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“Effective Follow-on Spare Support through Foreign Military Sales (Optimization of CLSSA)”

“Konstantinos Alexiadis”

Supervisor: “Nikolaos Thomaidis”

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“Konstantinos Alexiadis”

Supervising Committee

Supervisor:

“Nikolaos Thomaidis”

“Associate Professor of Computational Methods in Management and Finance

Department of Financial and Management Engineering

University of the Aegean”

&

“Assistant Professor of Econometrics

Aristotle University of Thessaloniki”

Co-Supervisor:

“Alexandros Diamantidis”

“Assistant Professor, Department of Economics

Aristotle University of Thessaloniki”

Patras, Greece, “June” “2023”

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Abstract

Foreign military sales (FMS) is a program that allows countries that meet certain requirements to buy defense goods, services, and training from the U.S. government through a negotiated intergovernmental agreement. In regards to the various kinds of agreements offered for follow-on support, the purchasing nation has numerous alternatives. In offering follow-on support, specified order cases, general order cases, and Cooperative Logistics Supply Support Arrangements (CLSSAs) are all utilized.

The fact that material needs are generally satisfied from the Department of Defence (DOD) stockpiles only if on-hand materials are above the control level, generally referred to as the reorder point, is a crucial characteristic of both specified order and generalized order cases. Only via a mature (programmed) CLSSA can FMS purchase orders generally be fulfilled below this reorder level.

CLSSA generates a Stock Level Quantity (SLQ) for each asset by looking at the history of demand, the lead time of the asset, and how the asset is ordered. Since a higher SLQ amount not only enhances service levels but also costs more money, asset SLQs have an impact on both CLSSA program expenses and the level of service FMS users get. To evaluate the effect that alternative purchasing patterns have on SLQ levels, we have replicated the CLSSA calculations in an Excel and Matlab environment and used a multi-agent metaheuristic algoreithm (Consensus Based Optimization) to find the optimal order program for a combination of demand levels and leat times. This provides for the best possible customer service while significantly reducing customer program expenses.

FMS countries could take advantage of the algorithmic outcomes to modify the frequency with which they place CLSSA orders to boost their level of service and budget.

Keywords

Foreign Military Sales (FMS), Cooperative Logistics Supply Support Arrangement (CLSSA), Follow-on Support (FOS), Stock Level Quantity (SLQ), Security Assistance Management Information System (SAMIS), Air Force Security Assistance and Cooperation (AFSAC)

"Αποτελεσματική Εν συνεχεία Υποστήριξη Ανταλλακτικών μέσω Στρατιωτικών Πηγών Προέλευσης ΗΠΑ (Βελτιστοποίηση της CLSSA)"

"Κωνσταντίνος Αλεξιάδης"

Περίληψη

Το πρόγραμμα πωλήσεων μέσω στρατιωτικών πηγών προέλευσης ΗΠΑ, επιτρέπει σε χώρες που πληρούν συγκεκριμένες προϋποθέσεις, να αγοράζουν αμυντικό εξοπλισμό, υπηρεσίες και εκπαίδευση από την κυβέρνηση των ΗΠΑ μέσω της σύναψης μιας διακρατικής συμφωνίας. Όσον αφορά το είδος της παρεχόμενης συμφωνίας, το κράτος-χρήστης του υπόψη προγράμματος έχει αρκετές επιλογές για την εν συνεχεία υποστήριξη των οπλικών του συστημάτων. Δύναται να συναφθούν συμβάσεις που είτε προσδιορίζουν το είδος και την ποσότητα εξοπλισμού, υλικών και υπηρεσιών, είτε περιλαμβάνουν ένα προκαθορισμένο χρηματικό όριο έναντι του οποίου υποβάλλονται παραγγελίες για διάφορα υλικά. Οι υπόψη απαιτήσεις ικανοποιούνται εφόσον υπάρχει ικανό απόθεμα στις αποθήκες των ΗΠΑ. Παρέχεται επίσης η δυνατότητα υποστήριξης σε ισοδύναμο με αυτό των ΗΠΑ επίπεδο, μέσω επένδυσης κεφαλαίου στο Υπουργείο Άμυνας των ΗΠΑ, με σκοπό τη δημιουργία επιπλέον αποθέματος (CLSSA), για την απρόσκοπτη κάλυψη των μελλοντικών απαιτήσεων της χώρας που συμμετέχει στο υπόψη πρόγραμμα.

Βασισμένη σε μαθηματικό τύπο, η τελευταία δυνατότητα δημιουργεί ποσότητα αποθέματος για κάθε υλικό, ανάλογα με το ιστορικό ζήτησης, τον χρόνο παράδοσης και τη συχνότητα παραγγελιών. Μια μεγαλύτερη ποσότητα αποθέματος σαφώς και βελτιώνει από τη μία το επίπεδο παρεχόμενης υποστήριξης, από την άλλη όμως αυξάνει το κόστος χρήσης του υπόψη προγράμματος. Για το λόγο αυτό κατασκευάστηκε ένας αλγόριθμος προσομοίωσης του προγράμματος CLSSA σε περιβάλλον Excel & Matlab και χρησιμοποιήθηκε ένας πολυπαραγοντικός μετευρετικός αλγόριθμος (Consensus Based

Optimization) για την εύρεση του βέλτιστου σχήματος παραγγελίας για διάφορους συνδυασμούς επιπέδων ζήτησης και χρόνων παράδοσης υλικών Από τη μελέτη των βέλτιστων λύσεων του προβλήματος μπορέσαμε να αξιολογήσουμε την επίδραση που έχουν στην δημιουργία της ποσότητας αποθέματος οι παραπάνω παράγοντες.

Η έρευνα παρέχει τον πιο αποτελεσματικό τρόπο τοποθέτησης παραγγελιών ανάμεσα σε όλους τους πιθανούς συνδυασμούς που μπορεί να συμβούν ανάλογα με τη ζήτηση και τον χρόνο παράδοσης των υλικών, με σκοπό τη βελτιστοποίηση του εν λόγω προγράμματος υποστήριξης προς όφελος του πελάτη με σημαντική μείωση του κόστους αυτού.

Τα κράτη που συμμετέχουν στο υπόψη πρόγραμμα μέσω στρατιωτικών πηγών προέλευσης ΗΠΑ, θα μπορούσαν να επωφεληθούν από τα αποτελέσματα, τροποποιώντας τη συχνότητα και το μοτίβο παραγγελιών τους για να ενισχύσουν το επίπεδο εξυπηρέτησης και τον προϋπολογισμό τους.

Λέξεις – Κλειδιά

Προμήθειες μέσω στρατιωτικών πηγών ΗΠΑ, Εν συνεχεία υποστήριξη οπλικών συστημάτων, πολεμική αεροπορία.

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List of Abbreviations & Acronyms

AFMC - Air Force Materiel Command

AFSAC - Air Force Security Assistance Center

AMD - Average monthly demand

CLSSA - Cooperative Logistics Supply Support Arrangement.

DLA - Defense Logistics Agency: Handles the whole worldwide defense SC, from feedstock to end-user disposal.

DOD – Department of Defence

DSCA - Defense Security Cooperation Agency: Offers economic and technical support to allies, transfers defense equipment, training, and services, and fosters military-to-military connections.

F/AD - Force Activity Designator (The F/AD tells us how important the operation is from a defense point of view). Is the supply priority based on which the requisitioner may order material.

FMS - Foreign Military Sales

FMSO I and II - Foreign Military Sales Orders that implement CLSSA. The one is used by USAF for the funding of the forecast, while the other is utilized by FMS customers for ordering those prepared items.

FOS - Follow-on Support: Programs chosen by FMS customers that provide ongoing assistance after the original support package has been exhausted.

ILCO - International Logistics Control Organization

Investment item: Item that is repairable and reusable.

LOA - Letter of Offer and Acceptance

MDE - Major Defense Equipment: Equipment that is specially designed for military use and has a high acquisition cost.

NSN - National Stock Number: A unique identifier assigned to each item of supply in a logistics system.

PLT - Procurement lead time

SAMIS - Security Assistance Management Information System: System for monitoring the supply and economic performance of established LOAs and reporting statuses to FMS clients.

SCM - Supply Chain Management

SLQ - Stock Level Quantity

SME - Significant Military Equipment: Articles for which extra export restrictions are required due to their significant military value or capability.

USAF - United States Air Force

USG - United States Government.

1. Introduction

Supply chain management is the lifeblood of any military and the domain that combines procurement, maintenance, availability, and shipping along with the operational, economical, and communicational activities in order to meet joint force material needs in a results-driven manner. Military logistics developed an assortment of strategies that have now been extensively used in business. Altering the ways in which we fight whether in military or in business results in shifts in the ways in which we support these endeavors (Zanjirani Farahani et al., 2009).

1.1 Background and Problem Definition.

The availability of the fleet at high levels is a fundamental objective in the sphere of national defense in each country. Most nations utilize American aircraft, which they acquire via FMS, a program that streamlines the transfer of US military assets to other government entities. FMS users may employ several support packages to ensure the aircraft's long-term viability. The CLSSA is one of the programs that nations have mostly used for this purpose. CLSSA is intended to deliver beneficial and ongoing support services for U.S.-made military materiel held by foreign countries and worldwide organizations, and it is typically the most efficient method to deliver common components and secondary-item support for equipment of U.S. origin held in the inventories of cooperating and partner nations.

