-related analyses (Altay, 2011).

For the repair and stock cycle of components to be more effective and efficient, spare parts should not be kept in excess to prevent long waiting times for parts in stock and mutual agreements should be made with repair companies so that when the repair time exceeds a certain period, exchange components should be requested (Alfieri, 2014). The purpose of calculating the number of spare parts is to ensure that flight operations are not interrupted and to ensure the supply of parts that will provide service at the desired reliability level (Kilpi, 2007). Operating in the aviation maintenance/repair sector, the company has been investing significantly in its spare parts inventory since the second quarter of 2022 during the post-COVID normalization process. For 2023, it would be wise to carry out this policy by using mathematical approaches in line with today’s conditions of increased competition.

To increase the company's profit margin by optimizing inventory costs, it would be the right choice to manage inventories with a holistic approach. In this application, the company aims to achieve inventory optimization by reducing inventory costs while achieving the service level promised to third party customers and ensuring customer satisfaction. In the study, 192 components with inventory shortage for the year 2022 for 3rd party customers who are serviced for the spare parts of narrow body aircraft are considered. To achieve 96% service level average, how much spare investment should be made for each of the 192 components is calculated by using Mixed Integer DP technique. For 10 different scenarios, Poisson statistical distribution is used to calculate how much service level is achieved at various reserve amounts. The objective function is set to minimize the inventory cost while achieving the targeted service level. Currently, inventory reserve calculation is done on an individual basis in the company and there is no approach for inventory optimization as a whole. With mixed integer linear programming, it will be possible to manage the reserve inventory with an efficient and mathematical methodology and thus minimize inventory costs. In the application, the mathematical model established for cost minimization is solved with KTDP. CPLEX Optimization Studio 12.8 application was used to minimize the inventory cost.

1. AVIATION MAINTENANCE AND REPAIR SECTOR

MRO (Maintenance, Repair, Overhaul) is the name given to companies that provide maintenance and repair services to aircraft. According to the Directorate General of Civil Aviation, the definition of MRO is as follows. "MRO refers to companies that provide services including service, control, maintenance-repair, modification and overhaul activities to ensure that aircraft remain airworthy throughout their service life, starting from the production of the aircraft until the end of their service life." Around 500 MRO companies in the world provide maintenance and repair services to approximately 20 thousand aircraft. The aviation sector is a sector involving high costs and large capital investments (SHGM, 2017). Within the sector, aviation maintenance and repair expenditures have high costs and account for 10 percent of all expenditures in the airline sector. Today, international MRO companies have an economic volume of 60 billion dollars and this figure is expected to exceed 80 billion dollars in the future. When the MRO companies worldwide are analyzed; it is seen that the USA has 35% of this market, Europe has 26%, Asia-Pacific has 17%, while the remaining 20% share belongs to companies operating in other regions (airlinehaber, 2019).

Minimizing MRO costs, which are considered as a very important cost item for companies operating in the aviation industry, undoubtedly depends on supplier performance. Due to the competitive situation that exists among MRO companies, minimizing the costs of these companies depends on ensuring efficiency in the supply chain and effective and efficient use of resources. Company officials are strict in supplier selection and require suppliers to have certain certifications and patents. Therefore, there is limited product diversity in the procurement of aircraft materials.

This situation obliges companies to procure aircraft materials by mandatorily directing them to certain suppliers (Kuyucak & Şengür, 2009). Aircraft maintenance is extremely important for airlines in terms of safety, time, and cost effectiveness. When an airplane cannot provide service due toa malfunction or an airplane is delayed, costs increase. This is not good for the economy, customer satisfaction and brand value. Therefore, the performance of supply chain management plays an important role in the effectiveness of maintenance and repair operations of MRO companies. When the products supplied by the company are examined, it is seen that airplanes consist of thousands of different materials. The aircraft maintenance and repair sector are a vital sector for aircraft to be ready for flight. In addition, in the aviation maintenance and repair sector, aircraft maintenance is carried out in accordance with the maintenance and repair standards set by international organizations such as the Federal Aviation Administration (FAA) or the European Aviation Safety Agency (EASA) (Bahar, 2018).

1.1. Importance of Aircraft Maintenance and Repair

Repair and maintenance of aircraft spare parts is of vital importance for flight safety and security. It is very important that airplanes are constantly checked and inspected. If these checks and inspections are not carried out, the airplanes will never be able to take off. It is often said that pilots are at the center of a flight, but in terms of flight safety, the technician team performing maintenance and repair activities is as responsible as the pilots. In order to maintain the performance of the aircraft, 'Check-Up' is carried out continuously. Passenger airplanes undergo a control called "A-Check" at each airport where they land. This careful walk-around inspection can reveal many problems at first glance. If necessary, a more thorough "B and C Checks" can be carried out. These checks are carried out meticulously around the aircraft, ensuring that necessary maintenance and repairs are carried out in a timely manner (SHGM, 2017).

An airplane has approximately 370 thousand components. It is imperative for maintenance and repair technicians and authorized flight crews to check and make sure that each one of the aircraft's components is in working order and that they are performing their duties in full. The size of the components is never important here. Because even a missing screw jeopardizes the safety of the flight and shows us that it has the possibility of causing major disasters. Companies go to various restrictions to maximize their revenues and minimize their costs. If these restrictions are of the kind that affect the maintenance and repair of the aircraft, this will end in disaster. Because there are no restrictions in maintenance and repair activities. There are no restrictions in situations that jeopardize flight safety and security. There is no cost cutting in maintenance and repair activities because the money spent on maintenance and repair is certainly not a luxury. These are mandatory expenditures and are aimed at ensuring safe flight operations and eliminating the risk to the lives of passengers.

The maintenance determined by aviation laws is carried out in accordance with international standards. In the event that these maintenances are not performed in accordance with the standards, airline companies may increase their revenues, but this increase will not prevent those companies from disappearing into history in some cases. Because companies that are sentenced to compensation for any aircraft involved in an accident and will never be able to continue their activities with the loss of customers will go bankrupt and disappear from the aviation scene (Ekin, 2020).

1.2. Spare Parts Inventory Management in Aviation Industry

Inventory is a key component for businesses providing spare parts services. Inventory imposes costs on companies, but it is also important to keep the optimum number of components in stock. Since companies tend to keep the cost at the minimum level and the service quality at the maximum level, they have to balance their stock levels and components (Ecer, 2009).

Companies operating in the aircraft maintenance/repair sector also need inventory to avoid any disruption in the operation in case of failure. Keeping a spare parts inventory is essential to be prepared for fluctuations in demand and unexpected situations. When the spare parts inventory is not used, it does not create any added value for the business, but creates an additional cost, so inventory management is an issue that needs to be monitored (Kasap, Biçer, & Özkaya, 2010). Another issue in inventory management is to meet the expectations of customers at a reasonable level, to respond quickly to demands and to minimize the costs to be encountered (Aktürk, Özkale, Fığalı, & Engin, 2005). Finding the optimum reserve quantity that minimizes inventory costs is the main objective of companies in inventory control. In this case, two different situations are encountered apart from keeping the stock level in balance. These are overstock and understock situations. There are various disadvantages of having excessive stock on hand. These are deterioration, wear and tear, loss of value, and warehouse rental costs. On the other hand, having insufficient inventory on hand will lead to an inability to respond to incoming demands in a timely manner or to a decrease in the rate at which demands are met. As a result, having a balanced stock level is the most important goal in inventory management.

The purpose of stock control in inventory management is to make the right product available at the right place and time, in the amount of demand (Kasap, Biçer, & Özkaya, 2010). While stock control is important, it is also extremely important to meet customer satisfaction. Regardless of the sector, and our sector for this study is the aviation sector, the aim of the companies is to provide maximum customer satisfaction at the lowest cost. To achieve this, inventory must be managed rationally, effectively and in balance (Genç, 2009).

Spare parts can be categorized into three groups in aviation. These are:

1) Repairable parts (repairable): Parts that are feasible and reasonable to repair. This means that the cost of repairing these parts is lower than the cost of buying new ones (Kilpi, 2007). Aircraft parts that can be repaired include engines, generators, pumps, large actuators, and valves.

2) Expendable components: These are components that have completed their useful life and are scrapped. These parts are not repairable or economical and are therefore scrapped.

3) Consumables are parts that cannot be reused once installed in a device and are scrapped when they fail. These parts have higher replacement rates than repairable parts and are affordable (Alfieri, 2014).

2. LINEAR PROGRAMMING

Linear programming (LP) is one of the mathematical modeling techniques. LP solves optimization problems involving a set of linear constraints and a linear objective function. In other words, it tries to optimize the objective function related to a set of variables with linear constraints. It is a useful method when an objective needs to be realized under a certain condition or constraint. These problems are generally concerned with the efficient use of resources under a set of constraints to achieve a specific objective. It provides an effective solution especially for large and complex problems.

Linear programming (LP) is an optimization method used in many different application areas. Some areas of use include Business management, engineering, finance, energy, healthcare, transportation and logistics. In business management, linear programming is used in production planning, inventory management, logistics and distribution, cost analysis, marketing and advertising strategies. In engineering, linear programming is used in engineering design, optimization of production processes and raw material utilization, project management and scheduling. In finance, linear programming is used to make financial decisions such as financial risk management, portfolio management, investment decisions and forecasting, cost analysis and profit maximization (Taha, 2007). These problems are usually solved using special algorithms and mathematical solution techniques. The concept of linear programming is the expression of a mathematical technique that uses optimization methods to solve linear inequalities or systems of linear equations constrained by the contribution of a set of variables to a linear objective function. Linear programming deals with the maximization or minimization of an objective function subject to linear equality and inequality constraints in many variables (Danztig & Thapa, 1997). The word “linear” in linear programming implies that all mathematical functions in the model to be solved must be linear. As a result, linear programming involves planning activities to find the optimal (closest to the best) solution that meets a specified objective from a set of feasible alternatives (Özçiloğlu, 2009).

Businesses aim to make the most effective use of limited resources in models programmed with linear programming. DP is a mathematical modeling designed to optimize the use of limited resources (Taha, 2003). Linear programming problems are the optimization of a linear objective function with linear equality and inequality constraints.

The six basic assumptions of linear programming are: certainty, linearity, divisibility, additivity, proportionality, and non-negativity Linear Programming solution methods Linear Programming is a mathematical modeling tool used to solve optimization problems, especially when dealing with large data sets and complex systems. Linear programming problems can be solved by various methods. These are: Graphical method, Simplex method, Duality method, Interior point method (Öztürk, 2003).

2.1. Integer Programming

Integer programming is a special type of DP and was developed to obtain integer results to DP problems. This method refers to a special subset of general linear programming models where all or some of the variables can only take integer values (Katrancı & Organ, 2021).The application areas of TSP are quite broad and include efficient allocation of sales territories by sellers, capital planning, research and development on warehouse layouts, traveling salesman problems, loading problems, assignment problems, etc. (Turan, 2002).

Studies on TSP were conducted and developed in the 1950s by researchers such as Gomory, Land and Doing in various fields. Following these studies, the method has found a wide range of applications. Today, assembly line balancing, assignment problems, personnel scheduling, site selection, advertising scheduling, production planning, vehicle routing and many other problems are successfully solved using integer programming (Katrancı & Organ, 2021). TSP aims to avoid outcomes that may arise in linear programming models that do not reflect the real world. When integer results are not obtained in certain linear programming models, this can impair the adaptability of the model to real-world problems (Katrancı & Organ, 2021). In operations research applications, linear programming problems are mathematical models in which a linear objective function is optimized by constraining it with linear equations and inequalities (Erdoğan, 2019).The integer linear programming model is a variant of the linear programming model with integer value conditions added to the constraints. This requires that the variables in the objective function take integer positive values (Turan, 2002).

