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PERFORMANCE OPTIMIZATION THROUGH TECHNOLOGICAL INDIGENIZATION OF SUPPLY CHAINS: A CONCEPTUAL FRAMEWORK DEVELOPMENT

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ABSTRACT

In order to maintain the border sovereignty of the country, militaries need to continue investigating contemporary innovative technologies which can improve their war-fighting capabilities, raise mission readiness, and enable their continuous operations in a fiscally constrained environment. Navies around the world have been forced to adopt technological indigenization in their Supply Chains to maintain in-service equipment due to the high expense of maintaining military-systems combined with prolonged life cycles. In the public sector, where the budgetary constraints severely impact decision making, it makes it an imperative area to be explored in detail. The present research study has focused on adoption of Additive Manufacturing technology in Naval Supply Chains which resulted in proposing a framework of IV (Adoption of Indigenous Additive Manufacturing) and DVs (Demand Satisfaction, Obsolescence Management, and Financial Spending) for prospective future research paths within this field. In addition, major factors related to performance optimization of Naval platforms have been summarized. Furthermore, a comprehensive literature review has been undertaken followed by identification of specific research questions along with research methodology for future researches.

Keywords: International Trade, Naval Supply Chain, Additive Manufacturing, Obsolescence Management

TEDARİK ZİNCİRLERİNİN TEKNOLOJİK YERLİLEŞTİRİLMESİ YOLUYLA PERFORMANS OPTİMİZASYONU: BİR KAVRAMSAL ÇERÇEVE GELİŞTİRME

ÖZET

Ülkenin sınır egemenliğini koruyabilmek için, orduların savaşma kabiliyetlerini artırabilecek, görev hazırlık düzeylerini yükseltecek ve mali kısıtlamalar altındaki ortamlarda sürekli operasyonlarını sürdürebilecek çağdaş ve yenilikçi teknolojileri araştırmaya devam etmeleri gerekmektedir. Dünyadaki donanmalar, askeri sistemlerin bakım maliyetlerinin yüksekliği ve uzun ömür döngüleri nedeniyle, hizmetteki ekipmanların sürdürülebilirliğini sağlamak amacıyla tedarik zincirlerinde teknolojik yerlileştirmeye yönelmek zorunda kalmışlardır. Kamu sektöründe ise bütçe kısıtlamalarının karar alma süreçlerini ciddi şekilde etkilemesi, bu alanı ayrıntılı şekilde incelenmesi gereken kritik bir konu haline getirmiştir. Bu araştırma çalışması, donanma tedarik zincirlerinde Katmanlı Üretim (Additive Manufacturing) teknolojisinin benimsenmesine odaklanmış ve bu doğrultuda gelecekteki araştırmalar için IV (Yerli Katmanlı Üretim Teknolojisinin Benimsenmesi) ve DV'ler (Talep Karşılama, Demode Ürün Yönetimi ve Finansal Harcamalar) çerçevesini önermiştir. Buna ek olarak, deniz platformlarının performans optimizasyonuyla ilgili başlıca faktörler özetlenmiştir. Ayrıca kapsamlı bir literatür taraması gerçekleştirilmiş; bu doğrultuda gelecekteki araştırmalar için belirli araştırma soruları ve izlenecek araştırma metodolojisi ortaya konulmuştur.

Anahtar Kelimeler: Uluslararası Ticaret, Deniz Tedarik Zinciri, Katmanlı Üretim, Modası Geçme Yönetimi

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1. INTRODUCTION

In a global perspective, the role of logistics and supply chain management has become increasingly vital over the past decade (Dadzie & Richard, 2025) which has forced the organizations to shape their operational strategies in light of changing dynamics to maximize operational availability of their strategic assets (Nagy et al., 2023). One major reason for this change in approach has been the realization of the fact that an ineffective or below par supply chain, adversely impacts organizational performance ultimately affecting the pursuit of strategic goals (Mustafi et al., 2024). One of the most fundamental aims of operating a supply chain is swift and timely availability of inventory (Guo et al., 2025) to ensure optimum demand fulfillment as "*you can't sell from an empty wagon*". On the other hand, another vital goal is to reduce the expenses associated with supply chain operations and to facilitate in achieving financial success. Further, organizations must aim at maximizing resource productivity, eliminating any duplication of efforts, and these steps can yield benefits such as reduction in financial spending, reduction in waste and achievement of an efficient Supply Chain which will ultimately help in enhancing operational readiness.