A fundamental component of CLSSA is the forecast of stocks in the USAF depot in anticipation of each user country's needs. The USAF takes into account the number of requests placed by the nation, the requested quantity, and the time period during which the requests are placed in order to forecast this stock. This amount is referred to as SLQ, and it is calculated based on a mathematical formula that will be discussed in Chapter 3. SLQ is the expected quantity of every component that the customer will need, considering the customer's demand, their purchasing pattern, and the asset's lead time.

Another aspect is that when a nation puts an order for a quantity that is equal to or lesser than the SLQ, the order is marked as "programmed," but when the amount that is ordered goes above the SLQ, it is marked "non-programmed." Programmed requests are permitted to be satisfied by readily available or on-order assets, but nonprogrammed purchases are only completed if there is surplus inventory for the specific component; otherwise, the timeline to be completed will be the lead time from the purchase.

The projected cost for every component is the item's SLQ multiplied by its price, which must be advanced in order for the USAF to establish the forecast. The SLQ varies according to the purchasing demand trend, influencing the total cost of the entire program. Low levels of SLQs elevate non-programmed requests, whereas higher SLQs provide greater assistance but require larger expenditures. The objective of using CLSSA successfully is to figure out the optimal requisition sequence that keeps the SLQ at the lowest possible level while ensuring programmed requests.

1.2 Purpose

The present dissertation aims to furnish information that can serve as a valuable instrument for the development of an efficient requisitioning policy. This policy is intended to optimize the support provided by the CLSSA program while minimizing the associated costs. The dissertation will delve into the various processes and formulations that are built into the CLSSA program, with the objective of providing a comprehensive understanding of the program's workings. Ultimately, the dissertation seeks to contribute to the development of a purchasing strategy that can effectively leverage the resources of the CLSSA program to achieve the desired outcomes.

1.3 Methodology

This study aims to analyze the computation of SLQ to ascertain the impact of distinct requisitioning strategies on SLQ. The investigation will consider both the upfront cost of the forecast and the efficacy of programmed orders. The present study aims to develop an algorithm that can effectively generate optimal ordering placements while minimizing up-front expenses and using specific criteria to ensure that the programmed orders are achieved depending on demand levels, item lead times, and ordering patterns in the computation of the SLQ, which forms the basis of the algorithm. The proposed algorithm is expected to provide a practical solution to the challenges associated with ordering placements in the context of utilizing the CLSSA program.

1.4 Findings

It has been identified that greater SLQs are related to increasing expenses, while lower SLQs lead to a higher number of nonprogrammed items being ordered. The SLQ grows in tandem with the lengthening of the lead time, and whenever there is a higher demand, the SLQ will likewise rise. As lead time increases, it has been noticed that placing fewer orders is more successful in generating better outcomes than placing a larger number of orders, and vice versa. Extremely short lead periods, such as three or four months, have an unexpected effect on SLQ, and it is not always feasible to fulfill all requisitions programmed when the lead time of the asset is very low.

1.5 Limitations

The objective of this research is to determine the requisitioning pattern that is optimal with regard to the CLSSA SLQ computational formula in order to guarantee the highest possible percentage of requests fulfilled while maintaining the lowest possible cost that is committed to the contract in order for the assets to be stocked for the anticipated demands. This dissertation is limited to the aforementioned objective since nations undoubtedly have different standards by which to assess an overall inventory strategy. As a result of the fact that CLSSA was developed for peacetime operational supplies rather than emergency or wartime logistics, the current study does not focus on either of those areas.

1.6 Organization

An overview of the remaining sections of the dissertation will be presented, providing an outline for the study, which is structured into five distinct chapters. Chapter 1: Introduction; Chapter 2: Literature Review; Chapter 3: Methodology; Chapter 4: Analysis and Outcomes; and Chapter 5: Conclusion and Recommendations

The purpose of Chapter 2 is to present an overview of the literature to help figure out the context of this dissertation. Terms related to FMS, FOS, and CLSSA will be outlined, followed by information regarding the SAMIS, SLQ, and CLSSA service levels, as well as the distinctions among programmed and nonprogrammed support. A FMS lead times will also be determined. Due to the fact that the CLSSA program is comprised of a wider inventory management and demand forecasting context, certain key inventory and forecasting principles will be introduced in order to place the CLSSA functioning within the larger SCM framework. Finally, past CLSSA research will be reviewed to give more context to the present dissertation.

Chapter 3 provides specific information on the actual SLQ computational formula as well as its fundamental concepts, followed by essential assumptions for the design and implementation of the algorithm and the basic criteria that will be evaluated. In addition, an overview will be provided describing the software that was used to evaluate the data and execute the algorithm, with consideration for any possible weaknesses.

Chapter 4 presents a case study chosen for analysis, a comparison of the outcomes to research that was conducted in the past, and an examination of the implications for a financial analysis. The chapter is also intended to facilitate the way FMS country inventory managers establish an effective requisitioning strategy using the data from different simulation runs of the algorithm.

Chapter 5 includes all aspects of the study while highlighting the key results. Furthermore, this chapter will not only bring the present study to a close but will also act as an entry point for additional investigations, indicating prospective routes for future research.

2. Literature Review

2.1 Foreign Military Sales

Most civilian and military members of the Department of Defence have come across the phrase "Foreign Military Sales (FMS)" at some point in their careers. FMS look easy and uncomplicated at first glance—sell military equipment, software, assistance, or training to a friendly government. FMS may be a useful instrument for augmenting military cooperation activities and improving security cooperation with allied states. Most significantly, FMS is sometimes seen as just a means of selling military equipment to other nations. Nevertheless, this notion is incorrect; there is much more to FMS than meets the eye. It is a complex procedure that is overseen by various authorities, rules, and regulations (Brian B. Yoo et al., 2009).

Not only is the United States by far the world's greatest military force, but as depicted in figure 1 below, it is also the leading exporter of weapons, accounting for 40% of global military exports. (Pieter D. Wezeman et al., 2023).

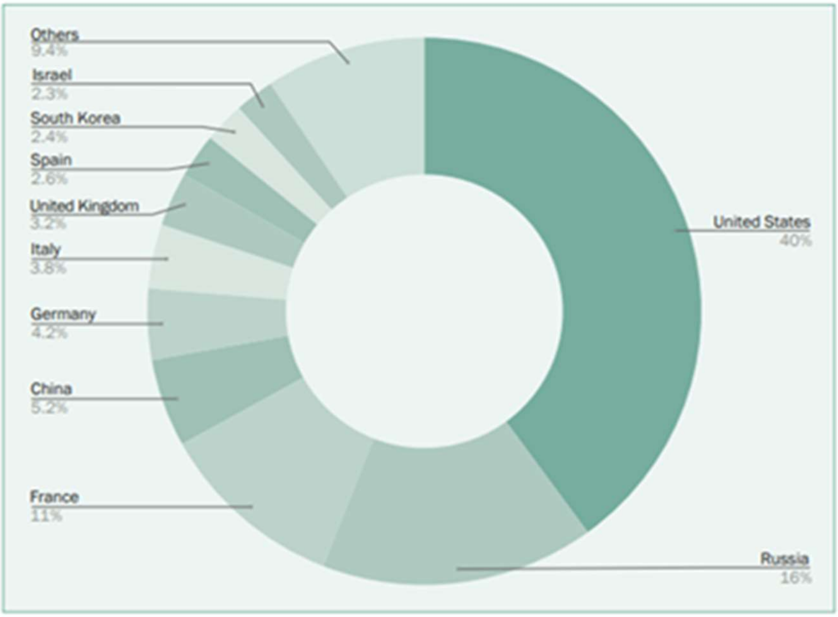

Figure 1 The worldwide proportion of significant weapons exports by the top ten exporters 2018–2022 (Pieter D. Wezeman et al., 2023).

The following table 1 depicts the annual sales data of the top ten countries from fiscal year 1950 through FY 2021. (in billion) to better understand the magnitude of FMS (Defense Security Cooperation Agency, 2021).

Table 1 FMS Annual Sales from FY 1950 to FY 2021

Country	FY 1950 to 2021	Percentage of Worldwide Total
Saudi Arabia	$174.43	18.49%
Israel	$49.13	5.21%
Japan	$48.94	5.19%
Taiwan	$47.59	5.05%
South Korea	$43.45	4.61%
Egypt	$41.89	4.44%
Australia	$39.35	4.17%
United Kingdom	$33.05	3.50%
United Arab Emirates	$31.89	3.38%
Kuwait	$27.11	2.87%

The FMS program is a security cooperation program (Defense Security Cooperation University & Department of Defence, 2022) that is managed by DSCA in order to foster stability around the world. Under this program, qualifying foreign governments are able to acquire military products, services, and training from the United States Government. The acquiring government is responsible for paying all of the expenditures that are related with the sale. There is an intergovernmental agreement between the USG and a government of another nation, which is regularly memorialized in a Letter of Offer and Acceptance (LOA). Each LOA is simply referred to as a "case" in common parlance, and for the purposes of accounting, each case is given a distinctive identification code (Defence Security Cooperation Agency & Department of Defence, 2022).

The FMS program is one of the principal ways the US government supports its overseas partners, selling billions of dollars in goods and services to them each year. The FMS program is designed to function on a "no profit, no loss" basis, with no unnecessary costs paid to customers and cost-recovering service fees (United States Government Accountability Office, 2019). Despite the fact that it includes administrative fees, the FMS will constantly benefit from the US government's expertise with a system as well as economies of scale purchasing power in order for a nation to acquire a lower unit price than they would otherwise (TINA S. KAIDANOW, 2017).

