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IMPLEMENTATION OF THE SINGLE FUEL CONCEPT FOR THE NAVY'S SURFACE FLEET: AN ANALYSIS OF LONG-TERM SOLUTIONS

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IMPLEMENTATION OF THE SINGLE FUEL CONCEPT FOR THE NAVY'S SURFACE FLEET: AN ANALYSIS OF LONG-TERM SOLUTIONS

by

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December 2021

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The U.S. Navy's surface fleet has been operating on two primary types of fuel for several decades, F-76 for ships and JP-5 for maritime aircraft. Since the implementation of these two fuels, multiple research projects have been conducted to recommend a Single Fuel Concept (SFC), but the Navy has not changed its fuel concept. In today's environment, the Navy needs solutions to cut costs and simplify the supply chain in an effort to focus on the Great Power Competition (GPC) while being mindful of defense budget constraints. Over the past several years, the JP-5 and F-76 price differential has decreased significantly, which provides an opportunity to implement an SFC based on cost benefits. This paper conducts regression analyses on both types of fuel and predicts consumption trends for the future based on the large fleet expansion set forth by the 30-Year Shipbuilding Plan. Cost and standard pricing metrics are used to show the possible cost savings by using JP-5 as a single fuel across the fleet. Implementation of an SFC will take time, especially with a growing fleet, so a phased rollout plan was developed to recommend timeframes for introduction of the SFC while mitigating risk to the fleet. This thesis recommends immediate implementation of the SFC in a phased rollout in order to cut costs, simplify the supply chain, and provide a long-term solution to a growing logistics problem.

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ABSTRACT

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LIST OF ACRONYMS AND ABBREVIATIONS

ARG	Amphibious Ready Group
CG	Guided Missile Cruiser
CI/LI	Corrosive Inhibitor/Lubricity Improver
CNA	Center of Naval Analyses
CSG	Carrier Strike Group
CVN	Nuclear Aircraft Carrier
DDG	Guided Missile Destroyer
DESRON	Destroy squadron
DFSP	Defense Fuel Support Points
DLA	Defense Logistics Agency
DMO	Distributed Maritime Operations
DOD	Department of Defense
DON	Department of the Navy
DOS	days of supply
FFG	Guided Missile Frigate
FSII	Fuel System Icing Inhibitor
GPC	Great Power Competition
LCS	Littoral Combat Ships
LEL	Lower explosive limit
LHD	Landing Helicopter Dock
MSC	Military Sealift Command
NAVSUP	Naval Supply Systems Command
NDS	National Defense Strategy
NSS	National Security Strategy
NSTM	Naval Ship Technical Manual
OPORD	Operational Orders
SDA	Static Dissipative Additive

SFC	Single Fuel Concept
SLOC	Sea lanes of Communication
UEL	Upper explosive limit
UNREPS	Underway Replenishments
USA	United States Army
USAF	United States Air Force
USMC	United States Marine Corps
USN	United States Navy
VTA	Voluntary Tanker Agreement

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I. INTRODUCTION

In recent years, the Great Power Competition (GPC) with China and Russia, as well as other emerging threats, has pressured United States leaders to improve capability, sustainment, and operability all while working within budget constraints. Recent policy has driven a goal of increasing the surface fleet from the current 296 ship fleet to between 398 and 512 total ships (Congressional Budget Office, 2021b). It generally appears contradictory to increase ship numbers while decreasing the budget; therefore, policymakers and naval leadership must find a way to balance desired ends (size of the fleet), ways (strategy), and means (financial and material resources) to determine which areas of U.S. defense will require prioritization and additional risk. Based on these goals and challenges, we find that one way to cut costs, maintain operability, and improve efficiency, is for the Navy to shift to the Single Fuel Concept (SFC).

For several decades the U.S. Navy's surface fleet, consisting of a variety of types of ships, has been operating on four primary types of fuel: F-76, JP-5, steam, and nuclear power. This research project is focused on conventional fuel types due to the reality that nuclear power is expensive and unlikely to be distributed across all platforms of the U.S. Navy's surface fleet. Prior research on the SFC has demonstrated that between JP-5 and F-76, the former is a universal fuel source. It can be used in both naval surface vessels, because of its similarities in properties to F-76 that allow it to operate in gas turbine engines as well as diesel engines, and as effective propulsion for aircraft (Jimenez et al., 2020). Investigating further into the SFC at sea, we aim to build upon existing research to further prove the concept and demonstrate how it would benefit the fleet. Our research and analysis examined the historic consumption of F-76 and JP-5, projections for future fuel consumption, transportation costs, and other impacts of the Navy's surface fleet shifting to an SFC. We further devised a roll-out plan to demonstrate the timeframe necessary to implement the SFC while considering risks to mission, budget, and operations. Finally, we demonstrate how the Navy's goal to increase the size of its fleet can be attained in part by the cost and efficiency savings of the fuel shift across the fleet.