If we talk about the formulation of Integer Linear Programming; The basic structure of linear programming includes three important components: the objective function, constraint functions and positive constraints.

The formulation of integer linear programming is expressed in the following notation:

$$\text{Objective function:} \quad \max(\min) \, Z = \sum_{j=1}^{n} c_j x_j \text{ where } (j = 1, 2, \dots, n)$$

The explicit formulation representation of the objective function is shown in the form:

$$Z = c_1 x_1 + c_2 x_2 + \cdots + c_n x_n$$

Constraints:

$$\sum_{i=1}^{m}\sum_{j=1}^{n} a_{ij}x_j \leq (=; \geq)\ b_i \ where\ (\mathrm{i} = 1, 2, \ldots, \mathrm{m}), (\mathrm{j} = 1, 2, \ldots, \mathrm{n})$$

Positive constraint:

$$x_j\ \geq 0\ and\ x\ is\ an\ integer$$

An explicit formulation representation of the constraints is:

$$a_{11}x_{11} + a_{12}x_{12} + \cdots + a_{1n}x_{1n} \leq b_1$$
$$a_{21}x_{21} + a_{22}x_{22} + \cdots + a_{2n}x_{2n} = b_2$$
$$\vdots$$
$$a_{m1}x_{m1} + a_{m2}x_{m2} + \cdots + a_{mn}x_{mn} \geq b_m$$

Such models represent integer linear programming models where all variables must have integer values at the end of the solution (Özder, 2009).

2.2. Mixed Integer Linear Programming

Mixed Integer Linear Programming is a powerful mathematical optimization approach developed to solve complex decision problems faced by businesses and engineering applications. This approach addresses linear programming problems involving both integer and non-integer (continuous) decision variables. Mixed integer linear programming can be applied to many real-world scenarios and, due to their complexity, are widely used, especially in fields such as industrial engineering, business management, transportation and logistics, production planning, etc. To handle this mixed combination of integer and non-integer variables, mixed integer linear programming comes into play. MNLP is a mathematical optimization approach in which k of the n decision variables in an optimization problem must be integer and the other n-k must be positive at the same time (Çevik, 2006).

The KTDP model must fulfill the following constraints. These constraints are in the following format:

$$if\ j > i$$
$$x_j\ \geq 0\ and\ x_i\ is\ an\ integer$$

Under these constraints, the model aims to satisfy the condition that some variables (xi's) are integers, which ensures that the variable xi produces an integer result, while for other x's a fractional or integer result is obtained (Özder, 2009). The following formulation is used as a mathematical expression for the KTDP model.

$$Z_{max/min} = \sum_{j=1}^{n} c_j x_j$$

Figure 1. Mathematical formulation of mixed integer linear programming model (Turan, 2002)

The constraints of the model are,

$$\sum_{i=1}^{m}\sum_{j=1}^{n} a_{ij}x_j \begin{Bmatrix} \leq \\ \geq \\ = \end{Bmatrix} b_i \qquad (j=1,2,...,n)$$

$$(i=1,2,...,m)$$

ve

$$x_j \geq 0 \qquad (j=1,2,...,n)$$

$$x_j \text{ tamsayıdır} \qquad (j=1,2,...,I) \qquad (I \leq n)$$

Figure 2. Mixed integer linear programming model constraints (Turan, 2002)

3. POISSON DISTRIBUTION

This probability distribution was first developed by Siméon-Denis Poisson, who lived between 1781 and 1840. Poisson first introduced this distribution in his work "Studies on the probability of judgments in criminal and civil law" published in 1838. The Poisson distribution is related to the Poisson process. The Poisson process represents a model in which certain events that occur intermittently (i.e. 0, 1, 2, 3... times) occur with a constant probability in a unit period, area, space or volume. While the Poisson distribution is often used in problems involving certain fixed units of time interval, it can be adapted with the same success to other unit-based problems (e.g. problems involving unit distance, area, or volume) (Vikipedist, 2023). The Poisson distribution is suitable for integer-based analysis, but not for decimal analysis. For example, if you want to simulate a situation with continuous variables, such as traffic flow, the discrete nature of the Poisson distribution is not suitable for this type of analysis. Instead, continuous rather than discrete probability distributions or other appropriate statistical models should be used for such situations.

As a result, the Poisson distribution can be a powerful tool for analyzing integer data, but it is not a suitable option for decimal analysis that does not deal with discrete probability distributions (Erişkin, 2021).

Definition 1. The Poisson distribution is a mathematical relation that measures the randomness of a data set, allows experimental data to be fitted to a theoretical curve, and is used to make certain predictions from the underlying data (Adult, 2021). The Poisson probability distribution function (PDF) and Poisson cumulative distribution function (CDF) are shown in Equations (1) and (2) respectively. (Adult, 2021).

$$ODF = \lambda ne - \lambda n! \, (1)$$
$$KDF = e - \lambda \sum \lambda i \; i! \, n \; ii \; = 0 \; (2)$$

In this context, “n” represents the number of data, “λ” represents the arithmetic mean of n data, and “e” represents the natural logarithmic base value known as the Euler number. These values are often used in data analysis, statistics, and probability calculations. λ, representing the mean of the data, reflects a characteristic feature of the data set, while “n” is the number of samples in that data set. These parameters are used to model statistical distributions such as the Poisson distribution and to estimate the frequency of rare events (Erişkin, 2021).

4. APPLICATION

4.1. Information on Companies Operating in Aviation Maintenance and Repair Sector

The application was carried out in a company operating in the aviation maintenance and repair sector in Turkey. With the opening of Sabiha Gökçen facilities in 2014, which is the main headquarters of the company, the quality of service provided for aircraft and their spare parts has increased and the spare parts inventory management process has started to be carried out effectively and rationally. With seven hangars in Istanbul and Ankara, the Company has a total covered area of 576,000 square meters. The Company provides maintenance and repair services to airlines and VIP jet operators. The Company provides component services to more than 100 airlines in Europe, Middle East, North Africa and Asia. The Company provides maintenance and repair services for landing gear, flight electronics components, hydraulic-pneumatic components, braking systems, tires and wheels and mechanical components used in aircraft and performs some of the maintenance and repair of defective spare parts in-house. Excluding the Company’s own aircraft, the number of aircraft for which the Company provides “component pool” services is approximately 800. The Company successfully completes avionic component maintenance operations on approximately 25,000 aircraft annually in its workshops. At the Sabiha Gökçen HABOM facility, maintenance and repair services are provided to customers in modern avionics workshops built on 14,000 m2 of land. The Company performs testing, repair, and overhaul of components.

4.2. LP Implementation

In this section, the model defined and detailed below is solved by mixed integer linear programming. The application study was carried out at an aviation maintenance and repair base based in Istanbul.

The study is based on the parts provided by the company to 3rd party customers with A320 narrow-body aircraft fleet under a component swap agreement (pool agreement). For the year 2022, the number of spares available at the end of the year within the scope of the parts provided to the A320 contracted customers and the service level (Poisson distribution) achieved with these spare numbers were calculated. 10 scenarios were determined in total with 10% spare increases (Recommended Number of Spares - Number of Spares Available). For these 10 scenarios, the service level and the required reserve increase amount were calculated. One of these scenarios was selected and the problem of how much spare investment should be made in contracted components in the A320 fleet in 2023 was solved by linear programming method.

While serving 3rd party customers, the components serviced to narrow body aircraft customers were analyzed. A mixed integer linear programming application was performed for 192 components with a shortage of spare parts as of the end of December 2022 (based on the service level provided for the relevant components as of December 31). The application was solved in CPLEX 12.8. To determine the required amount for the spare inventory, the company uses the services of a consulting firm. This firm has a recommended number of spares. However, it is investigated whether it is optimal for the company to invest in spares according to the recommended number of spares and to minimize the inventory cost according to the number of spares that provide the desired service level. While determining 192 components, components with a service level lower than 96% for 3rd party customers who need narrow body components were analyzed. The 192 components, which are the number of components that we could not meet 96% as service level, were taken into consideration. Because the service level promised to 3rd party customers and signed agreements is 96% on average. In the study, 192 components, which are the number of components that we could not meet 96%, were taken into consideration as the service level. A320 Airbus type aircraft components include the services provided to 3rd party customers (aircraft serviced other than company aircraft). There are a total of 2376 components in this service pool. Since the service level promised in the spare parts agreements with the customers is 96% on average, the components with a service level below 96% are taken as the focal point in the application. Poisson distribution (Excel) was used to calculate the service level to be achieved based on certain spare quantities. According to Airbus and the authorities in the field of aviation maintenance and repair, Poisson distribution is the most suitable distribution for components that are in a continuous repair cycle and in a closed loop and for the failure structure of the components.

4.3. Methodology of the Study

It is extremely important to solve the problem related to the inventory management of the business and to have sufficient stock with the available budget. It is very important for businesses to use resources effectively for the continuity of the business. In this case, businesses resort to some solution techniques. The most widely used mathematical method to ensure that scarce resources are used more economically and effectively is linear programming (Erişkin, 2021). The main reason for choosing the linear programming technique is that with the linear programming technique, businesses can produce alternative solutions by expressing their resources in numbers rather than based on experience. In practice, the mathematical model established for cost minimization will be solved by linear programming. With this method, the company will reach the service level promised to 3rd party customers and ensure customer satisfaction, while achieving the goal of stock optimization by reducing inventory costs.

4.4. Inputs to the Problem

Inputs for the problem are available in the Appendix. For 192 components, the average workshop load (λ) is calculated by multiplying the annual demand and cycle times by each other and dividing by 365. Using the average workshop load, the current reserve level (x) and the service level achieved at the reserve levels recommended by the consultant company are calculated with the help of Poisson cumulative distribution function.

$$\lambda = \frac{\text{annual demand } \times \text{cycle times}}{365}$$

$$p = e^{-\lambda} \sum_{i=0}^{x} \frac{\lambda^i}{i!}$$

There are 10 different scenarios in our integer programming model: (Recommended Reserve Level - Current Reserve Level) x 0.1; (Recommended Reserve Level - Current Reserve Level) x 0.2; ...; (Recommended Reserve Level - Current Reserve Level) x 1.

The linear integer programming model selects only one out of 10 of these scenarios and produces a solution that guarantees an average service level of 96%. Another parameter used as input in the problem is the average purchase price of the components. Purchase prices are critical for cost minimization in the objective function.

4.5. Objective Function and Constraints

Variable definitions, objective function, and constraints in the CPLEX program are given below.

X_{ij} is a logical variable that takes the values 0 or 1 where 1 of 10 scenarios is selected for 192 components. I indicate the number of components (192) and j indicates the number of scenarios (10).

Y_i is number of components to be ordered in the optimum solution. It is the variable that shows how many reserve increases should be made from each component. It is the amount of reserve increase corresponding to the scenario where X takes the value 1 in any of the 192 components.

Objective Function:

$$Z_{min} = \sum_{i=1}^{192} price_i \ x \ y_i$$

Constraint Equations

$\sum_{j=1}^{10} x_{ij}$=1 for all i from 1 to 192 (1)

$\sum_{j=1}^{10} services\ level\, X x_{ij} \geq 0{,}8$ for all i from 1 to 192 (2)

$\sum_{i=1}^{192}\sum_{j=1}^{10} services\ level\ _{ij}\ X\ x_{ij} \geq 192\ \times 0{,}96$ (3)

$\sum_{j=1}^{10} reserve\ quantity_{ij}\ X\ x_{ij} \leq\ y_i$ for all i from 1 to 192 (4)

Objective Function and Constraint Explanations

The objective function is the value that minimizes the product of the purchase price of 192 components and the amount of reserve increase. In other words, it minimizes the total purchase cost.