2.2 Follow on Support

Follow-on support (FOS) includes all of the services and equipment necessary to keep a weapon system operational after it has been began operating. FOS involves replenishment of the initial spares and maintenance component parts, purchase of additional support equipment not included in the first allotment, acquisition of repair and engineering assistance, ammunition resupply, technical publication updates, and so on (Defence Security Cooperation Agency & Department of Defence, 2022).

The Air Force Security Assistance and Cooperation (AFSAC) directorate develops, processes, and manages the implementation of the appropriate FMS cases for the Air Force's FOS from Air Force Materiel Command (AFMC) assets (Defence Security Cooperation Agency, 2021).

With regard to the various types of FMS cases accessible for FOS, the buying nation has many alternatives. FOS starts with the weapon system's functioning. It is required to replenish in-country operational supplies, which are utilized to keep the weapon system functional. Items that become inoperative of being used may be fixed or replaced. This necessitates both maintenance and acquisition efforts. There are three basic kinds of follow-on spare cases. Defined order cases, blanket order cases, and CLSSAs may all be utilized for both maintenance and procurement (BY ORDER OF THE SECRETARY OF THE AIR FORCE, 2018).

A "defined order" FMS case is one in which the customer specifies and quantifies in the LOA papers the defense items, services, or training courses that the foreign partner desires. This case is often utilized to sell significant military equipment like tanks, vessels, aircraft, rockets, classified items, and the associated initial support needed (Defence Security Cooperation Agency & Department of Defence, 2022).

A "blanket order" case refers to one in which the overseas partner orders a category of goods, services, or training at a predetermined dollar value ceiling without specifying the precise items or quantities requested. Foreign partners may submit requests on a blanket order case for as long as funds are sufficient. Spares and maintenance components, supporting equipment, and publications are often offered via blanket orders, but are not limited to them (Defence Security Cooperation Agency & Department of Defence, 2022).

The fact that material needs are generally satisfied from DOD stockpiles only if readily available assets are over the control level, also known as the reorder point, is a crucial characteristic of both “defined” and “blanket” order cases. Only via an established CLSSA can FMS requisitions generally be filled below this reorder threshold since CLSSA is an ongoing project and the previous two cases are one-time purchase situations (Defence Security Cooperation Agency & Department of Defence, 2022). The CLSSA case is also known as the “K case” since the initial letter of the case's designated name is K for each nation that utilizes it.

2.3 Cooperative Logistics Supply Support Arrangements

The Department of Defense (DOD) offers the Cooperative Logistics Supply Support Arrangements (CLSSA) as an efficient way of replacing in-country stockpiles of spares and maintenance components that were first supplied with end-of-life equipment. To cover its projected support needs, the government must make an investment in the DOD logistics system under the terms of the agreement. CLSSA is an 'agreement' among a U.S. military service and another nation's military service or entity that establishes the regulations and limitations for providing spares support to US Forces within F/AD. The CLSSA member turns into a partner in the supply networks of the USAF and the DLA (AFLCMC/WFALA, 2020).

CLSSA is not a compulsory program, despite the fact that traditionally the majority of FMS clients have participated in it. The customer has the option of participating in CLSSA, opting out of engaging in CLSSA entirely, or choosing to engage in a level selectively, such as maintenance or procurement (AFLCMC/WFALA, 2020).

The CLSSA is utilized to replenish consumables or replace parts that are able to be repaired. It could not be utilized to purchase ammunition, SME, MDE, confidential items, commercialized off-the-shelf material, bulk gasoline, or anything else that the DOD does not centrally stockpile or handle. The CLSSA is not designed to provide initial support but rather to replenish the initial support package. In exchange for this financial commitment, the country receives equal support from DOD inventories, provided that U.S. forces with the same force activity designator are involved (Defence Security Cooperation Agency & Department of Defence, 2022).

Several nations that hold US-origin weapon systems presently in use by US military forces see the CLSSA as an achievable option since they have improved access to the DOD's parts inventory. As a consequence, FMS replenishment of supplies is quicker, allowing the international partner's equipment to operate at full capacity. Instead of procuring the necessary equipment in other ways, the Greek government requested a CLSSA in 2021 for replenishment of stocks, delivery of standard spare components, and repair or replacement of components to support the Hellenic Air Force's defensive and transport aerial fleets, as well as other associated parts of program support. (Defense Security Cooperation Agency - News Release, 2021).

CLSSA is founded primarily on adequate inventories of supplied material in the purchasing nation, and a multitude of factors can affect its efficacy. The effectiveness of the CLSSA is based on the systematic and timely replenishment of this in-country stock. The engaging nation should submit replenishment requests on a regular basis and refrain from obtaining large quantities sporadically. In addition, CLSSAs are not intended to be used for a substantial rise in demand. These requirements must be met via a defined or blanket order case (AFLCMC/WFALA, 2020).

2.4 CLSSA Structure

With regard to the two-step structure of the arrangement, the CLSSA comprises of two independent FMS cases: one for DOD stock augmentation and one for material pullout; FMSO I and II, accordingly.

The FMSO I (or stock-level case) authorizes the USAF and DLA to acquire and store material in advance of CLSSA customer requests by increasing inventories to satisfy forecasted country-user demands. The purchaser is financially responsible for all FMSO I's stated obligations. However, the needed funding is 30% of the overall value (also referred to as the stock on hand). The USAF and DLA have the power to acquire and hold assets in advance of the CLSSA customer's anticipated requests because of the customer's financial responsibility and financial investment (Defence Security Cooperation Agency & Department of Defence, 2022).

The FMSO II (or requisition case) allows the customer to request replacement and maintenance items to replace depleted supplies. There are certain similarities between the FMSO II case and a blanket order case. It has a predetermined monetary limit and can last for as long as there are sufficient funds in the case. The nation places up its own requests and sends them to the relevant ILCO. F/AD will provide "programmed" requisitions for qualified FMSO I items at the same level of assistance as the USAF. "Non-Programmed" requisitions are not entitled to assistance equivalent to that supplied to the USAF, but may be supported from "Surplus Stock" or "Procurement" (Defence Security Cooperation Agency & Department of Defence, 2022).

2.5 Push and pull systems

A "push" production system is one in which things are manufactured in anticipation of demand, encompassing both known demand in the form of current orders and forecast demand. In other words, things are not manufactured precisely to order but rather in response to a forecasted demand. One underlying problem is the lead time gap, which occurs when the time it takes to source and produce items exceeds the customer's willingness to wait, particularly in the modern age of online commerce. In order to meet consumer demand within an acceptable timeframe, this gap must be decreased, removed, or filled with finished goods inventories. Demand forecasting must be performed, taking into account the material's ' lead times for delivery as well as client delivery needs. These projections are often based on historical data. (Alan Rushton et al., 2017).

A "pull" production system is one in which items are only produced in response to known requests from customers. This is because the manufacturing process only produces actual orders from clients. None of the items are being produced to be kept as completed product stockpiles to be sold later. As a result, firm orders from consumers are "pulling" all materials throughout the process from material suppliers, ending in shipment to the ultimate consumer. Just-in-time delivery is a "pull" mechanism. (Alan Rushton et al., 2017).

Products in a push process are automatically introduced into the SC based on predictions, while products in a pull process are requisitioned based on real consumer demand. If considered from this angle, the FMSO I case is analogous to a push-type mechanism, while the FMSO II case in point is analogous to a pull-type mechanism.

2.6 Security Assistance Management Information System

The Security Assistance Management Information System (SAMIS) manages economic and logistics data that is essential to the Air Force's operations. It is the electronic system that AFSAC utilizes for managing of FMS. SAMIS automates the process by which foreign nations acquire Air Force military supplies and equipment, increases their efficiency in doing so, and provides them with administrative and logistical assistance (System for Award Management (SAM.gov), 2017).

2.7 Stock Level Quantity

The methodology behind the computation of the stock level quantity (SLQ) will be described in great depth in chapter 3. At this stage, a brief description of what it is and some basic details will be provided.

SLQ is the anticipated quantity of each item that will be required by the customer, considering the customer's demand, the ordering pattern, and the overall lead time of the asset. In order to calculate the SLQ level, SAMIS uses an automatic forecasting system based on a weighted moving average of demand over the last 16 quarters as determined by FMS customers' requisitions, with more weight placed on the most recent quarter. SAMIS computes SLQ for both purchase and maintenance orders and it is recalculated on a quarterly basis. The amount calculated by multiplying the SLQ by the FMSO I cost of the material is the amount committed from the funds for making the forecast. The higher the asset's cost, the more funds from the case value are required. When both the price and the SLQ are high, the impact is amplified. Foreign officers must be cautious about the price of the materials and weigh it when choosing whether or not to obtain support from CLSSA, specifically if case funds are low (AFLCMC/WFALA, 2020).

2.8 Programmed and not programmed requisitions

The CLSSA FMSO II orders are designated as "programmed" or "non-programmed" in order to ensure the both USAF and DLA logistical systems can react with the same level of support given to US Forces within F/AD. When the quantity requested is equal or less than the SLQ, it is designated as "programmed" and is eligible for support from depot stockpiles. Any quantity requested above SLQ is coded "nonprogrammed" and is not qualified for support from the depot stockpile (AFLCMC/WFALA, 2020).