Militaries around the globe operate large number of complex platforms which require timely maintenance and upkeep to ensure optimum operational readiness of these strategic assets at all times (Mălinescu & Virca, 2022). For example, Table-1 gives an overview of the total number of platforms being supported through US Department of Defense (DOD) Supply Chain.

Table 1: Platforms Being Supported Through US DOD Supply Chain

Tactical Vehicles	346,000
Combat Vehicles	40,600
Aircrafts	14,800
Ships	256
Strategic Missiles	896

Source: (Cunningham et al., 2015)

Lately, the concept of Naval Defense Supply Chain Management has received focused attention from researchers. According to US Naval Supply Systems Command, "Naval *Supply Chain Management refers to the collection of processes that result in Naval-sector customers receiving the parts they need, when and where they need them, anywhere in the world*". According to Knofius et al. (2021), in a supply chain, smooth flow of spare parts inventories is vital to keep the non-operational time (i.e. down time) of assets within the reasonably acceptable limits. Sirichakwal & Conner (2016) defined spare parts as "*items that are used to maintain equipment or original product in operating condition while their characteristics can be highly diverse*". However, according to den Boer et al. (2020), there exists a major barrier in the form of financial or monetary requirements essential to aid timely spares supportability since an assortment of spare parts may contain expensive high value items, slow movers or those with longer lead times. Moreover, this is especially true for items which are manufactured with Conventional Manufacturing (CM) approaches such as milling, injection molding etc.

Another barrier which adversely affects Naval Defense Supply Chain's performance is the obsolescence of spare parts and equipment which has subsequently given birth to the concept of Obsolescence Management. According to International Institute of Obsolescence Management (IIOM), the term obsolescence can be defined as the unavailability of previously available spare parts or equipment (Boissie et al., 2022).

In order to maintain the border sovereignty of the state, the Defense Sector needs to continue investigating contemporary innovative technologies which can improve its war-fighting capabilities, raise mission readiness, and continue to operate in a fiscally constrained environment. Militaries in general and Navies in particular around the world have been forced to adopt technological indigenization in their Supply Chains to maintain in-service equipment due to the high expense of maintaining military systems combined with prolonged life cycles. In order to cater these financial, spares-supportability and obsolescence management related issues of Defense sector Supply Chain, countries like United States of America, United Kingdom, and France are increasingly making use of technological advancements to indigenize their Defense sector Supply Chains. In this regard, concept of Additive Manufacturing (AM) is being readily adopted throughout the Defense sector Supply Chains (*Background to Additive Manufacturing*, 2016). AM is a technological process which allows complicated designs and near-net shaped items to be manufactured. It gets its name from the fact that it produces a component, part, or product layer-by-layer from raw materials (additively). It is different from Conventional/ Subtractive Manufacturing as it does not involve the milling, injection molding etc.

With the advancement of AM technology, it is now possible to easily fabricate useable components with a chosen material in a single step. Moreover, it is now feasible to produce models that are nearly 100 percent dense and useful, and with the expansion of the range of acceptable materials, these systems have gotten more dependable and efficient over time. Therefore, the impact of adoption of AM technology on Naval Supply Chains is considered vital to optimize Naval Platform's performance in fiscally constrained environment in Public Sector.

This paper attempts to highlight the need to understand the importance of adoption of AM technology in ensuring the performance optimization of Naval Defense platforms including the stores, equipment, and systems. Furthermore, this study also aims to suggest future research directions in finding out future aspects of AM technology in Defense sector. Keeping in view the importance of this area, it is considered important to conduct this research study to explore the subject further.