Constraint 1: The number of scenarios selected among the 10 scenarios for each of the 192 components must be equal to 1. In other words, there is one scenario to be applied for each component, the variable x takes the value 0 for 9 scenarios and 1 for only 1 scenario.

Constraint 2: The service level for each component individually must be greater than 80%. This constraint exists because a service level below 80% is considered a failure.

Constraint 3: The average service level for 192 components must be greater than 96%. The average service level committed to customers is 96%.

Constraint 4: This constraint is required for the calculation of yi values. This constraint calculates the final order quantities for 192 components in the optimum solution by multiplying the selected scenario (xij=1) by the increases in the reserve quantity (ReserveQuantity ij) that will occur in 10 different scenarios.

```

int numRot = 192;
int numInvSpares = 10;
range Spares = 1..numInvSpares;
range Rotables = 1..numRot;

float Price[Rotables] = ...;
float RotSL[Rotables][Spares] = ...;
float SpareQty[Rotables][Spares] = ...;
dvar int x[Rotables][Spares] in 0..1;
dvar int y[Rotables];

minimize sum(i in Rotables) Price[i]*y[i];

subject to {

forall (i in Rotables)
  EqualToOne:
  sum (j in Spares) x[i][j]==1;

forall (i in Rotables)
  MinSLSatisfied:
  sum (j in Spares) RotSL[i][j]*x[i][j] >= 0.8;

  SLConstraint:
sum (i in Rotables, j in Spares)
  RotSL[i][j]*x[i][j] >= numRot*0.96;

  forall (i in Rotables)
    NumOfSpares:
    sum (j in Spares)
    SpareQty[i][j]*x[i][j] <= y[i];

  }
```

Figure 3. IBM CPLEX 12.8 Variables, Parameters, Objective Function and Constraints

4.6. Solving The Model

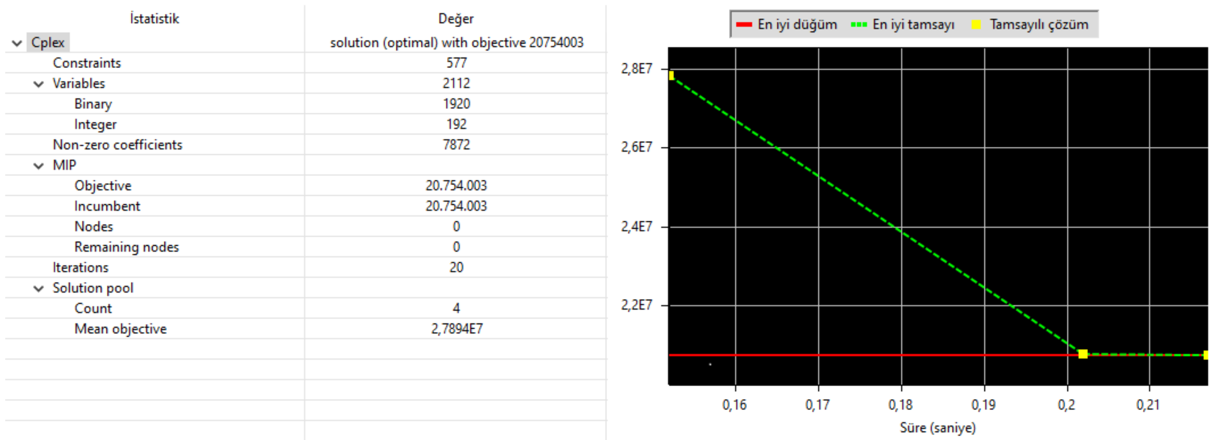
When the mixed integer programming model is run in CPLEX according to the objective function and constraints mentioned in the previous section, the following results are obtained.

In the optimum solution, the procurement cost was realized as 20,754,003 USD. In other words, this is the amount that the company should spend in 2023 within the scope of component investment for A320 narrow body 3rd party service. The solution and limit errors realized in the optimum solution are of the type expressed in fractions that can be considered very insignificant.

The variable y took the value 1 92 times in the solution set. In other words, in 92 out of 192 components, 1 spare increase was deemed necessary to achieve an average service level of 96%.

When the values of the variable x are analyzed, it is seen that scenario 1 is realized almost 50% of the time since it is related to y. In addition, it would be correct to state that scenario 10 was not realized at all and that scenario 5 and the scenarios before it was mostly realized.

577 constraints and 2112 variables (1920 binary and 192 integer). As can be seen from the solution statistics graph, there are 4 solutions in the solution set and the optimum solution was reached in > 0.21 seconds after 20 iterations.



İstatistik	Değer
Cplex	solution (optimal) with objective 20754003
Constraints	577
Variables	2112
Binary	1920
Integer	192
Non-zero coefficients	7872
MIP	
Objective	20.754.003
Incumbent	20.754.003
Nodes	0
Remaining nodes	0
Iterations	20
Solution pool	
Count	4
Mean objective	2,7894E7

Figure 4. Solution statistics

The objective function, error statistics and solution sets of variables (x, y) are given below. Objective Function for Optimum Solution = 20,754,003 USD

Mixed Integer Linear Programming solution norm |x| (Total, Max) = $7.94e^{+2}$+2, $1.30e^{+1}$

KTDP solution error (Ax=b) (Total, Max) = $8.92619e^{-14}$, $8.92619e^{-14}$

KTDP x limit error (Total, Max) = $0.00000e^{+00}$, $0.00000e^{+00}$

KTDP x integrity error (Total, Max) = $0.00000e^{+00}$, $0.00000e^{+00}$

KTDP loose limit error (Total, Max) = $1.42109e^{-13}$, $1.42109e^{-13}$

y = [5 1 1 1 1 1 1 1 1 1 1 11 9 5 7 5 1 10 1 1 1 1 4 1 1 2 2 1 3 5 4 1 1
5 1 5 5 5 1 1 1 2 1 1 2 1 1 1 1 1 1 1 1 1 5 1 1 1 3 1 1 1 1 13 1
1 2 1 3 3 1 2 5 8 1 2 9 7 2 1 2 3 1 1 2 3 1 1 2 2 5 5 5 12 1 1 1 1
1 1 1 7 7 9 5 2 1 1 3 1 7 7 1 1 1 7 4 1 2 3 2 2 1 2 1 7 5 1 5 1 6
5 1 7 5 3 3 5 1 3 3 1 1 1 1 1 2 3 7 4 1 7 7 5 1 12 1 1 10 1 5 1 10
4 3 9 5 2 2 1 1 1 12 3 1 1 2 1 4 2 8 5 6 13 1 2 5 1 12 10 2]

x = [[0 0 1 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0],
[1 0 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0],
[1 0 0 0 0 0 0 0 0 0], [0 0 1 0 0 0 0 0 0 0], [0 0 0 0 1 0 0 0 0 0], [0 0 0 0 1 0 0 0 0 0],
[0 0 0 1 0 0 0 0 0 0], [0 1 0 0 0 0 0 0 0 0], [0 0 1 0 0 0 0 0 0 0], [0 1 0 0 0 0 0 0 0 0],
[1 0 0 0 0 0 0 0 0 0], [0 0 0 0 1 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0],
[1 0 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [0 0 0 0 0 0 0 1 0 0], [1 0 0 0 0 0 0 0 0 0],
[1 0 0 0 0 0 0 0 0 0], [0 1 0 0 0 0 0 0 0 0], [0 1 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0],
[0 0 0 0 0 1 0 0 0 0], [0 0 0 0 0 0 0 0 1 0], [0 0 0 0 0 0 1 0 0 0], [1 0 0 0 0 0 0 0 0 0],
[1 0 0 0 0 0 0 0 0 0], [0 0 0 0 0 0 0 0 1 0], [1 0 0 0 0 0 0 0 0 0], [0 1 0 0 0 0 0 0 0 0],
[0 1 0 0 0 0 0 0 0 0], [0 1 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0],
[1 0 0 0 0 0 0 0 0 0], [0 1 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0],
[0 0 0 0 0 1 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0],
[1 0 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0],
[1 0 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [0 1 0 0 0 0 0 0 0 0],
[1 0 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [0 0 0 0 0 1 0 0 0 0],
[1 0 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0],
[0 0 0 0 1 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [0 0 0 0 0 1 0 0 0 0],
[1 0 0 0 0 0 0 0 0 0], [0 0 0 0 0 1 0 0 0 0], [0 0 0 0 0 0 1 0 0 0], [1 0 0 0 0 0 0 0 0 0],
[0 0 0 0 0 1 0 0 0 0], [0 0 0 0 0 0 0 0 1 0], [0 0 1 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0],
[0 1 0 0 0 0 0 0 0 0], [0 0 0 1 0 0 0 0 0 0], [0 0 1 0 0 0 0 0 0 0], [0 0 0 1 0 0 0 0 0 0],
[1 0 0 0 0 0 0 0 0 0], [0 1 0 0 0 0 0 0 0 0], [0 0 0 0 0 1 0 0 0 0], [1 0 0 0 0 0 0 0 0 0],
[1 0 0 0 0 0 0 0 0 0], [0 0 0 0 0 1 0 0 0 0], [0 0 1 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0],
[1 0 0 0 0 0 0 0 0 0], [0 0 0 1 0 0 0 0 0 0], [0 0 0 0 0 1 0 0 0 0], [0 1 0 0 0 0 0 0 0 0],
[0 1 0 0 0 0 0 0 0 0], [0 0 0 0 0 0 0 0 1 0], [0 0 0 0 1 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0],
[1 0 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0],
[1 0 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [0 0 1 0 0 0 0 0 0 0], [0 0 1 0 0 0 0 0 0 0],
[0 0 0 1 0 0 0 0 0 0], [0 1 0 0 0 0 0 0 0 0], [0 0 0 1 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0],

[1 0 0 0 0 0 0 0 0 0], [0 0 1 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [0 0 1 0 0 0 0 0 0 0],

[0 0 1 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0]

[0 0 1 0 0 0 0 0 0 0], [0 0 0 0 0 0 0 1 0 0], [1 0 0 0 0 0 0 0 0 0], [0 0 0 0 0 1 0 0 0 0],

[0 0 1 0 0 0 0 0 0 0], [0 0 1 0 0 0 0 0 0 0], [0 0 0 0 0 1 0 0 0 0], [1 0 0 0 0 0 0 0 0 0],

[0 0 0 0 0 1 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [0 0 1 0 0 0 0 0 0 0], [0 1 0 0 0 0 0 0 0 0],

[1 0 0 0 0 0 0 0 0 0], [0 0 0 0 0 0 0 0 1 0], [1 0 0 0 0 0 0 0 0 0], [0 0 0 1 0 0 0 0 0 0],

[0 1 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [0 0 1 0 0 0 0 0 0 0], [0 1 0 0 0 0 0 0 0 0],

[0 0 1 0 0 0 0 0 0 0], [0 0 0 0 1 0 0 0 0 0], [0 0 0 0 0 0 0 0 1 0], [1 0 0 0 0 0 0 0 0 0],

[0 0 0 0 0 0 1 0 0 0], [0 0 0 0 0 0 1 0 0 0], [1 0 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0],

[1 0 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [0 1 0 0 0 0 0 0 0 0],

[0 0 0 0 0 1 0 0 0 0], [0 0 1 0 0 0 0 0 0 0], [0 0 0 0 0 0 1 0 0 0], [1 0 0 0 0 0 0 0 0 0],