Figure 2 below depicts the USAF strategy on fulfillment from depot inventories, which is divided into many tiers. Programmed orders are satisfied from depot stockpiles down to these levels, depending on the urgency of the order. The orders that will be fulfilled first will be those starting from the bottom of the cylinder. Non-scheduled orders may be completed from the stockpile only if the stock is sufficient to meet all scheduled orders (assets are above the control level). The sole task of the item manager for an unschedule order is to put the order on contract lead time away.

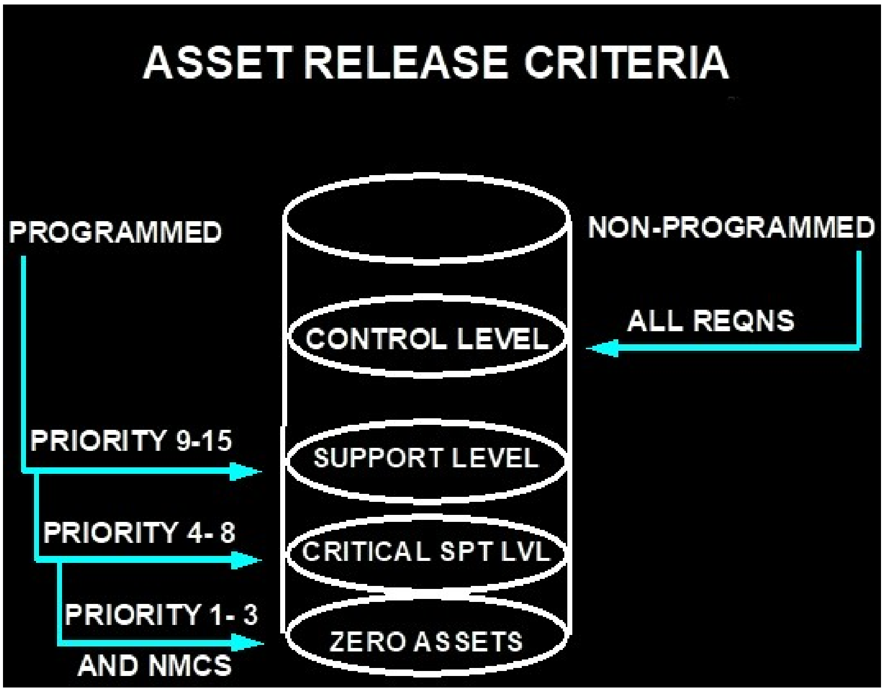

Figure 2 Asset release criteria

As an illustration, if the FMSO I case SLQ for a specific asset is 15 and the FMSO II requisition is 18, the 15 items are deemed "programmed," while the remaining 3 are "nonprogrammed." The 15 assets can usually be fulfilled directly from stockpile or on-order stocks, but the 3 nonprogrammed have no definite timeline other than that it will take about the whole administrative and purchasing lead time away from the order date. They could possibly be supported by excessive inventory, but this is a factor that deals with unpredictability, especially when it comes to fleet availability.

Moderately ordered volumes keep the SLQ at reasonable levels. Furthermore, if a great number of investment items are requested, the AF Depot will examine how they will influence USAF forces and could put the request on hold or totally cancel it (AFLCMC/WFALA, 2020).

2.9 Foreign military sales lead times

The term procurement lead time (PLT) refers to the time elapsed from the start of a procurement activity and the reception into the supply system of the manufacturing model (with the exception of prototypes) acquired as an outcome of such activities, expressed in months. Production lead time and administrative lead time are also components of PLT (Defence Security Cooperation Agency & Department of Defence, 2022).

SAMIS uses either the PLT or the maintenance lead-time for an item as the lead-time. The PLT will be between three and sixty months and the repair lead time will be approximately seven months (AFLCMC/WFALA, 2020).

2.10 Inventory and forecasting

Inventory management is a constant "weighing action," with inventory managers performing their utmost to ensure that there is sufficient stock on hand in order to make up for fluctuations in demand, thereby offering high levels of satisfaction to customers while maintaining minimal costs by keeping stocks as low as necessary (Mark A. Moon, 2018). Inventory shortages, excessive stock, and other supply issues may have a negative impact on DOD's ability to meet operating demands. When critical aircraft like the F-16 experience a shortage of replacement parts, their mission capability rates decline. Inaccurate forecasting of inventory needs and other management flaws might lead to an inadequate supply of spare parts (Hinton, 1999). Managing inventory is a major problem for DOD and FMS nations, and CLSSA is one of these significant logistical support programs.

Forecasting demand is the process of identifying the requirement for an item via smart effective management. Forecasting approaches are classified into two types: quantitative and qualitative. Quantitative approaches involve investigating historical data to uncover patterns of demand (Mark A. Moon, 2018).

The aforementioned concepts should be kept in mind since CLSSA is an inventory-driven model that also takes into account previous customer demand in order to provide forecasts.

2.11 Previous research

A research study was conducted in 2001 to investigate how FMS nations may influence CLSSA support levels and total cost to the FMS customer via FMSO II requisitions and subsequent adjustments to the SLQ (Robert A. Wasik, 2001).

In this research, particular examples of placing orders were used in order to compute the SLQ in accordance with its formula. Additionally, it was investigated which ordering cycle results are most beneficial when 1, 2, 4, 8, and 16 orders of the same quantity are placed across the 16 quarters. The findings are obviously applicable; however, the investigation was restricted to particular cases and did not consider almost all of the permutations of order placement that may take place during the duration of the 16 quarters, and they were not investigated.

Given that FMS countries can influence SLQ and thus CLSSA performance, support levels, and total cost to the FMS customer by placing their FMSO II requisitions with countless options of ordering patterns for a given demand, the key objective of this dissertation is to identify the most beneficial requisition pattern that maximizes programmed orders while avoiding unnecessary SLQs being billed for through additional costs.

2.12 Summary

This chapter intended to give an overview of FMS in order to provide a comprehensive analysis in an effective and knowledgeable manner. FMS nations have the choice of operating their follow-on logistics supply chain through CLSSA. Minimizing costs requires effective stock management and demand forecasting, which are crucial for the military due to tighter budget constraints, and inability to easily allocate additional funds towards logistics support (DEPARTMENT OF DEFENSE, 2017).

The chapter focused on the CLSSA procedure and structure, along with some introductory information about the SLQ calculation in the SAMIS. The significance of programmed FMSO II requisitions was emphasized during the examination of CLSSA service levels, which allows for better quality support and control over case budgeting. The necessity for further study in this specific area was addressed based on previous study findings and high levels of concern over the issues. The next chapter will cover the methodology implemented when analyzing the SLQ computational framework.

3. Methodology

3.1 The Fundamentals of SAMIS stock level quantity calculation

As stated in the preceding chapter, SAMIS computes the stock level quantity (SLQ) for FMS clients using an algorithmic procedure referred to as a weighted moving average. This method entails thoroughly examining and weighting FMS customers' requisitions over the previous 16 quarters. SAMIS gathers and consolidates the most recent four years of FMSO II case periodic orders for each NSN and each participating country, precisely completing this procedure on the first day of each three-month period. The orders are effectively categorized into different periods, yielding a total of 16 quarters. The total sum of these quarters accurately represents the entire country's demand for each NSN throughout the prior four-year period.

After figuring out the overall demand for each NSN during the past four years, SAMIS uses a computing procedure to derive the average monthly demand (AMD). SAMIS implements a method in which older requisitions are given less weight than current ones, particularly when there are interruptions or breaks in the quarterly requisition cycle. This is achieved by allocating a weighting factor to each quarter's amount. The weighting factor is initially set to 100%, suggesting equal relevance for all quarters. When a zero amount is detected for a specific quarter, the weighting factor is lowered by 6.25% (estimated as 100% divided by 16 quarters) for each occurrence of such an absence. In the following example, the most recent quarter, Quarter 1, starts with a weighting factor of 100 since the requisition quantity is not zero (AFLCMC/WFALA, 2020).

Table 2 SLQ Calculation

Quarter	*Requisition QTY*	*Weighting Factor*	*Weighted Requisition QTY*
1	1	100.00	1.0000
2	0	93.75	0.0000
3	2	93.75	1.8750
4	2	93.75	1.8750
5	1	93.75	0.9375
6	1	93.75	0.9375
7	0	87.50	0.0000
8	2	87.50	1.7500
9	0	81.25	0.0000
0	0	75.00	0.0000

11	1	75.00	0.7500
12	0	68.75	0.0000
13	1	68.75	0.6875
14	2	68.75	1.3750
15	1	68.75	0.6875
16	0	62.50	0.0000
TOTAL	14		11.8750

Following proper estimation of the total weighted requisition quantity, which in this case is 11.875, SAMIS determines the AMD by dividing the previous quantity by the total number of months, which is 48. In this instance, the outcome is 0.2474. The AMD is then multiplied by the PLT of the NSN in order to calculate the SLQ. If the calculated SLQ is below one, it is automatically rounded up to one. If the SLQ exceeds one, the ".5 rule" comes into effect. This rule states that amounts less than 0.5 get rounded down to the closest integer, whereas amounts equal to or higher than 0.5 get rounded up to the closest integer. In the above example, the procurement SLQ is: 0.2474 x 24 months PLT = 5.9376 = 6 which indicates that the system is estimating that the nation would need a total of six items of this specific NSN during the period of the next quarter. This similar line of reasoning is applied for the repair SLQ; however, SAMIS utilizes "days" rather than "months" since the repair time listed in the FMS catalog is in days, not months.