2. LITERATURE REVIEW

AM is defined as, "*an emerging technology that manufactures three-dimensional (3D) objects directly from digital models through an additive process, typically by deposition of successive layers of polymers, ceramics, or metal materials*" (Kumar et al., 2021). Despite a recent surge in prominence of AM, in fact, it's not at all a novel concept and has been around and being practiced in various industries since as early as 1980s. We found that researchers over the years have been using various diverse terminologies such as "Additive Fabrication", "Additive Processing", "Additive Layer Manufacturing", and "Freeform Fabrication" for AM. The phenomenon of evolution of AM can be attributed mainly to its associated advantages such as its ability to manufacture any rare and complex designs, waste reduction, cost reduction and manufacturing of obsolete items. Knofius et al. (2021) argues that AM has rapidly matured during last decade and has proven the fact that it can be an innovative part of

Supply Chains by contributing towards the indigenous production of spare parts inventory. Although, AM technology was basically designed with an aim of supporting prototyping but with the passage of time AM techniques have proven their worth in countless applications (Hussnain, 2022). Table-2 outlines the major notable events in the history of AM inception and shows the gradual integrated progression in industrial production setups. Further, the rise of awareness regarding benefits of AM adoption is evidenced by the surge in the adoption of AM enabling machines and equipment across the globe (Stavropoulos et al., 2023).

Table 2: Notable Events in History of Additive Manufacturing

YEAR	EVENTS
1981	Hideo Kodama of the Nagoya Municipal Industrial Research Institute, published information regarding the manufacturing of a solid printed model
1986-87	Charles W. Hull (Chuck Hull) invented stereolithography, or 3D printing
1990s	It wasn't until 1999 that scientists at the Wake Forest Institute were able to utilize 3D printing technology for medical applications – printing the synthetic scaffolds needed to grow a human bladder
Early 2000s	First commercially viable Selective Laser Sintering (SLS) machine, as well as the founding of OBJET, which developed a machine that could mix multiple materials, allowing parts to be created with different material properties
Present Day	While accuracy and resolution have continued to improve, prices have fallen drastically when compared to the genesis of the technology

Source: (Goldberg, 2018)

2.1. Additive Manufacturing in Navies around the Globe

The integration of any technology into the Defense Sector is subject to high level of analysis due to associated factors mainly related to involvement of Public Funds in form of Tax-payers money and safety of men and material. Review of literature revealed the adoption of AM by various Naval Forces around the globe. Sertoglu (2021) reported that Dutch Navy while embracing the need of AM in Defense sector Supply Chains has made huge investment in 3D printing technology known as INTSMSYS 3D with aim to improve the demand satisfaction rate of sea-going platforms. Further, researcher explained that a typical Dutch vessel carries around 30,000 spare parts onboard and induction of AM technology onboard these vessels will enable the Navy to be less dependent on conventional Defense Sector Supply Chains, reduce down times by enhancing demand satisfaction rate, and ensure availability of obsolete spare parts. French Navy has also been a forerunner in rigorously pursuing the adoption of AM in its Supply Chain and deployed an entire Ship's Propeller of 2.5 meters length and 05 x 200kg blades each and with this technological indigenization French Navy has become first entity in the world to deploy such a massive component ever built by using AM technology. US Navy has also successfully utilized AM technology to manufacture 200 units of Full Motion Video (FMV) systems for its MH-60S Sea Hawk Helicopters in order to increase their operational readiness. According to Madeleine (2022), USS ESSEX has a fully operational 3D printer installed onboard since 2014 which is helping in manufacturing of obsolete as well as urgently required spare parts on the go subsequently increasing demand satisfaction of the platform. Furthermore, USS ESSEX through onboard 3D printer has successfully indigenously manufactured a Miniature Quadcopter. Further, in 2015, the US Department of Navy deployed a state-of-the-art AM Suite onboard USS Harry S. Truman in order to further strengthen their spares supportability and operational readiness. According to Lopez (2019), the US Department of Navy formulated Defense sector Additive Manufacturing Executive Committee (NAM EXCOMM) in 2015 with the mandate to implement and oversee the US Navy's Additive Manufacturing Plan. Researcher further explains that introduction of NAM EXCOMM has significantly revolutionized the US Navy's Supply Chain as in last three years a total of 148 new initiatives have been undertaken to Additively Manufacture various projects. Figure 1 shows the aims of NAM EXCOMM.