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II. BACKGROUND

Several topics establish the context of this research. These include a history of maritime fuel, the naval strategy of Distributed Maritime Operations, maritime logistical agencies in the supply chain and types of fuels used by the Navy to assess the potential of implementing.

A. HISTORY OF NAVAL FUEL

In 1910, the first oil-burning destroyer, USS Paulding, was commissioned. Although many saw the advantages of shifting to oil as a single fuel source for the Navy, there was no rush to shift all naval vessels to oil versus coal (Dahl, 2001). It was not until World War II that every Navy vessel had finally adopted fuel oil as the stand-alone source of power (Dahl, 2001). Diesel fuel gave naval vessels the ability to travel further, less risk of compromising the fleet's location, more efficient designs, and reduced manning requirements. However, the most significant advantage was the possibility of refueling at sea to sustain ongoing operations and increase cruising ranges (Pike, n.d.). The advances made during the transition to fuel oil made the modern Navy possible.

The Navy has conducted previous studies into the SFC but the price difference between JP-5 and F-76 was significant and would have required additional funding. Pricing differences will be discussed later. The price difference was not the only concern; there was also the concern of not having a cohesive implementation plan. In later chapters there will be analysis on the price difference but also analysis methods to implement an SFC. The Navy must continue to make advancement in naval fuel to maintain maritime superiority during the era of the GPC.

B. KEY OPERATIONAL CONCEPTS

There are two key operational concepts: first is the Navy's contribution to the National Defense Strategy (NDS) and second is naval refueling behavior. This section will cover Distributed Maritime Operations (DMO) which is the Navy's strategy which aligns with the NDS and how an SFC benefits DMO. The understanding of naval refueling behavior will help illuminate why an SFC is beneficial to the Navy and the NDS.

1. Distributed Maritime Operations

Distributed Maritime Operations focuses on the lethality of the surface fleet which requires the Navy to have robust fuel supply chains; an SFC could possibly create a more durable and sustainable logistical force structure. In December 2017 President Donald Trump issued a new National Security Strategy (NSS). In support of the NSS, Secretary of Defense James Mattis issued a new National Defense Strategy (NDS). These two documents refocused the United States towards GPC with China, specifically operations in the South China Sea and Taiwan (A Design for Maritime Superiority, 2018). To maximize the Navy's contributions Fleet Forces created a new doctrine of Distributed Maritime Operations (DMO), which is primarily focused on unmanned systems and next generation surface combatants (Eyer et al., 2019). By simplifying the supply chain with an SFC, the Navy could obtain a more sustainable and agile logistical force structure. Shifting these next generation surface vessels to an SFC could prove exponentially beneficial in refueling capabilities in support of DMO objectives.

2. Naval Refueling Behavior

Naval refueling behavior assists in ensuring that the supply chain for fuel remains unbroken. Naval refueling behavior is based upon operational orders (OPORD) outlined by the Fleet Commanders, each of whom is given the discretion to determine the fuel level at which a vessel will return to port. The exact levels are classified; however, "*OPORD 201* Annex D, which is nearly identical to most other Fleet commander OPORD guidance for fuel, directs naval vessels to fill their fuel tanks at any practicable and available opportunity" (Jimenez et al., 2020). There is a two-fold benefit from cultivating this behavior: first, it allows the Navy to retain larger stocks of both F-76 and JP-5 and second it allows Surface Warfare Officers and Merchant Mariners to practice underway replenishment at sea (UNREPS) shiphandling skills. In the current peacetime environment these benefits are often overlooked; however, in a contested environment these practices could prove to be beneficial in maintaining shiphandler competency and the demand on the fuel supply chain. The OPORDs provide operational flexibility to commanding officers and ship masters on when to refuel. Each commanding officer and ship master factors in risk tolerances, operational environment, and requirements. Since each vessel's refueling needs will vary with commanding officer and ship master, the Navy requires agility and resilience in the fuel supply chains that SFC could provide.