The SLQ can change on a quarterly basis in response to the actual requisitions made for an item. Let's assume the next order coming in from the country is for a quantity of three items.

Table 3 SLQ Calculation (The next quarter)

Quarter	***Requisition QTY***	***Weighting Factor***	***Weighted Requisition QTY***
1	3	100	3.0000
2	1	100	1.0000
3	0	93.75	0.0000
4	2	93.75	1.8750
5	2	93.75	1.8750
6	1	93.75	0.9375
7	1	93.75	0.9375
8	0	87.5	0.0000
9	2	87.5	1.7500
0	0	81.25	0.0000
11	0	75.00	0.0000
12	1	75.00	0.7500

13	0	68.75	0.0000
14	1	68.75	0.6875
15	2	68.75	1.3750
16	1	68.75	0.6875
TOTAL	17		14.8750

Following the same line of reasoning, the new AMD is now 14.875/48, which equals 0.3099, and the new SLQ is 0.3099 multiplied by 24, which is 7.4376, which equals 7. This implies that the system now estimates that the country will need a total of seven pieces of this specific NSN throughout the next quarter.

The cost of this forecast is calculated by multiplying the SLQ by the NSN's FMSO I price. Assume the FMSO I pricing for this specific NSN is $30,000. The earlier quarter's estimated cost was $180,000, whereas the current predicted cost is $210,000. The FMSO I pricing has a considerable impact on the entire cost. More FMSO I case value is required as the FMSO I price rises. When both the FMSO I price and the SLQ are high, this impact is amplified. As a result, it is critical for national inventory managers to be aware of the expenses connected with the assets. When deciding whether to obtain support via the CLSSA, they should consider the cost, especially if FMSO I funds are restricted. Managers may make intelligent choices about how to allocate money and optimize the support level of the program. When taking into consideration the very large number of distinct NSNs that nations purchase via the CLSSA program, it requires a significant amount of work and coordination to ensure that there will be enough CLSSA case money for as long as the program is active.

3.2 Algorithm assumptions

Since requisitions over the SLQ level will be directed "nonprogrammed" and, as noted in the previous chapter, nations are obliged to pay 30% of the SLQ in advance, low SLQs can grow the number of nonprogrammed requisitions while simultaneously lowering costs; on the other hand, large SLQs can limit the number of nonprogrammed orders while simultaneously raising costs. As also indicated in the preceding chapter, "programmed" requisitions get higher levels of support, but "unprogrammed" requisitions have no set timetable. The first assumption is that the greatest number of requisitions as feasible will be coded "programmed."

The second assumption pertains to the capacity of the FMS nation to produce a proximate forecast of the expected demand for a certain NSN over the entire span of the four-year SLQ duration in the forthcoming period. The third assumption is that the lead time of each item established in the FMS catalog would remain constant over the course of the 4-year SLQ timeframe. Nevertheless, in the event of a modification, the algorithm possesses the capacity to recompute the SLQ by utilizing the updated lead time.

Upon placing orders, FMS customers have the ability to utilize their SLQ as a point of reference. The optimal approach for requisitioning items is to ensure that the individual requisition amounts are relatively small and that the requisitions are submitted as early as possible within the quarter, as is practically feasible. Doing so will maximize the number of requisitions that can be coded “programmed” (AFLCMC/WFALA, 2020).

But how exactly should these small quantities of orders be placed depending on the total demand and the lead time of each material in order to achieve the lowest SLQ in combination with zero nonprogrammed requisitions?

3.3 Algorithm basics

SAMIS determines the SLQ on a quarterly basis, and as demonstrated in the above example, the SLQ was 6 one quarter and 7 the next, in direct response to orders made. It was also noted that what is expected to cost for each quarter is the SLQ times the FMSO I price of the item's NSN. Given that 16 SLQs are created in each 4-year period, the average of these 16 quantities (AvSLQ) multiplied by the price of the material constitutes the total forecasted cost for the previous 4-year period. However, the AvSLQ is not taken into consideration when evaluating if the FMSO II requisitions can be programmed or not. The SLQ that matters is the one that is really being used at the moment when the order is being placed. Therefore, in order to keep costs to a minimum, this AvSLQ should be reduced to the greatest extent feasible.

In the previous chapter, it was mentioned that when the quantity ordered in a quarter is less than or equal to the SLQ, then the order is coded “programmed” otherwise the quantity in excess of the SLQ is coded “nonprogrammed”. For example, if the SLQ is 20 and the country places an order for 12, it is considered “programmed”, but the country is charged for the forecast of 8 additional materials. In the CLSSA case, the funds for these 8 items have already been committed; therefore, the goal would be to reduce to the absolute minimum the quantity of materials that are forecasted but not ordered. This is also an element that the algorithm incorporates to achieve the best possible combination.

Based on the above, we employed a multi-agent meta-heuristic algorithm (Consensus Based Optimization-CBO) to determine the best requisition ordering pattern that generates "programmed" requisitions in conjunction with the lowest AvSLQ over the next four years, which creates the smallest amount of forecasted but not ordered quantity, considering the anticipated demand in the future and the lead time of the asset. In simple words, if a country's demand for the next 4 years is Q materials of an NSN with a lead time of 3 to 60 months, how should it place this Q quantity divided into orders of 16 quarters in order to achieve the best possible combination of the above parameters?

When utilizing the CBO algorithm to calculate the best feasible arrangement for the ordering pattern, the outcome will be for the future 16 quarters even if the SAMIS SLQ period is the past 16 quarters. In fact, they refer to the exact same concept.

In brief, the following criteria will be evaluated by the algorithm throughout the duration of four years:

- C1: AvSLQ should be minimum
- C2:Unprogrammed QTY should be zero
- C3:Forecasted but not ordered quantity should be minimum.

3.4 Consensus Based Optimization

Consensus Based Optimization (CBO) is a stochastic multi-agent metaheuristic technique for solving complex optimization problems (Fornasier et al., 2021). CBO employs multiple agents to explore the solution space and detect possibly good solutions. The exploration is guided by random elements but the algorithm also has controls that allow individual agents to share the collective experience accumulated in previous iterations (Carrillo et al., 2016). At each iteration, the dynamics of the flock is controlled by two mechanisms:

- *Advection*: particles are pulled towards the centroid of the flock by a force that is proportional to their deviation from the centroid. The centroid is calculated dynamically by weighting each particle by its fitness value.

- Diffusion: to avoid premature convergence to a suboptimal region of the solution space, CBO acts a (random perturbation) diffusion force to each agent. The level of diffusion varies within the flock so that that particles that are far from the centroid are diffused more. This way the algorithm forces further exploration of the solution space without distorting convergence (Carrillo et al., 2021).

In this dissertation, we employed a version of the main CBO framework detailed in (Carrillo et al., 2016) that is suitable for solving constrained integer optimization problems. This version jointly optimizes the three criteria mentioned in the previous section (C1-C3) by using a composite objective function that is an equally weighted average of the three criteria. The constraints of the optimization problem are also incorporated in the composite objective in the form of penalty terms. All experimented were performed in MATLAB R2022a.

3.5 Weaknesses of the model

Because there are so many different permutations, the amount of time needed to compute varies. When it comes to accuracy, the outcome is directly proportional to the processing speed of the computer that is performing the algorithm. A much faster system may do calculations more effectively, allowing for a more complete analysis of the outcome space and perhaps more exact results. As a consequence, investing in more processing power could result to better algorithmic outcomes.

3.6 Summary

The SLQ computational formula's essential principles and algorithm design and implementation parameters have been explained in this chapter. The chapter also lists the important algorithm evaluation criteria. An overview of data assessment and algorithm execution software has also been presented, highlighting possible shortcomings.

In the following section, data will be extracted from the algorithm based on the criteria and parameters that have been provided.

4. Analysis and outcomes

4.1 Case Study Selection

On the basis of the previously addressed concepts about the CLSSA structure, the item's demand levels throughout the SLQ period, and the item lead-times, the category of 80 items of anticipated demand will be investigated further in this chapter under a length of item lead time 7, 12, 18, 24, 36, 48, and 60 months.

This analysis is adequate for the FMS countries to comprehend how their requisitioning patterns affect their overall program budgets and service levels and provide them with insights into how to create a better ordering policy. Additionally, the customer is expected to figure out and compare their requisitioning patterns with the algorithm patterns, providing them with statistics on how to enhance their ordering policy. FMS clients can effectively utilize the requisitioning patterns outlined in this study as an alternative to their existing ordering patterns. This will enable them to customize their requisitioning choices and evaluate the consequences associated with opting for an alternative ordering pattern as opposed to the ones recommended in the current dissertation.

4.2 Demand 80 Analysis Case Study

As was discussed in the prior chapter, there are sixteen SLQs spread out over the course of a four-year period. In order to keep expenses to a minimum, the average SLQ should be lowered to the maximum degree possible, along with 100% programmed requisitions and the smallest amount of the quantity that was forecast but not ordered.

If, for example, the expected demand for an asset with a 48-month lead time is 80 items over the course of the next four years, the most efficient way to place orders applying the algorithm throughout the course of the next 16 quarters should follow the pattern that is outlined in blue in Table 4 below.