[0 0 0 0 0 0 0 1 0 0], [0 0 1 0 0 0 0 0 0 0], [0 0 0 0 0 0 0 0 1 0], [1 0 0 0 0 0 0 0 0 0],

[0 0 0 0 0 1 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [0 0 0 0 1 0 0 0 0 0],

[1 0 0 0 0 0 0 0 0 0], [0 1 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [0 0 0 0 1 0 0 0 0 0],

[0 0 0 0 0 0 1 0 0 0], [0 0 0 0 0 0 1 0 0 0], [0 0 0 1 0 0 0 0 0 0], [0 0 0 0 1 0 0 0 0 0],

[0 0 1 0 0 0 0 0 0 0], [0 0 0 1 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0],

[1 0 0 0 0 0 0 0 0 0], [0 0 0 0 0 1 0 0 0 0], [0 0 0 0 0 1 0 0 0 0], [1 0 0 0 0 0 0 0 0 0],

[1 0 0 0 0 0 0 0 0 0], [0 0 0 1 0 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [0 0 0 0 0 0 0 1 0 0],

[0 1 0 0 0 0 0 0 0 0], [0 0 0 0 0 1 0 0 0 0], [0 1 0 0 0 0 0 0 0 0], [0 0 0 1 0 0 0 0 0 0],

[0 0 0 0 1 0 0 0 0 0], [1 0 0 0 0 0 0 0 0 0], [0 0 0 0 0 1 0 0 0 0], [0 0 1 0 0 0 0 0 0 0],

[1 0 0 0 0 0 0 0 0 0], [0 0 0 0 1 0 0 0 0 0], [0 0 0 0 0 1 0 0 0 0], [0 0 0 1 0 0 0 0 0 0]]

The CPLEX Optimization Studio problem solving statistics for the preliminary solution, branch and cut method processing times are shared in the table below. 4 nodes were selected and the final solution was obtained by applying cuts (flow cut and zero-half cut) to them.

Table 1: Processor Statistics

Tried aggregator 3 times.

MIP Presolve eliminated 284 rows and 1459 columns.

MIP Presolve modified 3163 coefficients.

Aggregator did 200 substitutions.

Reduced MIP has 93 rows, 407 columns, and 762 nonzeros.

Reduced MIP has 405 binaries, 2 generals, 0 SOSs, and 0 indicators.

Presolve time = 0,02 sec. (9,57 ticks)

Found incumbent of value 4,2250037e+07 after 0,02 sec. (10,51 ticks)

Probing time = 0,00 sec. (0,14 ticks)

Tried aggregator 1 time.

MIP Presolve added 4 rows and 4 columns.

Reduced MIP has 97 rows, 411 columns, and 797 nonzeros.

Reduced MIP has 405 binaries, 6 generals, 0 SOSs, and 0 indicators.

Presolve time = 0,00 sec. (0,83 ticks)

Probing time = 0,00 sec. (0,15 ticks)

Clique table members: 92.

MIP emphasis: balance optimality and feasibility.

MIP search method: dynamic search.

Parallel mode: deterministic, using up to 8 threads.

Root relaxation solution time = 0,00 sec. (0,44 ticks)

	Nodes					Cuts/		
	Node	Left	Objective	IInf	Best Integer	Best Bound	ItCnt	Gap
*	0+	0			4,22500e+07	1,95540e+07		53,72%
*	0+	0			2,78091e+07	1,95540e+07		29,68%
	0	0	2,07540e+07	1	2,78091e+07	2,07540e+07	19	25,

```
    0     0   2,07540e+07     1   2,78091e+07   2,07540e+07       19   25,37%
*   0+    0                       2,07624e+07   2,07540e+07             0,04%
    0     0   2,07540e+07     4   2,07624e+07      Cuts: 2       20    0,04%
*   0+    0                       2,07540e+07   2,07540e+07             0,00%
    0     0       cutoff          2,07540e+07   2,07540e+07      20    0,00%
Elapsed time = 0,05 sec. (15,35 ticks, tree = 0,01 MB, solutions = 4)
Flow cuts applied:  1
Zero-half cuts applied:  1
Root node processing (before b&c):
Real time = 0,05 sec. (15,47 ticks)
Parallel b&c, 8 threads:
Real time =  0,00 sec. (0,00 ticks)
Sync time (average) = 0,00 sec.
Wait time (average) = 0,00 sec.
                          ------------
Total (root+branch&cut) =    0,05 sec. (15,47 ticks)
```

CONCLUSION AND EVALUATION

In this study, one of the most important companies in the aviation maintenance and repair sector has addressed the 2023 spare increase problem using mixed integer programming method. The company is currently analyzing all aircraft components individually rather than in a holistic approach and determining the reserve order quantities by calculating the current service level according to Poisson distribution. It also receives consultancy services from a firm in the field of inventory management. With this methodology, it is not possible for the company to make inventory optimization. Because each component is analyzed individually as if it were not part of a system. By using linear programming, which is a systemic approach, it will be possible to minimize inventory costs.

In the application, firstly, the number of breakdowns and repair cycle times of the company's A320 aircraft in 2022 were obtained in the data collection phase. Then, the average workshop load was calculated with this data. Afterwards, with the help of the average workshop load (λ) values in the Possion distribution according to the number of available spares (x), service levels were found with the POISSON.DIST formula in Excel.

Then, the service levels at the reserve levels recommended by the consultant firm were compared with the service levels in the current situation. According to the 10 scenarios determined, the values of (Number of Recommended Reserves - Number of Existing Reserves) were divided into 10 slices. 10 different scenarios were prepared with 10%, 20%, 30%, ..., 90%, 100% reserve increase and the reserve increases required for these scenarios were also calculated by Poisson distribution. Within the framework of the company's goal and vision, the steps mentioned above were applied for 192 components with a service level below 96% out of 2376 A320 3rd party serviceable components. After determining 10 different scenarios and the components to which the scenarios will be applied, the variables, objective function and constraints were created as a model in the CPLEX Optimization Studio program and the parameter data in the appendix were entered into the program. The objective function was chosen as minimum since it is the optimization of inventory and purchasing costs as mentioned in the problem definition.

Two decision variables, x (taking values 0-1) and y (integer), are defined. The x variable determines which scenario is chosen, while the y variable indicates the reserve increment amounts and enables the calculation of the cost in the objective function. The constraints are designed to achieve an average service level target of 96% and a minimum success rate of 80%. There are also two different constraints that allow the selection of one of the 10 scenarios and calculate the reserve increase amount of the selected scenario. When the problem is solved in the light of this information and data, the objective function is obtained as 20,754,003 USD in the optimum solution. It is likely that the company will face very serious purchasing and inventory costs if it makes inventory investments according to the recommended spare quantities for all components on an individual basis. This is because, in such a case, the company will not be able to consider its component inventory collectively as part of a system and will have to calculate a separate spare for each component. This problem mentioned here can also be addressed as another project study in the rest of the thesis.

Without using the TSDP approach, the order cost for 2023 would have been 62,700,839 USD (USD) if component investments had been made in the number of spares recommended by the consultant company. However, as a result of the solution of the established optimization model, the spare investment amount was obtained as 20,754,003 USD (USD) and it is obvious that the cost was minimized to a very significant extent and the amount of spare components recommended by the consultant company was excessive and therefore the investment amount was not optimum.

When the order is made in the reserve amount recommended by the consultant company, an average service level of 0.9855 is achieved. The service level we reach in linear programming is 0.96. In other words, in the case of the reserve amount recommended by the consultant firm, there is a 2.5 percent increase in the service level, but the investment cost has increased by 300 percent. This situation is not rational and optimum. DP allows us to keep the service level at reasonable levels while minimizing the cost.

This is a strong feature of DP. In this respect, the study is considered to contribute both to the sector where the application is made and to the literature because it provides a solution to an existing problem, optimization of inventory costs, successful inventory control, profit maximization and cost minimization, customer satisfaction and company continuity, and optimum determination of the amount to be invested in the reserve to meet the service level.

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SUFFIXES

Table 1: Spare Parameters for 192 Components

	TANIM	YILLIK TALEP	CEVRİM SÜRESİ	MEVCUT YEDEK	ÖNERİ
00H883	DRAIN MAST	138	30,91	13	29
701-000	MLG RETRACTION ACTUATOR	45	55,57	10	20
3007	MLG RETRACTION ACTUATOR	45	55,57	10	20
3008	MLG RETRACTION ACTUATOR	45	55,57	10	20
3009	MLG RETRACTION ACTUATOR	45	55,57	10	20
3010	MLG RETRACTION ACTUATOR	45	55,57	10	20
0001	MLG RETRACTION ACTUATOR	45	55,57	10	20
	OIL VISUAL INDICATOR	5	62,75	2	3
99-401-0	OIL VISUAL INDICATOR	5	62,75	2	3
00-02	OIL VISUAL INDICATOR	5	62,75	2	3
001-015	SYNC. LOCKING FEEDBACK ACT.	15	78,58	6	7
700-003	FLIGHT DATA RECORDER	30	48,33	0	22
6000-00	FLIGHT DATA RECORDER	30	48,33	0	22
023-002	COCKPIT VOICE RECORDER	18	49,31	0	21
025-02	COCKPIT VOICE RECORDER	18	49,31	0	21
0012-00	COCKPIT VOICE RECORDER	18	49,31	0	21
0000-03	FLOW CONTROL VALVE	13	84,46	5	6
0000-02	FLOW CONTROL VALVE	44	59,63	0	19
0008-0002	FADEC-PRESSURE SUB SYSTEM (PSS)	4	34	1	3
81-101	OXYGEN SENSOR	3	56,5	1	2
6082-2	ISOLATION VALVE	29	47,31	6	7
I34P04	FMU	1	120	1	2
I2	AIR COMPRESSOR	11	74,33	1	5
-230	FLUSH VALVE	9	61,88	3	6
90-101-0	IDG OIL COOLER	13	87,81	6	8
5-04645	BRAKE ACCUMULATOR	83	57,34	19	29
3-04645	BRAKE ACCUMULATOR	83	57,34	19	29
5-2	ENGINE ANTI-ICE VALVE	43	34,16	7	8
365-1	FUEL CONTROL UNIT	49	61,74	8	12
0-0303-0316	ADIRU	24	120	6	11
0-03040316	ADIRU	24	120	6	11
1-00-600	CONTROLLER HEAT	18	71,14	6	7
8-004	INLET GUIDE VANE ACTUATOR	77	47,62	15	17
05	APU L/C DISCHARGE SENSOR	40	37,33	3	8
00-10202	T3CAS COMPUTER	16	92,35	6	7
I44P01	START AIR VALVE	88	75,11	17	39
083-1	START AIR VALVE	88	75,11	17	39
083-2	START AIR VALVE	88	75,11	17	39
T-0003	GAUGE TRANSMITTER	4	120	3	4
T0003	GAUGE TRANSMITTER	4	120	3	4
0AA06	CENT.FAULT DISPLAY UNIT	3	37,29	0	2
7102	NORMAL BRAKE MANIFOLD	22	82,36	5	12
	CHECK VALVE	21	76,5	5	6
5	CONTROL MODULE	29	67,3	7	8
0202	-	3	46,33	0	2
3003-23	UPPER FEEDBACK ACTUATOR	13	44,01	2	8
3003-32	UPPER FEEDBACK ACTUATOR	13	44,01	2	8
41-22	UPPER FEEDBACK ACTUATOR	13	44,01	2	8
41-50A	UPPER FEEDBACK ACTUATOR	13	44,01	2	8
41-51A	UPPER FEEDBACK ACTUATOR	13	44,01	2	8