~Increased Readiness/Sustainment~

- *Rapid Tooling*
- *Additive Repair*
- *End use components*
- *Production at point of need*

~Enhanced Warfighting Capabilities~

- *Embedded sensors*
- *Part Consolidation*
- *Increased Lethality*
- *Superior electronics*
- *Customized Solutions*
- *Increased range and payload*
- *Enhanced survivability*
- *Improved acoustical performance*

Figure 1: Aims of NAM EXCOMM
Source: (Lopez, 2019)

Subsequent to the success of AM in Australian Army, Royal Australian Navy has installed its first ever 3D printer at HMAS Coonawarra Port with an aim to enhance the overall efficiency of Defense sector Supply Chain by increasing the demand satisfaction rate of Defense sector Platforms (Sarraf, 2020). Royal Navy with an aim to reduce long lead times, financial spendings and increased operational readiness has also successfully manufactured a small aircraft using indigenous AM technology with a wingspan of 1.5 meters and cruising speed of approximately 50 knots and made its maiden flight onboard HMS Mersey (Busachi et al., 2016).

2.2. AM and Demand Satisfaction

Meeting the requirements of end users in a timely and efficient manner has been the basis of inception of the whole logistics setup within Defense sector Supply Chains. Further, contemporary technological trends such as AM have augmented the overall demand satisfaction rates of platforms in Defense sector Supply Chains (*Military 3D Printing, n.d.*) by demonstrating their effectiveness in ensuring swift availability of complex and precisely manufactured spare parts (Sirichakwal & Conner, 2016) and organizations can save 43 percent to 75 percent time by simply adopting AM instead of Conventional Manufacturing. Further, researchers while emphasizing the effectiveness of AM in demand satisfaction stated that *"…when the Defense Advanced Research Projects Agency (DARPA) asked for proposals to improve the design of Vertical Takeoff and Landing (VTOL) aircraft in 2013, Boeing additively manufactured a prototype, whose construction would have otherwise taken several months—in less than 30 days".*

In the year 2018, a US Navy Ship USS John C. Stennis lost its internet service due to faulty rotary joint of Commercial Broadband System Program (CBSP). The conventional supply chain would have taken weeks to deliver the item onboard; however, the ship's crew utilized the AM technology and additively manufactured the faulty joint ending up meeting the most critically needed spare part. In 2016, V-22 aircrafts of the US Navy faced flight safety hazard due to non-availability of a spare part. In response, the part was additively manufactured and passed all quality and flight tests; hence, ensuring timely availability of critically required spare part.

2.3. AM and Financial Spending

According to Norako (2021), the US Navy successfully additively manufactured the visor clip of H-1 helmets used by US Marine Corps. The purchase price of Visor Clip was $300; however, with AM the same was indigenously manufactured in less than half of the price at which it was being procured through normal procurement channel. The largest repair services provider to US Navy's aircrafts known as Advanced Composite Structures (ACS) uses AM in order to manufacture the majority of its tools and resultantly reduces 79 percent of lead-time and 96 percent of overall costs. Thomas & Gilbert (2014) carried out detailed research to study the impact of adoption of AM on various cost factors. The results of the study revealed that adoption of AM leads to reduction in raw-material related costs through the concept of economies of scale.

2.4. AM and Obsolescence Management

Obsolescence of inventory and equipment has remained a common hurdle in the defense industry (Saygın & Onay, 2024) since its supply chain not only involves longer lead times but also the fact that platforms or strategic assets are required to be operated in-service for a period generally spreading over multiple decades. Further, the researcher claimed that up to 70 to 80 percent of all electronic components generally become obsolete even before the deployment of their parent system in service. Obsolescence of inventory and equipment has major financial implications in general and on Defense sector Supply Chain in particular and these implications vary from country to country and case to case basis. For example, the projected total life-cycle obsolescence costs of UK Royal Navy's Maritime Patrol Aircraft NIMROD MRA4 (which never entered the service) were £780m and on the other hand the obsolescence issues faced by United States Department of Navy costs as high as $750m on yearly basis (Erkoyuncu & Roy, 2015). According to Halilović (2022), inventory can become obsolete at any stage of life cycle of a platform; hence, obsolescence management needs to be considered from the inception stages of the platform. Thus, there can be two basic approaches to effectively catering the obsolescence issues within Defense sector Supply Chains i.e. proactive and reactive.