Table 4 Algorithm outcome for demand 80 and lead time 48 months

QUARTER 1				QUARTER 2				QUARTER 3				QUARTER 4			
		LT	48			LT	48			LT	48			LT	48
i	Q(i)	W(i)	R(i)	i	Q(i)	W(i)	R(i)	i	Q(i)	W(i)	R(i)	i	Q(i)	W(i)	R(i)
1	0	93.75	0	1	0	93.75	0	1	0	93.75	0	1	12	100	12
2	0	87.5	0	2	0	87.5	0	2	0	87.5	0	2	0	93.75	0
3	0	81.25	0	3	0	81.25	0	3	0	81.25	0	3	0	87.5	0
4	0	75	0	4	0	75	0	4	0	75	0	4	0	81.25	0
5	0	68.75	0	5	0	68.75	0	5	0	68.75	0	5	0	75	0
6	0	62.5	0	6	0	62.5	0	6	0	62.5	0	6	0	68.75	0
7	0	56.25	0	7	0	56.25	0	7	0	56.25	0	7	0	62.5	0
8	0	50	0	8	0	50	0	8	0	50	0	8	0	56.25	0
9	0	43.75	0	9	0	43.75	0	9	0	43.75	0	9	0	50	0
10	0	37.5	0	10	0	37.5	0	10	0	37.5	0	10	0	43.75	0
11	44	37.5	16.5	11	0	31.25	0	11	0	31.25	0	11	0	37.5	0
12	24	37.5	9	12	44	31.25	13.75	12	0	25	0	12	0	31.25	0
13	0	31.25	0	13	24	31.25	7.5	13	44	25	11	13	0	25	0
14	12	31.25	3.75	14	0	25	0	14	24	25	6	14	44	25	11
15	0	25	0	15	12	25	3	15	0	18.75	0	15	24	25	6
16	0	18.75	0	16	0	18.75	0	16	12	18.75	2.25	16	0	18.75	0
	80	TOTAL	29.25		80	TOTAL	24.25		80	TOTAL	19.25		80	TOTAL	29
Average monthly demand			0.6094	Average monthly demand			0.5052	Average monthly demand			0.4010	Average monthly demand			0.6042
SLQ1			29	SLQ2			24	SLQ3			19	SLQ4			29
programmed			0	programmed			0	programmed			0	programmed			12
unprogrammed			0	unprogrammed			0	unprogrammed			0	unprogrammed			0
Forecasted but not ordered			34	Forecasted but not ordered			29	Forecasted but not ordered			24	Forecasted but not ordered			7

QUARTER 5				QUARTER 6				QUARTER 7				QUARTER 8			
		LT	48			LT	48			LT	48			LT	48
i	Q(i)	W(i)	R(i)	i	Q(i)	W(i)	R(i)	i	Q(i)	W(i)	R(i)	i	Q(i)	W(i)	R(i)
1	0	93.75	0	1	24	100	24	1	44	100	44	1	0	93.75	0
2	12	93.75	11.25	2	0	93.75	0	2	24	100	24	2	44	93.75	41.25
3	0	87.5	0	3	12	93.75	11.25	3	0	93.75	0	3	24	93.75	22.5
4	0	81.25	0	4	0	87.5	0	4	12	93.75	11.25	4	0	87.5	0
5	0	75	0	5	0	81.25	0	5	0	87.5	0	5	12	87.5	10.5
6	0	68.75	0	6	0	75	0	6	0	81.25	0	6	0	81.25	0
7	0	62.5	0	7	0	68.75	0	7	0	75	0	7	0	75	0
8	0	56.25	0	8	0	62.5	0	8	0	68.75	0	8	0	68.75	0
9	0	50	0	9	0	56.25	0	9	0	62.5	0	9	0	62.5	0
10	0	43.75	0	10	0	50	0	10	0	56.25	0	10	0	56.25	0
11	0	37.5	0	11	0	43.75	0	11	0	50	0	11	0	50	0
12	0	31.25	0	12	0	37.5	0	12	0	43.75	0	12	0	43.75	0
13	0	25	0	13	0	31.25	0	13	0	37.5	0	13	0	37.5	0
14	0	18.75	0	14	0	25	0	14	0	31.25	0	14	0	31.25	0
15	44	18.75	8.25	15	0	18.75	0	15	0	25	0	15	0	25	0
16	24	18.75	4.5	16	44	18.75	8.25	16	0	18.75	0	16	0	18.75	0
	80	TOTAL	24		80	TOTAL	43.5		80	TOTAL	79.25		80	TOTAL	74.25
Average monthly demand			0.5000	Average monthly demand			0.9063	Average monthly demand			1.6510	Average monthly demand			1.5469
SLQ5			24	SLQ6			44	SLQ7			79	SLQ8			74
programmed			0	programmed			24	programmed			44	programmed			0
unprogrammed			0	unprogrammed			0	unprogrammed			0	unprogrammed			0
Forecasted but not ordered			29	Forecasted but not ordered			0	Forecasted but not ordered			0	Forecasted but not ordered			79

QUARTER 9				QUARTER 10				QUARTER 11				QUARTER 12			
		LT	48			LT	48			LT	48			LT	48
i	Q(i)	W(i)	R(i)	i	Q(i)	W(i)	R(i)	i	Q(i)	W(i)	R(i)	i	Q(i)	W(i)	R(i)
1	0	93.75	0	1	0	93.75	0	1	0	93.75	0	1	0	93.75	0
2	0	87.5	0	2	0	87.5	0	2	0	87.5	0	2	0	87.5	0
3	44	87.5	38.5	3	0	81.25	0	3	0	81.25	0	3	0	81.25	0
4	24	87.5	21	4	44	81.25	35.75	4	0	75	0	4	0	75	0
5	0	81.25	0	5	24	81.25	19.5	5	44	75	33	5	0	68.75	0
6	12	81.25	9.75	6	0	75	0	6	24	75	18	6	44	68.75	30.25
7	0	75	0	7	12	75	9	7	0	68.75	0	7	24	68.75	16.5
8	0	68.75	0	8	0	68.75	0	8	12	68.75	8.25	8	0	62.5	0
9	0	62.5	0	9	0	62.5	0	9	0	62.5	0	9	12	62.5	7.5
10	0	56.25	0	10	0	56.25	0	10	0	56.25	0	10	0	56.25	0
11	0	50	0	11	0	50	0	11	0	50	0	11	0	50	0
12	0	43.75	0	12	0	43.75	0	12	0	43.75	0	12	0	43.75	0
13	0	37.5	0	13	0	37.5	0	13	0	37.5	0	13	0	37.5	0
14	0	31.25	0	14	0	31.25	0	14	0	31.25	0	14	0	31.25	0
15	0	25	0	15	0	25	0	15	0	25	0	15	0	25	0
16	0	18.75	0	16	0	18.75	0	16	0	18.75	0	16	0	18.75	0
	80	TOTAL	69.25		80	TOTAL	64.25		80	TOTAL	59.25		80	TOTAL	54.25
Average monthly demand			1.4427	Average monthly demand			1.3385	Average monthly demand			1.2344	Average monthly demand			1.1302
SLQ9			69	SLQ10			64	SLQ11			59	SLQ12			54
programmed			0	programmed			0	programmed			0	programmed			0
unprogrammed			0	unprogrammed			0	unprogrammed			0	unprogrammed			0
Forecasted but not ordered			74	Forecasted but not ordered			69	Forecasted but not ordered			64	Forecasted but not ordered			59

QUARTER 13				QUARTER 14				QUARTER 15				QUARTER 16			
		LT	48			LT	48			LT	48			LT	48
i	Q(i)	W(i)	R(i)	i	Q(i)	W(i)	R(i)	i	Q(i)	W(i)	R(i)	i	Q(i)	W(i)	R(i)
1	0	93.75	0	1	0	93.75	0	1	0	93.75	0	1	0	93.75	0
2	0	87.5	0	2	0	87.5	0	2	0	87.5	0	2	0	87.5	0
3	0	81.25	0	3	0	81.25	0	3	0	81.25	0	3	0	81.25	0
4	0	75	0	4	0	75	0	4	0	75	0	4	0	75	0
5	0	68.75	0	5	0	68.75	0	5	0	68.75	0	5	0	68.75	0
6	0	62.5	0	6	0	62.5	0	6	0	62.5	0	6	0	62.5	0
7	44	62.5	27.5	7	0	56.25	0	7	0	56.25	0	7	0	56.25	0
8	24	62.5	15	8	44	56.25	24.75	8	0	50	0	8	0	50	0
9	0	56.25	0	9	24	56.25	13.5	9	44	50	22	9	0	43.75	0
10	12	56.25	6.75	10	0	50	0	10	24	50	12	10	44	43.75	19.25
11	0	50	0	11	12	50	6	11	0	43.75	0	11	24	43.75	10.5
12	0	43.75	0	12	0	43.75	0	12	12	43.75	5.25	12	0	37.5	0
13	0	37.5	0	13	0	37.5	0	13	0	37.5	0	13	12	37.5	4.5
14	0	31.25	0	14	0	31.25	0	14	0	31.25	0	14	0	31.25	0
15	0	25	0	15	0	25	0	15	0	25	0	15	0	25	0
16	0	18.75	0	16	0	18.75	0	16	0	18.75	0	16	0	18.75	0
	80	TOTAL	49.25		80	TOTAL	44.25		80	TOTAL	39.25		80	TOTAL	34.25
Average monthly demand			1.0260	Average monthly demand			0.9219	Average monthly demand			0.8177	Average monthly demand			0.7135
SLQ13			49	SLQ14			44	SLQ15			39	SLQ16			34
programmed			0	programmed			0	programmed			0	programmed			0
unprogrammed			0	unprogrammed			0	unprogrammed			0	unprogrammed			0
Forecasted but not ordered			54	Forecasted but not ordered			49	Forecasted but not ordered			44	Forecasted but not ordered			39

AVERAGE SLQ	45.8750
Unprogrammed QTY over the 4 year period	0
Forecasted but not ordered over the 4 year period	654

According to the results of the algorithm, the optimal ordering strategy for this situation would be to place an order for 12 in the fourth quarter, 24 in the sixth quarter, and 44 in the seventh quarter, but to refrain from making orders in the other 13 quarters. Based on the calculations described in the previous chapters, the algorithm calculated the minimum SLQ of 45.875 by arranging the orders in this way, guaranteeing that they would be coded as "programmed". It has also been determined that this customized pattern generates as little as possible of the amount of materials that will remain "forecasted but not ordered." This ensures that there is not a significant amount of additional material left on the shelf, and the nation is billed for as little as possible.