C. FUEL CHARACTERISTICS AND DESCRIPTIONS

Naval fuel has several requirements to be acceptable for use onboard a naval vessel or aircraft. This section will go over a few of the most important requirements.

1. Flash Point

Flash Point is the lowest temperature at which vapors will ignite by ignition source. Both F-76 and JP-5 require a minimum flash point of 140^{O}F (Ship Fuel and Fuel Systems, 2019). If the flash point is any lower there is a potential of excess heat from the flight deck or engineer room to ignite the fuel leading to a fire aboard a naval vessel.

2. Explosive Range

The explosive range, which is measured in percent by volume of air, is the range in which the explosive or flammable mixture will ignite/explode. This range is centered around the flash point and is composed of the upper explosive limit (UEL) and the lower explosive limit (LEL). A mixture above the UEL is primed for ignition whereas any mixture below the LEL will not ignite (DA, 2015). Explosive range requirements vary for fuel types.

3. Jet Fuel Additives

The standard additives in naval jet fuel are Fuel System Icing Inhibitor (FSII), Static Dissipative Additive (SDA) and Corrosive Inhibitor/Lubricity Improver (CI/LI). FSII is added to jet fuel to reduce the freezing point of water and prevent the formation of ice crystals so that at high altitudes, or at lower temperatures, the engine will not stall out. SDA is added to increase fuel's electrical conductivity and reduce the potential for electrostatic buildup and explosive hazards (DA, 2015). SDA is particularly important during rotary wing inflight refueling also known as a “hot pump.” CI/LI is used to reduce corrosion and improve lubrication in the fuel line tubing.

D. FUEL TYPES

The military uses several different fuel types, but the three main types are JP-5, JP-8, and F-76. F-76 is the fuel used for most of the naval surface fleet; the few exceptions are the steam ships and the nuclear power ships. JP-5 is used specifically for aircraft onboard naval vessels due to the higher flash point to support flight deck operations. JP-8 is used for naval aircraft that are not on-board naval vessels and have properties similar to the commercial jet fuels; therefore, it is outside the scope of this project. The following section will lay out the DON requirements for F-76 and JP-5.

1. F-76

F-76 is the main fuel type used by all surface vessels in the naval. The exceptions to the consumption of F-76 are nuclear aircraft carriers (CVNs) and all except one landing helicopter dock (LHDs). All the LHDs are steam powered except the Makin Island, which is a diesel electric turbine vessel. The primary delivery method for F-76 is UNREPs. Naval vessels are required to ensure that when onloading F-76 they meet the standards required in the Naval Ship Technical Manual (NSTM) Chapter 541. F-76 density at 59^{O}F is between .800 kg/L and .876 kg/L. The flash point must be at a minimum 140^{O}F. The explosive range is between 0.6 LEL and 6.5 UEL. Additionally, F-76 must not have a cloud point higher than 10^{O}F to prevent equipment damage. All naval vessels are required to ensure that the fuel is clear of sediment known as the “clear” test, the sample must also be bright, which is an inspection for water particles in the fuel known as the “bright” test. The clear and bright test is required to be at the beginning, middle and end of fueling along with every 15 minutes during fueling.

2. JP-5

JP-5 has similar requirement that must be meet to onload the fuel to a naval vessel, Table 1 is a comparison of fuel specification requirements. Due to the similar requirement in testing, there would be no additional requirements the DON would have to meet in order to use JP-5 as an SFC. Additional, JP-5 is the exclusive fuel used on-board naval vessels for aircrafts. If an aircraft with any other type of fuel lands on a naval vessel, the fuel will immediately be off-loaded, and the aircraft will be refueled with JP-5 for the safety of the vessel and crew. This is done to ensure that the flash point is appropriate for flight deck operations. JP-5 is the stand-alone fuel for aircrafts on board naval vessels for this reason. Other requirements of JP-5 are a density at 59^{O}F is between .788 kg/L and .845 kg/L. The explosive range is between 0.7 percent LEL and 5.0 percent UEL. JP-5 can be used as a means of propulsion for naval vessels because of the similarities between the fuels; however, F-76 cannot be used as an aircraft fuel because of the lack of additives to prevent icing at high altitudes and low temperature and the SDA used during "hot pumps." "In 1982 and 1983, during the Iranian crisis, which restricted access to F-76 stores and shipping lanes through the Persian Gulf, JP-5 was used in lieu of F-76 onboard navy vessels in the Indian Ocean without any documented negative consequences" (Jimenez et al., 2020 p. 16). Thus, JP-5 is the only possible fuel for an SFC at sea.