3003-13	M.D.U.	8	94,8	3	4
44-20E	M.D.U.	8	94,8	3	4
H050830B	AFT ATTENDANT PANEL	1	35	0	1
0002	MLG RETRACTION ACTUATOR	45	55,57	10	20
0004	MLG RETRACTION ACTUATOR	45	55,57	10	20
032-003	COCKPIT VOICE RECORDER	18	49,31	0	21
165P05	FADEC-PRESSURE SUB SYSTEM (PSS)	4	34	1	3
106B	SENSOR VIBRATION TURBINE	8	38,8	1	4
157	FMU	1	120	1	2
-590-1	STANDBY ALTIMETER	18	52,59	5	9
1-1	DEDICATED ALTERNATOR STAT	17	39,87	4	13
38-2	INLET GUIDE VANE ACTUATOR	77	47,62	15	17
79-201	APU ECB	1	120	0	1
00-10204	T3CAS COMPUTER	16	92,35	6	7
14-203	STRIKE CENTER	87	84,36	20	46
3AA04	FMGC	3	25	0	2
H030830B	AFT ATTENDANT PANEL	1	35	0	1
513-02	MAIN INSTRUMENT PANEL LIGHT	3	59	1	3
55-803-0	ACTUATOR VBV	21	101,3	8	10
1-4	FUEL CONTROL UNIT	49	61,74	8	12
15-01-02	PRESELECTOR	46	32,54	6	9
00-61	OPTICAL QUICK ACCESS REC.	5	56,5	1	2
40-7	COOLING FAN ASSY	7	57,82	2	4
46	APU L/C DISCHARGE SENSOR	27	37,33	3	8
14-9	STRIKE CENTER	87	84,36	20	46
0AA04	CENT.FAULT DISPLAY UNIT	3	37,29	0	2
41-51	UPPER FEEDBACK ACTUATOR	13	44,01	2	8
-045-22	FLIGHT DATA RECORDER	30	48,33	0	22
020-02	COCKPIT VOICE RECORDER	18	49,31	0	21
-0102	MULTITANK INDICATOR	4	36,67	1	4
-230-201	FLUSH VALVE	9	61,88	3	6
3	DEDICATED ALTERNATOR STAT	17	39,87	4	13
365-2	FUEL CONTROL UNIT	49	61,74	8	12
-01AA	CONTROLLER HEAT	18	71,14	6	7
T2002-000	GAUGE TRANSMITTER	4	120	3	4
4-932-430-8	-	3	46,33	0	2
56509-02	LED WING STROBE LIGHT WHITE-LH	6	54,68	1	11
00-01	OIL VISUAL INDICATOR	5	62,75	2	3
1055-0303	FADEC-PRESSURE SUB SYSTEM (PSS)	4	34	1	3
05-000-033	SENSOR VIBRATION TURBINE	8	38,8	1	4
1004	HP RELIEF VALVE	8	120	5	7
032-020	COCKPIT VOICE RECORDER	18	49,31	0	21
228-02	COCKPIT VOICE RECORDER	18	49,31	0	21
44	APU L/C DISCHARGE SENSOR	27	37,33	3	8
14-201	STRIKE LOWER/UPPER	120	78,44	28	51
3030001-111	CDSS MONITOR	6	68,75	2	3
0AA03	CENT.FAULT DISPLAY UNIT	3	37,29	0	2
A200WR	FLTDATA INTERFA&MANA.UNIT	2	38,5	0	2
44-20	M.D.U.	8	94,8	3	4
H2EB	TAT SENSOR	7	72,08	3	4
53022020	FLIGHT WARNING COMPUTER	25	16,17	2	3
501-503	ICU	4	120	3	4
750-001	FLIGHT DATA RECORDER	30	48,33	0	22
750-009	FLIGHT DATA RECORDER	30	48,33	0	22
-043-00	FLIGHT DATA RECORDER	30	48,33	0	22
032-001	COCKPIT VOICE RECORDER	18	49,31	0	21

-230-205	FLUSH VALVE	9	61,88	3	6
1A	INTEGRATED DRIVE GENERATOR	62	47,31	9	15
40-10	COOLING FAN ASSY	7	57,82	2	4
56509-01	LED WING STROBE LIGHT WHITE-LH	6	54,68	1	11
001-001	DUAL REDUND.ANTENNA DRIVE	8	70,2	3	4
750-003	FLIGHT DATA RECORDER	30	48,33	0	22
-245-00	FLIGHT DATA RECORDER	30	48,33	0	22
7000-001	OXYGEN SENSOR	3	56,5	1	2
3B	OIL SCAVENGE FILTER ASSY.	17	91,81	6	9
-350	VACUUM GENERATOR	79	83,24	25	29
-043-02	FLIGHT DATA RECORDER	30	48,33	0	22
l12	AIR COMPRESSOR	11	74,33	1	5
20-4	LUBE MODULE	8	58,44	3	5
3000	SELECTOR VALVE	12	63,89	4	6
56509-03	LED WING STROBE LIGHT WHITE-LH	6	54,68	1	11
005-001	RP-1 RADAR PROCESSOR	14	43,78	1	5
-1391	IDG OIL COOLER	13	87,81	6	8
40-11	COOLING FAN ASSY	7	57,82	2	4
325V06	VENTILATION COMPUTER	7	38,48	1	3
001-017	SYNC. LOCKING FEEDBACK ACT.	15	78,58	6	7
-045-00	FLIGHT DATA RECORDER	30	48,33	0	22
l44P04	START AIR VALVE	88	75,11	17	39
6AA00	FLIGHT AUGMENTATION COMP.	19	62,79	4	7
0-03030316	ADIRU	24	120	6	11
1-00-601	CONTROLLER HEAT	18	71,14	6	7
01010	MG TPIS ROTATING MECHANSM	79	52,04	15	29
226-02	COCKPIT VOICE RECORDER	18	49,31	0	21
0002-020	MLG RETRACTION ACTUATOR	45	55,57	10	20
026-02	COCKPIT VOICE RECORDER	18	49,31	0	21
083-4	START AIR VALVE	88	75,11	17	39
7102-2	NORMAL BRAKE MANIFOLD	22	82,36	5	12
430	TPIS ROTATING MECH.-NLG	23	38,45	4	9
53021212	FLIGHT WARNING COMPUTER	76	14,41	0	5
0000-04	FLOW CONTROL VALVE	13	84,46	5	6
3	OIL SCAVENGE FILTER ASSY.	17	91,81	6	9
-1	CHECK VALVE	21	76,5	5	8
0083	ACTUATOR VBV	21	101,3	8	10
-101	SLIDE OFFWING -LH	26	63,53	8	9
1	DEDICATED ALTERNATOR STAT	17	39,87	4	13
00-11203	T3CAS COMPUTER	16	92,35	6	7
6100-1	HYDRAULIC CONTROL UNIT	22	76,4	7	9
41-50	UPPER FEEDBACK ACTUATOR	13	44,01	2	8
-580-1	STANDBY ALTIMETER	18	52,59	5	9
750-002	FLIGHT DATA RECORDER	30	48,33	0	22
20567-01	ACTUATOR	19	43,9	3	7
97	INTEGRATED DRIVE GENERATOR	62	47,31	9	15
450	PRESSURE TRANSDUCER,NLG	21	39,35	0	8
022-001	COCKPIT VOICE RECORDER	18	49,31	0	21
90	APU L/C DISCHARGE SENSOR	27	37,33	3	8
05308-05	STROBE LIGHT UNIT	28	28,91	4	5
0000-01	FLOW CONTROL VALVE	44	59,63	0	19
-	CONTROL MODULE	29	67,3	7	8
H000231B	CIDS DIRECTOR	29	31,96	5	6
00000-02	FLOW CONTROL VALVE	44	59,63	0	19
6082-3	ISOLATION VALVE	29	47,31	6	7
032-023	COCKPIT VOICE RECORDER	18	49,31	0	21

20	EXTRACTION FAN	20	34,38	4	5
0000-01	FLOW CONTROL VALVE	44	59,63	0	19
5967-01	POWER SUPPLY UNIT	34	41,18	5	10
5-02-03	PRESELECTOR	46	32,54	6	9
700-042	FLIGHT DATA RECORDER	30	48,33	0	22
900	AUTOMATIC FIXED ELT	69	22,64	5	14
4-513	SLIDE FW LH/RH	59	22,58	4	8
5-513	SLIDE AFT LH/RH	53	17,81	3	6
5-3	ENGINE ANTI-ICE VALVE	43	34,16	7	8
0003	MLG RETRACTION ACTUATOR	45	55,57	10	20
H000333B	CIDS DIRECTOR	48	36,77	8	9
0000-02	FLOW CONTROL VALVE	44	59,63	0	19
1-5	FUEL CONTROL UNIT	49	61,74	8	12
03	INTEGRATED DRIVE GENERATOR	62	47,31	9	15
502-02	ELT KANNAD AF	63	44,46	12	13
990-003	HF TRANSCEIVER	62	35,86	9	12
88-3	INLET GUIDE VANE ACTUATOR	77	47,62	15	17
0000-01	ACTUATOR - INLET	75	49,59	12	16
6-04644	BRAKE ACCUMULATOR	83	57,34	19	29
-230	FLUSH VALVE	75	51,5	13	25
083-3	START AIR VALVE	88	75,11	17	39
01011	MG TPIS ROTATING MECHANSM	79	52,04	15	29
4-11	STRIKE CENTER	87	84,36	20	46
-375	VACUUM GENERATOR	79	83,24	25	29
15-4501	MULTI USE PRINTER	97	58,6	19	21
00H883-00	DRAIN MAST	138	30,91	13	29
-1	BOX ASSY	113	22,18	11	14
4-7	STRIKE LOWER/UPPER	120	78,44	28	51
01030	TRANSDUCER,WHEEL PRES MLG	136	31,58	11	27
A010001	CSAS OZONE CONVERTER	150	61,77	32	35

Table 2: Service Level (10 Different Scenarios) and Price Parameters for 192 Components

PN	+%10	+%20	+%30	+%40	+%50	+%60	+%70	+%80	+%90	+%100	FİYAT (USD)
4-60000H883	0,866	0,948	0,970	0,991	0,995	0,999	1,000	1,000	1,000	1,000	13853
10-451701-000	0,953	0,977	0,989	0,995	0,998	0,999	1,000	1,000	1,000	1,000	40565
114193007	0,953	0,977	0,989	0,995	0,998	0,999	1,000	1,000	1,000	1,000	55315
114193008	0,953	0,977	0,989	0,995	0,998	0,999	1,000	1,000	1,000	1,000	55315
114193009	0,953	0,977	0,989	0,995	0,998	0,999	1,000	1,000	1,000	1,000	55315
114193010	0,953	0,977	0,989	0,995	0,998	0,999	1,000	1,000	1,000	1,000	55315
201590001	0,953	0,977	0,989	0,995	0,998	0,999	1,000	1,000	1,000	1,000	55315
125A3	0,988	0,988	0,988	0,988	0,988	0,988	0,988	0,988	0,988	0,988	2800
301-799-401-0	0,988	0,988	0,988	0,988	0,988	0,988	0,988	0,988	0,988	0,988	20162
1605100-02	0,988	0,988	0,988	0,988	0,988	0,988	0,988	0,988	0,988	0,988	20162
612C3001-015	0,982	0,982	0,982	0,982	0,982	0,982	0,982	0,982	0,982	0,982	83498
980-4700-003	0,439	0,789	0,950	0,992	0,999	1,000	1,000	1,000	1,000	1,000	3000
S800-3000-00	0,439	0,789	0,950	0,992	0,999	1,000	1,000	1,000	1,000	1,000	6100
980-6023-002	0,772	0,962	0,996	1,000	1,000	1,000	1,000	1,000	1,000	1,000	21016
2100-1025-02	0,772	0,962	0,996	1,000	1,000	1,000	1,000	1,000	1,000	1,000	10990
S200-0012-00	0,772	0,962	0,996	1,000	1,000	1,000	1,000	1,000	1,000	1,000	30800
1303A0000-03	0,966	0,966	0,966	0,966	0,966	0,966	0,966	0,966	0,966	0,966	3600