According to the information provided in the CLSSA manual, orders should be made often and in small amounts. Since it is recommended that orders be placed frequently and in small numbers, an examination of splitting the quantity of 80 into 1, 2, 4, 8, and 16 equal quantities will also take place. The divisions by 1, 2, 4, 8, and 16 are used as examples with the thought that this will result in an equitable distribution of the amount, which in turn would provide a frequency.

Following this rule, in the case of an item with a 48-month lead time and 80 items of anticipated demand, in order to achieve an equal distribution, orders should be placed as follows in Table 5:

Table 5 Equal quantity order placement for demand 80 and lead time 48 months

QUARTER	1 ORDER	2 ORDERS	4 ORDERS	8 ORDERS	16 ORDERS
1	80	40	20	10	5
2	0	0	0	0	5
3	0	0	0	10	5
4	0	0	0	0	5
5	0	0	20	10	5
6	0	0	0	0	5
7	0	0	0	10	5
8	0	0	0	0	5
9	0	40	20	10	5
10	0	0	0	0	5
11	0	0	0	10	5
12	0	0	0	0	5
13	0	0	20	10	5
14	0	0	0	0	5
15	0	0	0	10	5

16	0	0	0	0	5

By placing one order for 80 items, two orders for 40, four orders for 20, eight orders for 10, and sixteen orders for 5, the cumulative outcomes are outlined in Table 6 below:

Table 6 Outcomes of Equal quantity order placement for demand 80 and lead time 48 months

ORDERS	1 FOR 80	2 FOR 40	4 FOR 20	8 FOR 10	16 FOR 5
AVERAGE SLQ	42.5	45.5	50.5	60.5	80
Unprogrammed QTY over the 4y	75	24	0	0	0
Forecasted but not ordered	675	672	728	888	1200

Looking at the information provided above, placing an order for 20 once a year is clearly better, since all orders are coded "programmed" and the pattern provides the lowest Av.SLQ and "forecasted but not ordered quantity" combination.

Upon comparing the aforementioned ordering pattern with the algorithmically generated one, it is evident that both have all the requisitions programmed. However, it is noteworthy that the country is incurring an additional charge of 9.16% and is also being charged for the forecasted 74 supplementary items that currently remain in stock. In this particular case, with a demand level of 80, it appears that the escalation in costs may not be significant. However, it is important to note that this analysis pertains to a single item only. When considering the cumulative effect of cost reductions across a multitude of products, the resultant savings could be substantial. Additionally, it is plausible that the unit price for this specific item may be relatively high, and even small variations make a difference.The present line of reasoning shall serve as the fundamental basis for the computation of the most advantageous ordering strategy. This strategy shall encompass requisitions that are entirely programmed, with the objective of minimizing the Av.SLQ and reducing the number of residual items that remain on the shelf.

The next Table 7 provides a representation of the algorithmic outcomes and the ones pertaining to the optimal ordering pattern as per the CLSSA guidelines. The analysis encompasses a comprehensive range of lead times, which are 7, 12, 18, 24, 36, and 60 months.

Table 7 Algorithm outcomes and optimal ordering pattern as per the CLSSA guidelines for demand 80

	ALGORITHM OUTCOMES								BEST ORDERING PATTERN						
QUARTER	LT 7	LT 12	LT 18	LT 24	LT 36	LT 48	LT 60		LT 7	LT 12	LT 18	LT 24	LT 36	LT 48	LT 60
1	0	3	0	0	16	0	6		5	10	10	20	20	20	20
2	9	0	0	0	1	0	0		5	0	0	0	0	0	0
3	8	0	17	0	0	0	0		5	10	10	0	0	0	0
4	0	0	0	0	0	0	0		5	0	0	0	0	0	0
5	9	0	0	0	0	0	0		5	10	10	20	20	20	20
6	0	0	0	21	0	0	0		5	0	0	0	0	0	0
7	9	0	22	0	0	0	0		5	10	10	0	0	0	0
8	0	0	18	18	0	0	0		5	0	0	0	0	0	0
9	0	0	14	0	0	0	0		5	10	10	20	20	20	20
10	10	15	5	0	0	0	0		5	0	0	0	0	0	0
11	9	0	0	0	0	44	0		5	10	10	0	0	0	0
12	8	16	4	0	0	24	0		5	0	0	0	0	0	0
13	0	14	0	0	0	0	0		5	10	10	20	20	20	20
14	9	12	0	0	0	12	0		5	0	0	0	0	0	0
15	0	11	0	24	38	0	49		5	10	10	0	0	0	0
16	9	9	0	17	25	0	25		5	0	0	0	0	0	0
AV.SLQ	**9.0625**	**13.8750**	**19.8125**	**24.7500**	**35.5625**	**45.8750**	**56.7500**		**12**	**15**	**22.5**	**25**	**37.5**	**50.5**	**62.5**
UNPROGRAMMED	**0**	**0**	**0**	**0**	**0**	**0**	**0**		**0**	**0**	**0**	**0**	**0**	**0**	**0**
FORECASTED BUT NOT ORDERED	**65**	**142**	**237**	**316**	**489**	**654**	**828**		**112**	**160**	**280**	**320**	**520**	**728**	**920**

From the information shown in the Table 7, the average SLQ rises in tandem with the lengthening of the lead time for the material. Something similar takes place with the forecasted but not ordered quantity. The algorithm yields more favorable results for all lead times, and the economic implications of these findings are noteworthy. This is of paramount importance given the substantial number of NSNs procured through the CLSSA as well as the need for FMS customers to make intelligent choices about how to allocate money and optimize the support level of the program.

4.3 Financial analysis

In order to deeply comprehend the financial implications of a potential alteration in the ordering policy, it is imperative to present an illustrative example that is grounded in the aforementioned findings. This example examines the hypothetical scenario wherein a nation-state adheres to the guidelines set forth by the CLSSA handbook and acquires five NSNs at a unit cost of $20,000 per item, and each of the aforementioned NSNs has a different lead time of 7, 12, 24, 48, and 60 months, respectively. The projected demand is estimated to be 80 units for all five NSNs over a period of four years. The total forecasted cost for the country is determined by multiplying the Av.SLQ of each NSN by the unit price of the item.

Through the process of equally distributing the orders among the 16 quarters and subsequently selecting the optimal ordering pattern that yields the minimum average SLQ, the total projected cost for the forthcoming four-year period would amount to $3,300,000.

Table 8 Total projected cost of equally ordered distribution

NSN	PRICE	AV. SLQ	FORECASTED COST
1	20000	12.00	240000
2	20000	15.00	300000
3	20000	25.00	500000
4	20000	50.50	1010000
5	20000	62.50	1250000
TOTAL FORECASTED COST			**3300000**

If the nation were to choose the ordering pattern that the algorithm has determined to be the optimal one, the total cost to the government would be $3,006,250. The procurement of just five NSNs results in a savings of $293,750, or 8.90% on average. Especially for items that need a lead time of seven months, the cost reductions are up to 24.48%, which is a significant amount. This indicates that the nation will get a greater amount of support from the CLSSA program, as well as a corresponding increase in its purchasing power of the same proportion. Given the high number of NSNs ordered by FMS customers and the amount of money spent, as shown in Chapter 2, it is of the utmost significance to allot CLSSA funds at the highest feasible level.

Table 9 Total projected cost of algorithmic outcomes

NSN	PRICE	AV. SLQ	FORECASTED COST
1	20000	9.0625	181250
2	20000	13.8750	277500
3	20000	24.7500	495000
4	20000	45.8750	917500
5	20000	56.7500	1135000
TOTAL FORECASTED COST			**3006250**

Given the committed forecasted cost for the procurement of stocks to meet anticipated demand, the CLSSA case contract requires prudent management and careful consideration to ensure that the allocated funds are sufficient for the duration of the contract. It is imperative that the funds are not expended recklessly without providing additional support or advantage.

4.4 Examination of short lead times

It was observed that with exceptionally short lead-times such as three months, there might be substantial irregularities since they are so tiny. This is due to the concept that the SLQ is generated from the AMD multiplied by the lead-time in months; hence, exceptionally short lead-times are likely to affect the SLQ in the sense that it is not always feasible to accomplish 100% programmed requisitions at these extraordinary lead times. Despite the fact that this kind of lead time only accounts for a very small percentage of materials, the influence it has on the computation of SLQ is investigated.