Table 1. Comparison of F-76 and JP-5 Specification Requirements. Source: "Naval Sea System Command" (2019).

Requirement	**MIL-DTL-16884, F-76**	**MIL-DTL-5624, JP-5**
Appearance, visual	C&B[2]	C&B
Ash, wt % max	0.005	N/A[3]
Cetane Index, min	43	Report[4, 11]
Cloud Point, °C, max	-1	N/A[3]
Density, at 15 °C, kg/m^3	800-876	788-845
Distillation Temperature, 90% Recovered, °C, max	357	Report[3, 11]
Flash Point, °C, min	60	60
Freezing Point, °C, max	N/A	-46
Lubricity, µm, max	460	N/A
Particulate Contamination, mg/L	10	1.0
Pour Point, °C, max	-6	N/A[3]
Storage Stability, mg/100 mL, max[8]	3.0	N/A[3]
Sulfur, wt %, max	0.0015	0.3
Viscosity, cSt @ 40 °C:	1.7-4.3	N/A[10]

E. MARITIME FUEL LOGISTICS COMMANDS

The major logistics commands that influence the surface fleet of the Department of the Navy (DON) allocation, budgeting and procurement of fuel are Defense Logistics Agency (DLA) Energy and the Military Sealift Command (MSC). A general background for both commands will be detailed along with specific vessel types within the MSC that are imperative to refueling at sea in the section.

1. Defense Logistics Agency Energy

DLA Energy fact book states, that DLA is "America's combat logistics support agency responsible for sourcing and providing nearly every consumable item used" by the DOD worldwide (Defense Logistics Agency, 2019). DLA is also responsible for distributing, storing, and determining resilient energy solutions for the DOD. DLA has two major headquarters in the United States, eleven regional offices around the world plus an additional fifteen DLA energy liaison offices to provide worldwide support to operational units. The eleven regional offices are locations of fuel storage to provide shorter refueling lines. In 2004, DLA energy focused on improving efficiency and minimizing duplication and redundancy in the supply chain. The bulk petroleum supply chain includes JP-5 and F-76. DLA has four major purchase programs, which include the procurement bulk additives, bulk lubricants, and thermally stable aviation turbine fuel. The supply chain provides contracts both domestically and internationally, which facilitated the procurement of 10.133 million barrels (bbls) of JP-5 and 18.024 million bbls of F-76 during fiscal year 2019 (Defense Logistics Agency, 2019). The supply chain goes from procurement to terminal operations, which include ashore facilities and MSC. The final step in the fuel chain is for these terminal operations to provide fuel to tactical units through either ashore refueling or UNREPS.

2. Military Sealift Command

MSC provided the end users with the fuel required to maintain tactical operations supporting NDS goal in a more versatile and robust supply chain. MSC has several different types of replenishment vessel that are essential in maintaining reliable and uninterrupted sea lines of communications (SLOC). In order to maintain SLOCs the Navy has several composite structures that could be employed like the Carrier Strike group (CSG), the Amphibious Readiness group (ARG), and finally the Destroy Squadron (DESRON) shown in Figure 1. The commonality between all these groups is that they require massive amount of F-76 and JP-5 to support operational commitments. MSC has five classes of vessels that provide operational support to tactical units.

Figure 1. Destroy Squadron 23. Source: "DESRON 23" (2020).

a. Fleet Replenishment Oiler

The powerhouse of naval UNREPs is the USNS Henry J. Kaiser (T-AO 187) class fleet replenishment oilers, shown in Figure 2. These vessels have two variants, either a single or double hull. The double hull variants came about to comply with the Oil Pollution Act of 1990; therefore, the double hull variants only have a storage capacity of 77,160 bbls whereas the single variants have a storage capacity of 90,260 bbls. The T-AO can refuel on port and starboard sides of the ship simultaneously at a rate of 28,571 bbls of F-76 and 17,142 bbls of JP-5 per hour (DON, 2007). T-AOs have a maximum speed of 20 knots (kts) and a maximum operational range of 3,000 nautical miles (nm).