Erkoyuncu & Roy (2015) identified the following three methods to cater obsolescence in Defense Supply Chains which are also applicable to Defense sector Supply Chain dynamics:

a. Cannibalization
b. Fit, Form and Function replacement
c. Emulation or redesigning (i.e. replicating the obsolete part using state-of-the-art technology)

However, introduction of AM has catered to the issues of obsolescence to a greater extent. For example, when spare parts of US Navy's AV-8B Harrier aircrafts were declared obsolete by OEM, US Navy relied upon AM to indigenously manufacture those parts; hence, setting new standards in the field of AM and obsolescence management. In addition to AV-8B Harrier, US Navy is efficiently managing the obsolescence of aging platforms like P-3 Orions (Erkoyuncu & Roy, 2015) and F/A-18E/F Hornets using Additive Manufacturing technology (Jacob Skipper & Albrecht, 2022).

3. CONTRIBUTION AND FUTURE RESEARCH DIRECTIONS

This research paper highlighted the significance of adoption and implementation of AM technology particularly in Naval Supply Chains. The successful examples identified while undertaking review of relevant literature in this research paper have augmented the need to carry out a comprehensive research study in context of smaller Navies to find out the operational impacts of AM. According to Cunningham et al. (2015), the ultimate goal of adoption of technological indigenization such as AM in Defense sector Supply Chains is not only to manufacture 3D printed spare parts that shall replace the existing product line but also to provide a cost effective and swift solution in case of failure of a part onboard ship. Based on the literature review, it is revealed that adoption of AM in Naval Defense Supply Chains is a novel concept, and researches have been conducted mainly in USA, UK, Australia, Switzerland and France. However, developing countries are still lacking behind in understanding the importance of AM in Naval Defense Supply Chains due to lack of awareness and research work. Furthermore, apart from understanding the impact of AM adoption on Demand Satisfaction, Obsolescence Management, Financial Spending and overall Platforms' Performance Optimization, there is a need to further explore various avenues of application of AM in Defense Sector Supply Chains along with proper framework. Therefore, based on the discussions in this paper, the following future research directions are suggested to be pursued:

a. In what ways can the continuous progress in additive manufacturing technology enhance the level of demand fulfillment in the Defense industry supply chain?
b. What part do new AM technologies play in improving Defense platform obsolescence management strategies?
c. How might the ongoing improvement of AM procedures affect the Defense sector's financial decisions and spending trends?
d. How might the addition of additive manufacturing to more extensive defense supply chain procedures increase stakeholder collaboration and help meet demand?
e. What cooperative strategies and alliances between suppliers, AM technology providers, and defense contractors may be formed to maximize obsolescence management in defense platforms?
f. What is the impact of additive manufacturing implementation on cost-sharing and funding partnerships in the defense industry?
g. What impact may industry standardization initiatives have on improving financial predictability in Defense supply chains, and how can regulatory authorities influence the development of these standards?

4. RESEARCH QUESTIONS

Based on the discussion above, this study further presents some research questions which may be considered for exploring the topic further.

1. What is the impact of adoption of Indigenous AM Technology in Defense sector Supply Chain on Platforms' Demand Satisfaction?
2. What is the impact of adoption of Indigenous AM Technology in Defense sector Supply Chain on Platform's Obsolescence Management?
3. What is the impact of adoption of Indigenous AM Technology in Defense sector Supply Chain on financial spending?
4. How can the Defense sector Supply Chain be modeled to achieve the optimal level of platform efficiency and operational readiness?

5. RESEARCH METHODOLOGY

Future studies in this field may take a mixed-methods approach, integrating qualitative and quantitative methodologies to produce more thorough results. Jick (1979) proved that this strategy works well for handling complicated topics with limited data availability. Integrating interpretivist and positivist techniques can resolve both the "how" and "what" of causal links in policy, public decision-making, and social issues (Lin, 1998).