1806A0000-02	0,026	0,156	0,422	0,704	0,888	0,968	0,993	0,999	1,000	1,000	61211
262200008-0002	0,993	0,993	0,993	0,993	0,993	0,999	0,999	0,999	0,999	0,999	167300
2040081-101	0,988	0,988	0,988	0,988	0,988	0,988	0,988	0,988	0,988	0,988	25500
4063-16082-2	0,962	0,962	0,962	0,962	0,962	0,962	0,962	0,962	0,962	0,962	12410
2496M34P04	0,995	0,995	0,995	0,995	0,995	0,995	0,995	0,995	0,995	0,995	266091
8378M2	0,612	0,612	0,811	0,811	0,811	0,923	0,923	0,973	0,973	0,973	18366
14320-230	0,980	0,980	0,980	0,995	0,995	0,995	0,999	0,999	0,999	0,999	20637
301-790-101-0	0,985	0,985	0,985	0,985	0,985	0,995	0,995	0,995	0,995	0,995	159854
085225-04645	0,974	0,985	0,992	0,996	0,998	0,999	1,000	1,000	1,000	1,000	12840
085878-04645	0,974	0,985	0,992	0,996	0,998	0,999	1,000	1,000	1,000	1,000	12840
327155-2	0,978	0,978	0,978	0,978	0,978	0,978	0,978	0,978	0,978	0,978	94168
70722365-1	0,680	0,680	0,786	0,786	0,786	0,866	0,866	0,921	0,921	0,921	107068
465020-0303-0316	0,468	0,468	0,608	0,608	0,730	0,730	0,827	0,827	0,896	0,896	36837
465020-03040316	0,468	0,468	0,608	0,608	0,730	0,730	0,827	0,827	0,896	0,896	270350
600611-00-600	0,973	0,973	0,973	0,973	0,973	0,973	0,973	0,973	0,973	0,973	33236
B55968-004	0,972	0,972	0,972	0,972	0,972	0,985	0,985	0,985	0,985	0,985	54100
4950705	0,611	0,611	0,771	0,771	0,880	0,880	0,943	0,943	0,976	0,976	4500
9005000-10202	0,946	0,946	0,946	0,946	0,946	0,946	0,946	0,946	0,946	0,946	225000
2496M44P01	0,722	0,849	0,928	0,970	0,989	0,998	0,999	1,000	1,000	1,000	42256
63216083-1	0,722	0,849	0,928	0,970	0,989	0,998	0,999	1,000	1,000	1,000	101129
63216083-2	0,722	0,849	0,928	0,970	0,989	0,998	0,999	1,000	1,000	1,000	101129
C90ST-0003	0,989	0,989	0,989	0,989	0,989	0,989	0,989	0,989	0,989	0,989	15613
C90ST0003	0,989	0,989	0,989	0,989	0,989	0,989	0,989	0,989	0,989	0,989	13450
C12860AA06	0,962	0,962	0,962	0,962	0,962	0,996	0,996	0,996	0,996	0,996	59789
C24837102	0,767	0,870	0,934	0,934	0,969	0,987	0,987	0,995	0,998	0,998	104996
CT141	0,843	0,843	0,843	0,843	0,843	0,843	0,843	0,843	0,843	0,843	3118
S005-3	0,907	0,907	0,907	0,907	0,907	0,907	0,907	0,907	0,907	0,907	8843
S702Y0202	0,944	0,944	0,944	0,944	0,944	0,993	0,993	0,993	0,993	0,993	10500
740D8003-23	0,926	0,978	0,978	0,995	0,995	0,999	1,000	1,000	1,000	1,000	243408
740D8003-32	0,926	0,978	0,978	0,995	0,995	0,999	1,000	1,000	1,000	1,000	243408
TY1541-22	0,926	0,978	0,978	0,995	0,995	0,999	1,000	1,000	1,000	1,000	243408
TY1541-50A	0,926	0,978	0,978	0,995	0,995	0,999	1,000	1,000	1,000	1,000	243408
TY1541-51A	0,926	0,978	0,978	0,995	0,995	0,999	1,000	1,000	1,000	1,000	243408
744D8003-13	0,940	0,940	0,940	0,940	0,940	0,940	0,940	0,940	0,940	0,940	42382
TY1544-20E	0,940	0,940	0,940	0,940	0,940	0,940	0,940	0,940	0,940	0,940	14824
Z120H050830B	0,996	0,996	0,996	0,996	0,996	0,996	0,996	0,996	0,996	0,996	4750
201590002	0,953	0,977	0,989	0,995	0,998	0,999	1,000	1,000	1,000	1,000	55350
201590004	0,953	0,977	0,989	0,995	0,998	0,999	1,000	1,000	1,000	1,000	37301
980-6032-003	0,772	0,962	0,996	1,000	1,000	1,000	1,000	1,000	1,000	1,000	54500
2474M65P05	0,993	0,993	0,993	0,993	0,993	0,999	0,999	0,999	0,999	0,999	144813
6237M106B	0,945	0,945	0,945	0,989	0,989	0,989	0,998	0,998	0,998	0,998	54350
8062-1157	0,995	0,995	0,995	0,995	0,995	0,995	0,995	0,995	0,995	0,995	293365
64141-590-1	0,983	0,983	0,995	0,995	0,995	0,999	0,999	1,000	1,000	1,000	4500
430201-1	0,988	0,997	0,999	1,000	1,000	1,000	1,000	1,000	1,000	1,000	16500
3886188-2	0,972	0,972	0,972	0,972	0,972	0,985	0,985	0,985	0,985	0,985	18000
3888579-201	0,956	0,956	0,956	0,956	0,956	0,956	0,956	0,956	0,956	0,956	178225
9005000-10204	0,946	0,946	0,946	0,946	0,946	0,946	0,946	0,946	0,946	0,946	210015
AR4714-203	0,780	0,918	0,964	0,991	0,997	1,000	1,000	1,000	1,000	1,000	2500
C13043AA04	0,982	0,982	0,982	0,982	0,982	0,999	0,999	0,999	0,999	0,999	39000
Z120H030830B	0,996	0,996	0,996	0,996	0,996	0,996	0,996	0,996	0,996	0,996	8168
727-1313-02	0,987	0,987	0,987	0,987	0,987	0,998	0,998	0,998	0,998	0,998	2409
362-035-803-0	0,927	0,927	0,927	0,927	0,927	0,964	0,964	0,964	0,964	0,964	115591
441921-4	0,680	0,680	0,786	0,786	0,786	0,866	0,866	0,921	0,921	0,921	38000
796-815-01-02	0,943	0,943	0,943	0,975	0,975	0,975	0,990	0,990	0,990	0,990	2200
2248000-61	0,956	0,956	0,956	0,956	0,956	0,956	0,956	0,956	0,956	0,956	8400
3616140-7	0,974	0,974	0,974	0,974	0,974	0,994	0,994	0,994	0,994	0,994	14000

4951546	0,854	0,854	0,938	0,938	0,977	0,977	0,992	0,992	0,998	0,998	3600
AR4714-9	0,780	0,918	0,964	0,991	0,997	1,000	1,000	1,000	1,000	1,000	11171
C12860AA04	0,962	0,962	0,962	0,962	0,962	0,996	0,996	0,996	0,996	0,996	56942
TY1541-51	0,926	0,978	0,978	0,995	0,995	0,999	1,000	1,000	1,000	1,000	11000
2100-4045-22	0,439	0,789	0,950	0,992	0,999	1,000	1,000	1,000	1,000	1,000	14000
2100-1020-02	0,772	0,962	0,996	1,000	1,000	1,000	1,000	1,000	1,000	1,000	11001
10087-0102	0,992	0,992	0,992	0,999	0,999	0,999	1,000	1,000	1,000	1,000	2800
14320-230-201	0,980	0,980	0,980	0,995	0,995	0,995	0,999	0,999	0,999	0,999	20637
430153	0,988	0,997	0,999	1,000	1,000	1,000	1,000	1,000	1,000	1,000	4000
70722365-2	0,680	0,680	0,786	0,786	0,786	0,866	0,866	0,921	0,921	0,921	240136
23948-01AA	0,973	0,973	0,973	0,973	0,973	0,973	0,973	0,973	0,973	0,973	26987
D90ST2002-000	0,989	0,989	0,989	0,989	0,989	0,989	0,989	0,989	0,989	0,989	3000
5421-14-932-430-8	0,944	0,944	0,944	0,944	0,944	0,993	0,993	0,993	0,993	0,993	10500
2LA456509-02	0,937	0,987	0,998	1,000	1,000	1,000	1,000	1,000	1,000	1,000	3057
1605100-01	0,988	0,988	0,988	0,988	0,988	0,988	0,988	0,988	0,988	0,988	8600
261811055-0303	0,993	0,993	0,993	0,993	0,993	0,999	0,999	0,999	0,999	0,999	167639
144-405-000-033	0,945	0,945	0,945	0,989	0,989	0,989	0,998	0,998	0,998	0,998	21500
114151004	0,982	0,982	0,982	0,982	0,982	0,994	0,994	0,994	0,994	0,994	1950
980-6032-020	0,772	0,962	0,996	1,000	1,000	1,000	1,000	1,000	1,000	1,000	40890
2100-1228-02	0,772	0,962	0,996	1,000	1,000	1,000	1,000	1,000	1,000	1,000	28000
4950944	0,854	0,854	0,938	0,938	0,977	0,977	0,992	0,992	0,998	0,998	7500
AR4714-201	0,868	0,931	0,967	0,991	0,997	0,999	1,000	1,000	1,000	1,000	2000
AW233030001-111	0,972	0,972	0,972	0,972	0,972	0,972	0,972	0,972	0,972	0,972	4500
C12860AA03	0,962	0,962	0,962	0,962	0,962	0,996	0,996	0,996	0,996	0,996	54777
ED48A200WR	0,981	0,981	0,981	0,981	0,981	0,999	0,999	0,999	0,999	0,999	81357
TY1544-20	0,940	0,940	0,940	0,940	0,940	0,940	0,940	0,940	0,940	0,940	3000
102EH2EB	0,986	0,986	0,986	0,986	0,986	0,986	0,986	0,986	0,986	0,986	15495
350E053022020	0,974	0,974	0,974	0,974	0,974	0,974	0,974	0,974	0,974	0,974	8000
612C3501-503	0,989	0,989	0,989	0,989	0,989	0,989	0,989	0,989	0,989	0,989	51805
980-4750-001	0,439	0,789	0,950	0,992	0,999	1,000	1,000	1,000	1,000	1,000	42500
980-4750-009	0,439	0,789	0,950	0,992	0,999	1,000	1,000	1,000	1,000	1,000	33700
2100-4043-00	0,439	0,789	0,950	0,992	0,999	1,000	1,000	1,000	1,000	1,000	8250
980-6032-001	0,772	0,962	0,996	1,000	1,000	1,000	1,000	1,000	1,000	1,000	47150
14320-230-205	0,980	0,980	0,980	0,995	0,995	0,995	0,999	0,999	0,999	0,999	7500
772181A	0,812	0,885	0,885	0,934	0,934	0,965	0,982	0,982	0,991	0,991	390000
3616140-10	0,974	0,974	0,974	0,974	0,974	0,994	0,994	0,994	0,994	0,994	52500
2LA456509-01	0,937	0,987	0,998	1,000	1,000	1,000	1,000	1,000	1,000	1,000	3062
930-3001-001	0,980	0,980	0,980	0,980	0,980	0,980	0,980	0,980	0,980	0,980	30000
980-4750-003	0,439	0,789	0,950	0,992	0,999	1,000	1,000	1,000	1,000	1,000	38697
2100-4245-00	0,439	0,789	0,950	0,992	0,999	1,000	1,000	1,000	1,000	1,000	33925
3527W000-001	0,988	0,988	0,988	0,988	0,988	0,988	0,988	0,988	0,988	0,988	6830
4A7033B	0,931	0,931	0,931	0,969	0,969	0,969	0,988	0,988	0,988	0,988	62711
14330-350	0,971	0,971	0,983	0,983	0,983	0,990	0,990	0,994	0,994	0,994	17000
2100-4043-02	0,439	0,789	0,950	0,992	0,999	1,000	1,000	1,000	1,000	1,000	91865
8378M12	0,612	0,612	0,811	0,811	0,811	0,923	0,923	0,973	0,973	0,973	7500
4131020-4	0,990	0,990	0,990	0,990	0,990	0,998	0,998	0,998	0,998	0,998	102500
C24993000	0,980	0,980	0,980	0,980	0,980	0,994	0,994	0,994	0,994	0,994	5250
2LA456509-03	0,937	0,987	0,998	1,000	1,000	1,000	1,000	1,000	1,000	1,000	3920
930-1005-001	0,763	0,763	0,910	0,910	0,910	0,972	0,972	0,992	0,992	0,992	100875
45731-1391	0,985	0,985	0,985	0,985	0,985	0,995	0,995	0,995	0,995	0,995	2000
3616140-11	0,974	0,974	0,974	0,974	0,974	0,994	0,994	0,994	0,994	0,994	68491
87292325V06	0,961	0,961	0,961	0,961	0,961	0,993	0,993	0,993	0,993	0,993	7000
612C3001-017	0,982	0,982	0,982	0,982	0,982	0,982	0,982	0,982	0,982	0,982	88967
2100-4045-00	0,439	0,789	0,950	0,992	0,999	1,000	1,000	1,000	1,000	1,000	17950
2496M44P04	0,722	0,849	0,928	0,970	0,989	0,998	0,999	1,000	1,000	1,000	101129
C13206AA00	0,887	0,887	0,887	0,951	0,951	0,951	0,981	0,981	0,981	0,981	99376