Figure 2. USNS Henry J. Kaiser (T-AO 187). Source: “Navy Recognition” (2020).

b. Fleet Ordnance and Dry Cargo

The Lewis and Clark (T-AKE) class UNREP vessels were designed to provide cargo and ammunition to naval vessels, as shown in Figure 3. Although, the main purpose of the T-AKE is to provide ordnance and dry cargo it does have the capability to provide 7,000 bbls of F-76 and 17,000 bbls of JP-5 (DON, 2007). The Lewis and Clark class ship has a maximum speed of 20 kts and 14,000 nm.

Figure 3. USNS Lewis and Clark (T-AKE). Source: “Photo Gallery” (2006).

c. Petroleum Tankers

The petroleum tankers are part of the MSC’s support program and are designed to transport fuel to Defense Fuel Support Points (DFSP) worldwide (MSC, 2020e). The T-AOT tankers are essential in maintaining operational fuel requirements for forward deployed vessels, shown in Figure 4. The T-AOTs have a maximum capacity of 118,500 bbls of fuel and maximum range of 6,000 nm.

Figure 4. Empire State Petroleum Tanker. Source: “NavSource Online” (2010).

F. 30-YEAR SHIP BUILDING PLAN

The combat logistic ships that MSC use to provide fuel to DFSPs, and surface combatants are aging and require new vessels to replace them. Currently there are only 29 combat logistic ships to provide support to the surface fleet; without more oilers to provided fuel at sea the supply chains will be strained. The current ship building plan requires a 93 percent to 159 percent increase in combat logistic vessels to meet goals projected in the 30-year ship building plan (Congressional Budget Office, 2021b). The current surface force is comprised of 296 ships, but the ship building plan requires an overall increase to between 321 and 372 ships (Congressional Budget Office, 2021b). An increase will not only place a strain on the fuel supply chain due to the capacity of refineries but also due to capability to delivery fuel via the combat logistics ships. It is possible that an SFC and an increase in the combat logistics force will better support the NDS by simplifying the supply chain.

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III. LITERATURE REVIEW

This chapter covers prior research into the SFC that analyzed the effectiveness of an SFC and pricing trends of JP-5 and F-76. In addition to reviewing prior research into the SFC, there is also the need to understand the 30-year shipbuilding plan and potential difficulties of the fuel supply chain, which hinges on oil tankers as UNREP vessels.

A. TACTICAL AND OPERATIONAL EFFECTS OF THE SINGLE FUEL CONCEPT

A thesis written by Jimenez et al. in 2020 analyzed the effects of an SFC on tactical and operational readiness. The object of this research was to determine the impacts of the adoption of JP-5 as the sole source of fuel at sea. The thesis also analyzed whether the SFC would "enhance refueling logistics capabilities at operational and tactical levels of maritime warfare" (Jimenez et al., 2020, p. 3). As addressed earlier in the background section, the authors determined that JP-5 would have to be the sole source of fuel if the Navy shifted to an SFC due to stricter requirements it must meet in comparison to F-76. The authors also addressed the fact that in 1982 and 1983 naval ships conducted operations in the Persian Gulf while using JP-5 without any "documented negative consequences" (Jimenez et al., p. 16 2020). The authors used 27,250 data points from Naval Supply Systems Command (NAVSUP) and Center of Naval Analyses (CNA) to run a model based on a contested world environment scenario. Although previous research suggests that there could be a three percent efficiency loss that does not necessarily mean there is a difference in burn rate, further research into JP-5 and F-76 burn rate would be required to determine if there is a difference. In the 2020 thesis, the authors used different scenarios to analyze supply chain resiliency under an SFC. They used two scenarios with the same combat composition for different task forces. The first scenario used both F-76 and JP-5 while the second scenario used only JP-5. Days of supply (DOS) was used as a measurement of resiliency in the exercise and Figure 5 demonstrates the positive results for the SFC. Ultimately, the 2020 thesis concluded that the SFC had "measurable operational benefits to the responsiveness and flexibility of maritime refueling logistics" (Jimenez et al., 2020,

p. 57). The 2020 thesis recommended further research into multiple related topics including: amphibious operational impacts, prepositioning requirements, storage transition costs, a phased roll-out plan, and a total fuel supply system transition cost. To add value to the results of the 2020 thesis, this paper addresses the recommendation for further analysis into implementation of the SFC. This includes a rollout plan to demonstrate the timeframe necessary to implement the SFC while considering risks to mission, budget, and operations. Additionally, this paper analyzes how the Navy's goal to increase the size of its fleet can be attained in part by the cost and efficiency savings of the fuel shift across the fleet.