A Positivist paradigm is appropriate for discussing organizational and policy concerns. It may entail gathering data to measure monetary savings and doing regression analyses to better understand the correlations between variables. Qualitative methods, such as semi-structured interviews, might, however, identify underlying factors from an interpretivist perspective (Z. B. Junaid & Rashid Asif, 2022). The efficiency of this research method specifically in Military Sector researchers was demonstrated by (Borzillo & Deschaux-Dutard, 2020).

Review of relevant literature has paved way for formulation of following Conceptual Framework of present research. Figure 2 shows the constructs and proposed hypothesized relationships between them.

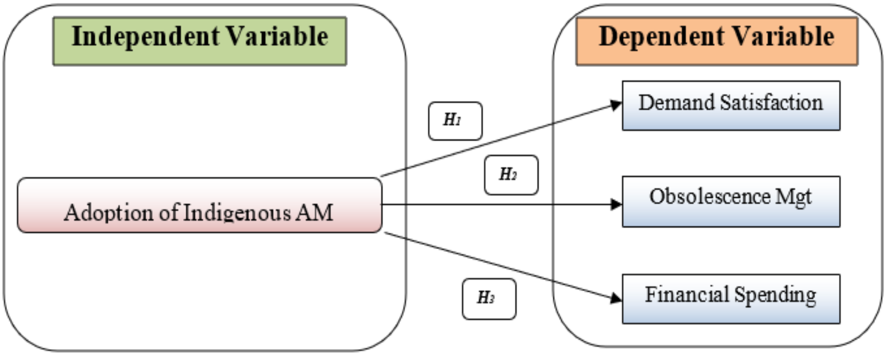

Figure 2: Conceptual Framework and Hypothesized Relationships

Based on the abovementioned conceptual framework, the following hypotheses have been deduced for subsequent testing:

Table 3: Hypotheses of Research Study

Hypotheses		Statement
H1	$H1_0$	Adoption of Indigenous AM will not increase demand satisfaction
	$H1_A$	Adoption of Indigenous AM will increase demand satisfaction
H2	$H2_0$	Adoption of Indigenous AM will not have a positive significant impact on obsolescence management
	$H2_A$	Adoption of Indigenous AM will have a positive significant impact on obsolescence management
H3	$H3_0$	Adoption of Indigenous AM will not cut down Financial Spending
	$H3_A$	Adoption of Indigenous AM will cut down Financial Spending

6. SIGNIFICANCE OF THE FUTURE RESEARCH

This research has tried to explore existing literature and aims at offering all stakeholders a detailed insight into the advantages associated with the adoption of contemporary technological indigenization trend i.e. AM. On the basis of insights provided in this research, future studies can further explore the contemporary issues in this field which will assist all parties involved in the procurement, provisioning, and purchase of defense equipment. Ultimately, this will result in cost savings and increased efficiency, particularly in long-term maintenance and progressive upgrades.

7. LIMITATIONS OF THIS RESEARCH STUDY

Main limitation of the study is the easy availability of data for analysis. Due to the sensitive nature of stores and equipment involved in the Defense sector Supply Chains, the data is not openly available (Z. B. Junaid & Rashid Asif, 2022). Therefore, the analysis will mainly rely on the available literature on the subject from sources such as Naval Postgraduate School California Research Databank, published research articles and research material and the available data from different organizations like Stockholm International Peace Research Institute (SIPRI). This research's primary drawback is its extensive theoretical and descriptive content. Nonetheless, it is beneficial to determine potential avenues for future study and inquiries to be pursued in this field. This research serves as a means of introspection for academics who seek to tackle the problems within this field. Limited data availability for analysis is another potential future constraint. Nonetheless, research can be carried out in-house at organizations, with the possibility that the findings won't be made public.

9. CONCLUSION

A review of the literature demonstrates that the Departments of Defense in different nations carried out some groundbreaking research in this field. However, financed programs served as a major driving force behind this endeavor. Furthermore, there isn’t much research or works of literature that suggest a well-developed framework or model for use in this field. Thus, it is imperative that we concentrate on putting out a framework for the development of defense stockpiles in our own country. This study aids in defining and establishing the path that other researchers will take as they investigate new angles.

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