465020-03030316	0,468	0,468	0,608	0,608	0,730	0,730	0,827	0,827	0,896	0,896	18000
600611-00-601	0,973	0,973	0,973	0,973	0,973	0,973	0,973	0,973	0,973	0,973	1500
4133801010	0,961	0,978	0,994	0,997	0,999	1,000	1,000	1,000	1,000	1,000	3250
2100-1226-02	0,772	0,962	0,996	1,000	1,000	1,000	1,000	1,000	1,000	1,000	26350
201590002-020	0,953	0,977	0,989	0,995	0,998	0,999	1,000	1,000	1,000	1,000	29500
2100-1026-02	0,772	0,962	0,996	1,000	1,000	1,000	1,000	1,000	1,000	1,000	12700
63216083-4	0,722	0,849	0,928	0,970	0,989	0,998	0,999	1,000	1,000	1,000	92285
C24837102-2	0,767	0,870	0,934	0,934	0,969	0,987	0,987	0,995	0,998	0,998	42000
1338-1430	0,963	0,963	0,988	0,988	0,996	0,996	0,999	0,999	1,000	1,000	2000
350E053021212	0,199	0,199	0,423	0,423	0,647	0,647	0,815	0,815	0,916	0,916	27500
1303A0000-04	0,966	0,966	0,966	0,966	0,966	0,966	0,966	0,966	0,966	0,966	4575
4A7033	0,931	0,931	0,931	0,969	0,969	0,969	0,988	0,988	0,988	0,988	4250
CT141-1	0,843	0,843	0,843	0,921	0,921	0,921	0,964	0,964	0,964	0,964	2601
8100-0083	0,927	0,927	0,927	0,927	0,927	0,964	0,964	0,964	0,964	0,964	67500
70012-101	0,982	0,982	0,982	0,982	0,982	0,982	0,982	0,982	0,982	0,982	61592
430201	0,988	0,997	0,999	1,000	1,000	1,000	1,000	1,000	1,000	1,000	38504
9005000-11203	0,946	0,946	0,946	0,946	0,946	0,946	0,946	0,946	0,946	0,946	260000
C24736100-1	0,955	0,955	0,955	0,955	0,955	0,980	0,980	0,980	0,980	0,980	32000
TY1541-50	0,926	0,978	0,978	0,995	0,995	0,999	1,000	1,000	1,000	1,000	11000
64141-580-1	0,983	0,983	0,995	0,995	0,995	0,999	0,999	1,000	1,000	1,000	4000
980-4750-002	0,439	0,789	0,950	0,992	0,999	1,000	1,000	1,000	1,000	1,000	91865
6610-20567-01	0,918	0,918	0,971	0,971	0,971	0,991	0,991	0,998	0,998	0,998	2000
1708897	0,812	0,885	0,885	0,934	0,934	0,965	0,982	0,982	0,991	0,991	178007
1338-1450	0,339	0,606	0,807	0,920	0,920	0,972	0,991	0,998	0,999	0,999	3300
980-6022-001	0,772	0,962	0,996	1,000	1,000	1,000	1,000	1,000	1,000	1,000	9500
4952590	0,854	0,854	0,938	0,938	0,977	0,977	0,992	0,992	0,998	0,998	4500
2LA005308-05	0,974	0,974	0,974	0,974	0,974	0,974	0,974	0,974	0,974	0,974	500
1806B0000-01	0,026	0,156	0,422	0,704	0,888	0,968	0,993	0,999	1,000	1,000	20003
S005-4	0,907	0,907	0,907	0,907	0,907	0,907	0,907	0,907	0,907	0,907	8843
Z014H000231B	0,985	0,985	0,985	0,985	0,985	0,985	0,985	0,985	0,985	0,985	51002
1806D0000-02	0,026	0,156	0,422	0,704	0,888	0,968	0,993	0,999	1,000	1,000	39795
4063-16082-3	0,962	0,962	0,962	0,962	0,962	0,962	0,962	0,962	0,962	0,962	3551
980-6032-023	0,772	0,962	0,996	1,000	1,000	1,000	1,000	1,000	1,000	1,000	41004
VD3920	0,987	0,987	0,987	0,987	0,987	0,987	0,987	0,987	0,987	0,987	2600
1806D0000-01	0,026	0,156	0,422	0,704	0,888	0,968	0,993	0,999	1,000	1,000	38633
8ES455967-01	0,906	0,906	0,958	0,958	0,983	0,983	0,994	0,994	0,998	0,998	7615
796815-02-03	0,943	0,943	0,943	0,975	0,975	0,975	0,990	0,990	0,990	0,990	3350
980-4700-042	0,439	0,789	0,950	0,992	0,999	1,000	1,000	1,000	1,000	1,000	4800
01N65900	0,858	0,930	0,969	0,987	0,995	0,998	0,999	1,000	1,000	1,000	6500
D30664-513	0,837	0,837	0,923	0,923	0,923	0,967	0,967	0,987	0,987	0,987	51000
D30665-513	0,879	0,879	0,879	0,952	0,952	0,952	0,983	0,983	0,983	0,983	46829
327155-3	0,978	0,978	0,978	0,978	0,978	0,978	0,978	0,978	0,978	0,978	65000
201590003	0,953	0,977	0,989	0,995	0,998	0,999	1,000	1,000	1,000	1,000	37230
Z014H000333B	0,974	0,974	0,974	0,974	0,974	0,974	0,974	0,974	0,974	0,974	117707
1806B0000-02	0,026	0,156	0,422	0,704	0,888	0,968	0,993	0,999	1,000	1,000	25000
441921-5	0,680	0,680	0,786	0,786	0,786	0,866	0,866	0,921	0,921	0,921	48500
1706903	0,812	0,885	0,885	0,934	0,934	0,965	0,982	0,982	0,991	0,991	320000
S1821502-02	0,975	0,975	0,975	0,975	0,975	0,975	0,975	0,975	0,975	0,975	6078
822-0990-003	0,953	0,953	0,953	0,978	0,978	0,978	0,990	0,990	0,990	0,990	10000
3886188-3	0,972	0,972	0,972	0,972	0,972	0,985	0,985	0,985	0,985	0,985	54109
1809A0000-01	0,850	0,850	0,906	0,906	0,906	0,944	0,944	0,969	0,969	0,969	9000
088256-04644	0,974	0,985	0,992	0,996	0,998	0,999	1,000	1,000	1,000	1,000	8500
14330-230	0,928	0,958	0,977	0,988	0,994	0,999	0,999	1,000	1,000	1,000	1850
63216083-3	0,722	0,849	0,928	0,970	0,989	0,998	0,999	1,000	1,000	1,000	88179
4133801011	0,961	0,978	0,994	0,997	0,999	1,000	1,000	1,000	1,000	1,000	4400
AR4714-11	0,780	0,918	0,964	0,991	0,997	1,000	1,000	1,000	1,000	1,000	3800

14330-375	0,971	0,971	0,983	0,983	0,983	0,990	0,990	0,994	0,994	0,994	25000
8055515-4501	0,891	0,891	0,891	0,891	0,891	0,928	0,928	0,928	0,928	0,928	4900
4-60000H883-00	0,866	0,948	0,970	0,991	0,995	0,999	1,000	1,000	1,000	1,000	13853
70895-1	0,976	0,976	0,976	0,989	0,989	0,989	0,995	0,995	0,995	0,995	7927
AR4714-7	0,868	0,931	0,967	0,991	0,997	0,999	1,000	1,000	1,000	1,000	2000
4133801030	0,706	0,861	0,911	0,968	0,982	0,995	0,999	0,999	1,000	1,000	6309
70227A010001	0,941	0,941	0,941	0,960	0,960	0,960	0,973	0,973	0,973	0,973	11450

Table 3. Spare Investment Parameters for 192 Components (10 Different Scenarios)