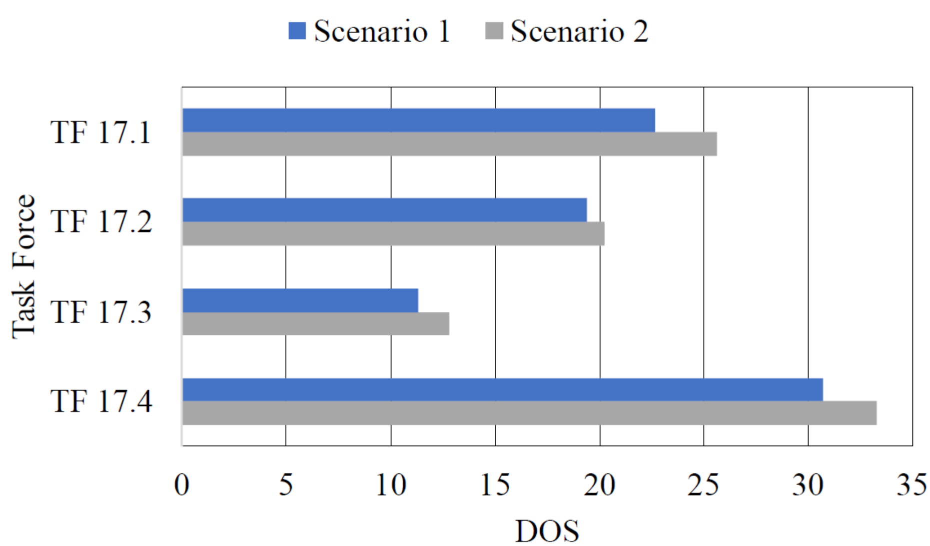


Figure 5. Task Force Endurance. Source: Jimenez et al. (2020), p. 55.

B. FUEL COST AND VOLUME RELATIONSHIP

A thesis written by Camarata et al. in 2021 analyzed the possibility of a relationship between the cost and volume of JP-5 and F-76. The purpose of their research was to investigate the cause of previously held notions that the SFC would not be cost effective to implement, primarily due to a perceived high cost of JP-5. The authors compared the price of crude oil to the prices of JP-5 and F-76, as well as the volume of sales and purchases. The results of their analysis demonstrate that the volume of JP-5 purchased by DLA and subsequently sold to DLA customers does not have a significant impact on the standard price or cost of JP-5. This can be seen in Tables 2 and 3, which show the results of regression analysis conducted on the relationship between the JP-5 cost as it relates to purchase volume, and the JP-5 standard price as it relates to sales volume. The p-value shown for each regression analysis are significantly higher than 0.05, which is the value commonly associated with being considered a significant relationship between the variables. The analysis also shows that the average cost of JP-5 is $0.03 less than F-76 and the resulting standard price set for DLA customers is $0.01 lower than the standard price for F-76. Figure 6 from Camarata et al. shows historic fuel costs and standard prices for JP-5 and F-76. The combination of publicly available information from the DLA Fact Books, as well as the analysis conducted by Camarata et al. demonstrates that historical prices and DLA pricing today should not prevent the Navy from adopting the SFC. Instead, moving forward with the SFC may result in an even more favorable cost and standard price of JP-5 to the fleet.

Table 2. JP-5 Cost as a Function of Purchase Volume. Source: Camarata et al. (2021), p. 21.

Table 5: JP-5 Cost as a Function of Purchase Volume				
Regression Statistics				
Multiple R	0.301438977			
R Square	0.090865457			
Adjusted R Square	-4.79973E-05			
Standard Error	0.264846891			
Observations	12			
ANOVA				
	df	*SS*	*MS*	*Significance F*
Regression	1	0.070106843	0.070106843	0.341014783
Residual	10	0.701438756	0.070143876	
Total	11	0.771545599		
	Coefficients	*P-value*	*Lower 95.0%*	*Upper 95.0%*
Intercept	1.422108419	0.081806399	-0.215760408	3.059977246
JP5 (Purchased)	-0.063679618	0.341014783	-0.205604118	0.078244882

Table 3. Diesel Std. Price as a Function of Net Sales Volume. Source: Camarata et al. (2021), p. 21.