An example of a demand for 20 assets with a lead time of three months is shown in the following table 10. This example illustrates the fact that the optimal ordering pattern via equitable distribution in accordance with the CLSSA instructions was unable to meet all of the requisitions programmed. The same occurs with regard to the algorithm. A second example shows demand for 1,000 assets with a lead time of three months. In this case, the optimum ordering pattern would produce 16 unprogrammed requisitions, but the algorithm would get a superior result by having all of the requisitions programmed.

Table 10 Demand 20 and 1000 with 3 months lead time

Demand 20	**1 ORDER**	**2 ORDERS**	**4 ORDERS**	**8 ORDERS**	**16 ORDERS**	**Algorithm outcome**
AVERAGE SLQ	1	1	1	1	1	1
Unprogrammed QTY over the 4y	19	18	16	12	4	4
Forecasted but not ordered	15	24	12	8	0	0
Demand 1000	**1 ORDER**	**2 ORDERS**	**4 ORDERS**	**8 ORDERS**	**16 ORDERS**	**Algorithm outcome**
AVERAGE SLQ	33.3125	35	39	47	63	63
Unprogrammed QTY over the 4y	996	958	868	640	16	0

Forecasted but not ordered	529	518	492	392	24	8

As a result of the fact that nonprogrammed orders are only assured that they will be delivered months away from the request, this becomes increasingly essential as lead times increase. Although if the lead periods are just three months, then the necessity of scheduled orders could shift to being less significant. This is because the deviation in delivery time among programmed and nonprogrammed deliveries can vary across narrow timeframes.

4.5 Comparison to previous research

As mentioned in Chapter 2, a research study was undertaken in 2001 with the aim of exploring the optimal ordering cycle outcomes when orders are uniformly distributed across the 16 quarters. Given the preceding case study involving 80 items, an analysis of a higher volume of demand will be presented, specifically for 1000 items, with the aim of comparing the algorithmic outcomes with those of the prior investigation. The author of the 2001 study evaluated a case of 1000 items of demand in his analysis, and the findings are depicted in the following Table 11, along with the algorithmic results.

Table 11 Demand 1000 comparison to previous research

	ALGORITHM OUTCOMES						PREVIOUS RESEARCH					
QUARTER	**LT 7**	**LT 12**	**LT 24**	**LT 36**	**LT 48**	**LT 60**	**LT 7**	**LT 12**	**LT 24**	**LT 36**	**LT 48**	**LT 60**
1	109	25	0	197	145	72	65	125	250	250	250	250
2	105	0	0	16	0	0	60	0	0	0	0	0
3	13	0	296	0	0	0	65	125	0	0	0	0
4	0	0	215	0	0	0	60	0	0	0	0	0
5	0	0	0	0	0	0	65	125	250	250	250	250
6	112	0	177	0	0	0	60	0	0	0	0	0
7	86	0	0	0	0	0	65	125	0	0	0	0
8	0	0	0	0	0	0	60	0	0	0	0	0
9	0	0	0	0	0	0	65	125	250	250	250	250
10	124	208	0	0	0	0	60	0	0	0	0	0
11	115	0	0	0	0	0	65	125	0	0	0	0
12	0	196	0	0	0	0	60	0	0	0	0	0
13	118	172	0	0	0	0	65	125	250	250	250	250
14	103	151	0	0	0	0	60	0	0	0	0	0
15	0	132	312	480	551	620	65	125	0	0	0	0
16	115	116	0	307	304	308	60	0	0	0	0	0
AV.SLQ	**117.4375**	**173.5000**	**308.7500**	**442.3750**	**573.0625**	**707.5000**	**146.0000**	**187.5000**	**312.5000**	**468.5000**	**625.0000**	**781.0000**
UNPROGRAMMED	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
FORECASTED BUT NOT ORDERED	**879**	**1776**	**3940**	**6078**	**8169**	**10320**	**1336**	**2000**	**4000**	**6496**	**9000**	**11496**

Based on the data presented in the aforementioned table, it can be inferred that the algorithm in question delivered superior results across all lead times, resulting in cost reductions of an average of 8.59% and providing greater support. Given the dynamic nature of the algorithm, it is pertinent to note that its efficacy is subject to improvement over time. As the algorithm runs repeatedly, it has the potential to generate increasingly optimal outcomes, thereby providing enhanced support to the CLSSA program.

5. Conclusion and recommendations

The continued operation of the CLSSA is of utmost importance, not only for the purpose of promoting global stability but also for the provision of supplementary economies of scale to the United States in the procurement of novel weapon systems or the maintenance of existing ones. The focal point of this investigation that has been identified as a key area of interest is the receiving of the highest possible level of assistance from the nations that use CLSSA, as evidenced by the submission of tailored orders, as well as the economic influence that these orders have on the total cost of utilizing the CLSSA program.

The employment of CLSSA by FMS countries is predicated on the perception that it represents the most optimal alternative among the available options. It is noteworthy that these countries possess the option to select alternative methods for follow-on logistics support but opt for CLSSA based on its perceived superiority. To keep the FMS nations within the ambit of the CLSSA, it is suggested that the provision of optimal customer service at a minimal aggregate expense be pursued. The establishment of an efficient requisitioning and inventory plan necessitates the resolution of two fundamental inquiries: when to place an order and how much quantity to request depending on the total forecasted demand.

The present study undertook an analysis of the effects engendered by the requisitioning patterns of customers of FMS, with a particular focus on customer service and cost. Hypotheses are challenging to make due to the fact that ordering patterns will vary depending on lead times and demand levels. Nonetheless, certain overarching guidelines may be articulated to generate the best requisitioning plan utilizing the CLSSA program and the criteria utilized in this research. It has been observed that higher SLQs are associated with increased costs, while lower SLQs result in a higher number of nonprogrammed items being ordered. It was also noticed that the average SLQ rises in line with the lengthening of the lead time for the material. Furthermore, very short lead times may influence the SLQ since 100% scheduled requisitions may not be possible. Another observation that was made it was that frequently occurring and small order quantities seem to be something that does not actually deliver the greatest potential outcomes but is a realistic technique to have a relative balance of cost and program support. This can be observed from the algorithm's findings, which show that placing orders irregularly and with enough order gaps in between yields optimal outcomes. Therefore, the challenge lies in developing a methodological approach that ensures a sufficiently high SLQ at the point of order placement, such that all assets are coded as programmed, while simultaneously maintaining an average SLQ that is as low as possible to minimize costs.

Organizations need replenishing inventory systems that improve customer service while simultaneously lowering capital expenses. This may be accomplished by keeping stock levels at a minimum without compromising quality of service, which in turn reduces the amount of unpredictability in an organization's environment (Myers et al., 2000). The economic success of an organization is positively correlated with the degree to which a computerized replenishment program provides value for the money spent. The strategic success of the organization is also positively correlated with the degree to which a computerized replenishment program provides an effective level of service. Scale economies are another way that benefits may be obtained, and they should be achieved (Myers et al., 2000). When all of those points and those brought up in the preceding chapters are taken into account, it becomes clear that the idea of CLSSA has quite a lot in common with the computerized replenishment programs. Therefore, it is of the utmost significance for the nations that utilize it to optimize it in order to reap the maximum benefits from it.

5.1 Future research

In light of the aforementioned, further investigation can be conducted regarding algorithm's capacities in order to broaden its utility and optimize its efficacy. By building surrogate models that utilize a subset of the space of solutions within the overall structure of an evolutionary algorithm, it could potentially be feasible to facilitate a more effective investigation of the enormous search space to find the optimal ordering pattern (Mallipeddi & Lee, 2015). A potential acceleration of the search process can be achieved by utilizing sophisticated hardware architectures, such as graphics processing units (GPUs), or specifically designed acceleration technologies. The exploration of possible solutions within a reasonable amount of time can be extended by examining parallel techniques or utilizing outstanding computing capabilities (John D. Owens et al., 2008). The extensive exploration area and highly complex computational intricacy inherent in the area of the algorithm demonstrate multiple possibilities for future investigation. The investigation of more effective techniques for searching represents an exciting opportunity for enhancing the performance of algorithms and enabling them to more successfully navigate the vast solution space.

Additionally, a more in-depth study might be done to investigate the influence that non-programmed orders have on fleet availability, depending on the amount of time it takes for these requests to be fulfilled and whether there are alternative supply options that are advantageous from an operational and financial point of view.

Furthermore, the present study for the optimization of the CLSSA program might potentially be applicable to analogous inventory forecasting systems that may be utilized by other organizations outside of the military in order to maximize their efficiency, as long as the respective organizations are aware of how the relevant programs they use calculate the corresponding forecasted quantity and other existing parameters.

5.2 Conclusion

CLSSA is the finest means of acquiring spare parts assistance from the United States and has been traditionally the program of choice for FMS nations for follow-on logistical support (Brian B. Yoo et al., 2009). It is also the most cost-effective option. The aggregated and larger purchase that the DOD makes results in a cheaper cost per unit for the customer. This is the most evident advantage of the customer adopting CLSSA. It has also been presented that the logistical aspect of supply support, which in this case encompasses the art of predicting and the spares support strategy used, is an effective method that, if handled correctly, has the potential to be a key availability and sustainability enabler for the FMS nation. Because the CLSSA process includes a complexity factor in terms of the computational formula as well as the identification of the most effective approach, a model like the current study's algorithm has the potential to contribute to a catalytic degree in finding the best solution, thereby ensuring effective CLSSA follow-on support in terms of cost and support offered.

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