PN	+%10	+%20	+%30	+%40	+%50	+%60	+%70	+%80	+%90	+%100
4-60000H883	2	4	5	7	8	10	12	13	15	16
10-451701-000	1	2	3	4	5	6	7	8	9	10
114193007	1	2	3	4	5	6	7	8	9	10
114193008	1	2	3	4	5	6	7	8	9	10
114193009	1	2	3	4	5	6	7	8	9	10
114193010	1	2	3	4	5	6	7	8	9	10
201590001	1	2	3	4	5	6	7	8	9	10
125A3	1	1	1	1	1	1	1	1	1	1
301-799-401-0	1	1	1	1	1	1	1	1	1	1
1605100-02	1	1	1	1	1	1	1	1	1	1
612C3001-015	1	1	1	1	1	1	1	1	1	1
980-4700-003	3	5	7	9	11	14	16	18	20	22
S800-3000-00	3	5	7	9	11	14	16	18	20	22
980-6023-002	3	5	7	9	11	13	15	17	19	21
2100-1025-02	3	5	7	9	11	13	15	17	19	21
S200-0012-00	3	5	7	9	11	13	15	17	19	21
1303A0000-03	1	1	1	1	1	1	1	1	1	1
1806A0000-02	2	4	6	8	10	12	14	16	18	19
262200008-0002	1	1	1	1	1	2	2	2	2	2
2040081-101	1	1	1	1	1	1	1	1	1	1
4063-16082-2	1	1	1	1	1	1	1	1	1	1
2496M34P04	1	1	1	1	1	1	1	1	1	1
8378M2	1	1	2	2	2	3	3	4	4	4
14320-230	1	1	1	2	2	2	3	3	3	3
301-790-101-0	1	1	1	1	1	2	2	2	2	2
085225-04645	1	2	3	4	5	6	7	8	9	10
085878-04645	1	2	3	4	5	6	7	8	9	10
327155-2	1	1	1	1	1	1	1	1	1	1
70722365-1	1	1	2	2	2	3	3	4	4	4
465020-0303-0316	1	1	2	2	3	3	4	4	5	5
465020-03040316	1	1	2	2	3	3	4	4	5	5
600611-00-600	1	1	1	1	1	1	1	1	1	1
B55968-004	1	1	1	1	1	2	2	2	2	2
4950705	1	1	2	2	3	3	4	4	5	5
9005000-10202	1	1	1	1	1	1	1	1	1	1
2496M44P01	3	5	7	9	11	14	16	18	20	22
63216083-1	3	5	7	9	11	14	16	18	20	22
63216083-2	3	5	7	9	11	14	16	18	20	22
C90ST-0003	1	1	1	1	1	1	1	1	1	1
C90ST0003	1	1	1	1	1	1	1	1	1	1
C12860AA06	1	1	1	1	1	2	2	2	2	2

C24837102	1	2	3	3	4	5	5	6	7	7
CT141	1	1	1	1	1	1	1	1	1	1
S005-3	1	1	1	1	1	1	1	1	1	1
S702Y0202	1	1	1	1	1	2	2	2	2	2
740D8003-23	1	2	2	3	3	4	5	5	6	6
740D8003-32	1	2	2	3	3	4	5	5	6	6
TY1541-22	1	2	2	3	3	4	5	5	6	6
TY1541-50A	1	2	2	3	3	4	5	5	6	6
TY1541-51A	1	2	2	3	3	4	5	5	6	6
744D8003-13	1	1	1	1	1	1	1	1	1	1
TY1544-20E	1	1	1	1	1	1	1	1	1	1
Z120H050830B	1	1	1	1	1	1	1	1	1	1
201590002	1	2	3	4	5	6	7	8	9	10
201590004	1	2	3	4	5	6	7	8	9	10
980-6032-003	3	5	7	9	11	13	15	17	19	21
2474M65P05	1	1	1	1	1	2	2	2	2	2
6237M106B	1	1	1	2	2	2	3	3	3	3
8062-1157	1	1	1	1	1	1	1	1	1	1
64141-590-1	1	1	2	2	2	3	3	4	4	4
430201-1	1	2	3	4	5	6	7	8	9	9
3886188-2	1	1	1	1	1	2	2	2	2	2
3888579-201	1	1	1	1	1	1	1	1	1	1
9005000-10204	1	1	1	1	1	1	1	1	1	1
AR4714-203	3	6	8	11	13	16	19	21	24	26
C13043AA04	1	1	1	1	1	2	2	2	2	2
Z120H030830B	1	1	1	1	1	1	1	1	1	1
727-1313-02	1	1	1	1	1	2	2	2	2	2
362-035-803-0	1	1	1	1	1	2	2	2	2	2
441921-4	1	1	2	2	2	3	3	4	4	4
796-815-01-02	1	1	1	2	2	2	3	3	3	3
2248000-61	1	1	1	1	1	1	1	1	1	1
3616140-7	1	1	1	1	1	2	2	2	2	2
4951546	1	1	2	2	3	3	4	4	5	5
AR4714-9	3	6	8	11	13	16	19	21	24	26
C12860AA04	1	1	1	1	1	2	2	2	2	2
TY1541-51	1	2	2	3	3	4	5	5	6	6
2100-4045-22	3	5	7	9	11	14	16	18	20	22
2100-1020-02	3	5	7	9	11	13	15	17	19	21
10087-0102	1	1	1	2	2	2	3	3	3	3
14320-230-201	1	1	1	2	2	2	3	3	3	3
430153	1	2	3	4	5	6	7	8	9	9
70722365-2	1	1	2	2	2	3	3	4	4	4
23948-01AA	1	1	1	1	1	1	1	1	1	1
D90ST2002-000	1	1	1	1	1	1	1	1	1	1
5421-14-932-430-8	1	1	1	1	1	2	2	2	2	2
2LA456509-02	1	2	3	4	5	6	7	8	9	10
1605100-01	1	1	1	1	1	1	1	1	1	1
261811055-0303	1	1	1	1	1	2	2	2	2	2
144-405-000-033	1	1	1	2	2	2	3	3	3	3
114151004	1	1	1	1	1	2	2	2	2	2
980-6032-020	3	5	7	9	11	13	15	17	19	21
2100-1228-02	3	5	7	9	11	13	15	17	19	21
4950944	1	1	2	2	3	3	4	4	5	5
AR4714-201	3	5	7	10	12	14	17	19	21	23
AW233030001-111	1	1	1	1	1	1	1	1	1	1
C12860AA03	1	1	1	1	1	2	2	2	2	2

ED48A200WR	1	1	1	1	1	2	2	2	2	2
TY1544-20	1	1	1	1	1	1	1	1	1	1
102EH2EB	1	1	1	1	1	1	1	1	1	1
350E053022020	1	1	1	1	1	1	1	1	1	1
612C3501-503	1	1	1	1	1	1	1	1	1	1
980-4750-001	3	5	7	9	11	14	16	18	20	22
980-4750-009	3	5	7	9	11	14	16	18	20	22
2100-4043-00	3	5	7	9	11	14	16	18	20	22
980-6032-001	3	5	7	9	11	13	15	17	19	21
14320-230-205	1	1	1	2	2	2	3	3	3	3
772181A	1	2	2	3	3	4	5	5	6	6
3616140-10	1	1	1	1	1	2	2	2	2	2
2LA456509-01	1	2	3	4	5	6	7	8	9	10
930-3001-001	1	1	1	1	1	1	1	1	1	1
980-4750-003	3	5	7	9	11	14	16	18	20	22
2100-4245-00	3	5	7	9	11	14	16	18	20	22
3527W000-001	1	1	1	1	1	1	1	1	1	1
4A7033B	1	1	1	2	2	2	3	3	3	3
14330-350	1	1	2	2	2	3	3	4	4	4
2100-4043-02	3	5	7	9	11	14	16	18	20	22
8378M12	1	1	2	2	2	3	3	4	4	4
4131020-4	1	1	1	1	1	2	2	2	2	2
C24993000	1	1	1	1	1	2	2	2	2	2
2LA456509-03	1	2	3	4	5	6	7	8	9	10
930-1005-001	1	1	2	2	2	3	3	4	4	4
45731-1391	1	1	1	1	1	2	2	2	2	2
3616140-11	1	1	1	1	1	2	2	2	2	2
87292325V06	1	1	1	1	1	2	2	2	2	2
612C3001-017	1	1	1	1	1	1	1	1	1	1
2100-4045-00	3	5	7	9	11	14	16	18	20	22
2496M44P04	3	5	7	9	11	14	16	18	20	22
C13206AA00	1	1	1	2	2	2	3	3	3	3
465020-03030316	1	1	2	2	3	3	4	4	5	5
600611-00-601	1	1	1	1	1	1	1	1	1	1
4133801010	2	3	5	6	7	9	10	12	13	14
2100-1226-02	3	5	7	9	11	13	15	17	19	21
201590002-020	1	2	3	4	5	6	7	8	9	10
2100-1026-02	3	5	7	9	11	13	15	17	19	21
63216083-4	3	5	7	9	11	14	16	18	20	22
C24837102-2	1	2	3	3	4	5	5	6	7	7
1338-1430	1	1	2	2	3	3	4	4	5	5
350E053021212	1	1	2	2	3	3	4	4	5	5
1303A0000-04	1	1	1	1	1	1	1	1	1	1
4A7033	1	1	1	2	2	2	3	3	3	3
CT141-1	1	1	1	2	2	2	3	3	3	3
8100-0083	1	1	1	1	1	2	2	2	2	2
70012-101	1	1	1	1	1	1	1	1	1	1
430201	1	2	3	4	5	6	7	8	9	9
9005000-11203	1	1	1	1	1	1	1	1	1	1
C24736100-1	1	1	1	1	1	2	2	2	2	2
TY1541-50	1	2	2	3	3	4	5	5	6	6
64141-580-1	1	1	2	2	2	3	3	4	4	4
980-4750-002	3	5	7	9	11	14	16	18	20	22
6610-20567-01	1	1	2	2	2	3	3	4	4	4
1708897	1	2	2	3	3	4	5	5	6	6
1338-1450	1	2	3	4	4	5	6	7	8	8

980-6022-001	3	5	7	9	11	13	15	17	19	21
4952590	1	1	2	2	3	3	4	4	5	5
2LA005308-05	1	1	1	1	1	1	1	1	1	1
1806B0000-01	2	4	6	8	10	12	14	16	18	19
S005-4	1	1	1	1	1	1	1	1	1	1
Z014H000231B	1	1	1	1	1	1	1	1	1	1
1806D0000-02	2	4	6	8	10	12	14	16	18	19
4063-16082-3	1	1	1	1	1	1	1	1	1	1
980-6032-023	3	5	7	9	11	13	15	17	19	21
VD3920	1	1	1	1	1	1	1	1	1	1
1806D0000-01	2	4	6	8	10	12	14	16	18	19
8ES455967-01	1	1	2	2	3	3	4	4	5	5
796815-02-03	1	1	1	2	2	2	3	3	3	3
980-4700-042	3	5	7	9	11	14	16	18	20	22
01N65900	1	2	3	4	5	6	7	8	9	9
D30664-513	1	1	2	2	2	3	3	4	4	4
D30665-513	1	1	1	2	2	2	3	3	3	3
327155-3	1	1	1	1	1	1	1	1	1	1
201590003	1	2	3	4	5	6	7	8	9	10
Z014H000333B	1	1	1	1	1	1	1	1	1	1
1806B0000-02	2	4	6	8	10	12	14	16	18	19
441921-5	1	1	2	2	2	3	3	4	4	4
1706903	1	2	2	3	3	4	5	5	6	6
S1821502-02	1	1	1	1	1	1	1	1	1	1
822-0990-003	1	1	1	2	2	2	3	3	3	3
3886188-3	1	1	1	1	1	2	2	2	2	2
1809A0000-01	1	1	2	2	2	3	3	4	4	4
088256-04644	1	2	3	4	5	6	7	8	9	10
14330-230	2	3	4	5	6	8	9	10	11	12
63216083-3	3	5	7	9	11	14	16	18	20	22
4133801011	2	3	5	6	7	9	10	12	13	14
AR4714-11	3	6	8	11	13	16	19	21	24	26
14330-375	1	1	2	2	2	3	3	4	4	4
8055515-4501	1	1	1	1	1	2	2	2	2	2
4-60000H883-00	2	4	5	7	8	10	12	13	15	16
70895-1	1	1	1	2	2	2	3	3	3	3
AR4714-7	3	5	7	10	12	14	17	19	21	23
4133801030	2	4	5	7	8	10	12	13	15	16
70227A010001	1	1	1	2	2	2	3	3	3	3