Table 6: Diesel Std. Price as a Function of Net Sales Volume				
Regression Statistics				
Multiple R	0.251286219			
R Square	0.063144764			
Adjusted R Square	-0.03054076			
Standard Error	0.368861905			
Observations	12			
ANOVA				
	df	*SS*	*MS*	*Significance F*
Regression	1	0.091704884	0.091704884	0.430794268
Residual	10	1.360591047	0.136059105	
Total	11	1.452295931		
	Coefficients	*P-value*	*Lower 95.0%*	*Upper 95.0%*
Intercept	2.761904531	0.107586634	-0.719783131	6.243592194
JP5 (Net Sales)	-0.126692582	0.430794268	-0.470536235	0.21715107

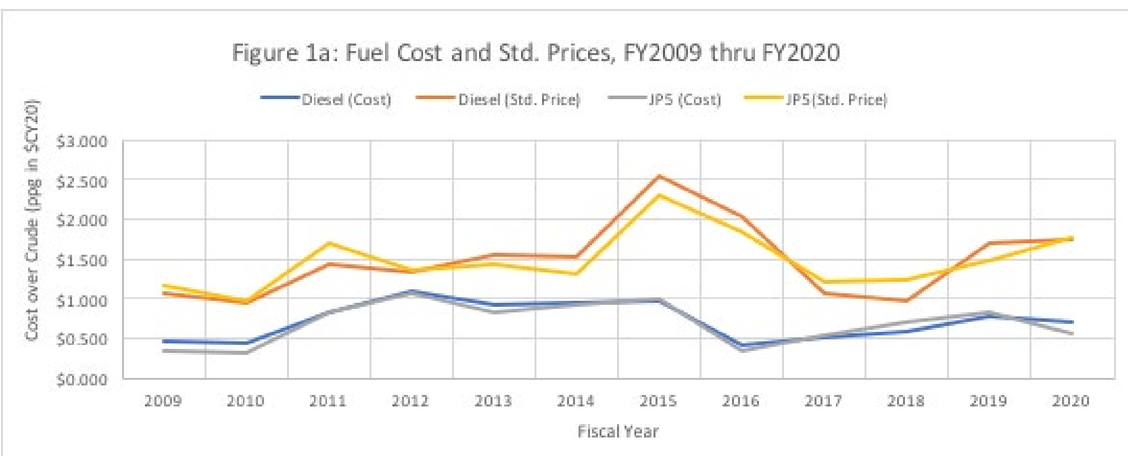


Figure 6. Fuel Cost and Std. Prices, FY 2009 to FY 2020. Source: Camarata et al. (2021), p. 17.

C. 30-YEAR SHIPBUILDING PLAN

The 30-year shipbuilding plan lays out the current force structure and predicted future force structure. The current number of naval vessels is 296 with the goal of 321 to 372 manned vessels and 143 to 242 unmanned vessels. By increasing the number of vessels, it could cause a heavy strain on the current UNREPS especially considering the requirement to carry both JP-5 and F-76. It is important to note the additional vessels help support the NDS of the GPC. These ships provide deterrence and maintain SLOC around the world. However, without more tankers and advancements in the fuel supply chains, it might be difficult maintain a forward presence. Additionally, many cruisers and destroyers are approaching the end of their service life and there is no identified plan on how to replace the vessels and the capability they bring to the NDS. The 30-year shipbuilding plan "lacks details about the precise number of ships and unmanned systems the Navy would purchase and how quickly the inventory of the future fleet would evolve, the plan embraces themes from previous shipbuilding plans and force structure assessments" (Congressional Budget Office, p. 3 2021b). The plan focuses on enlarging and diversifying the fleet with ships that are more capable to meet the NDS for the GPC.

D. OIL TANKERS AND REFUELING AT SEA

In an article written in Forbes in June of this year, the author writes about some of the challenges that the U.S. Navy faces regarding refueling at sea and the Navy's partnership with MSC. The Navy uses thirty-seven support ships from MSC but only twenty-five of these ships are oil tankers that can move fuel for the Navy. This means that the entire U.S. surface fleet of nearly 300 ships (and growing) is only able to maintain sustained operations at sea by the support of twenty-five oil tankers. The article argues that the U.S. would struggle to maintain fuel supplies in a future conflict in the Pacific because the oilers that the U.S. uses also have commitments around the globe. Given the distributed nature of the DMO concept, there is an extremely large area around the world for such a small fleet of ships to support. This is especially difficult given that it is unrealistic for every MSC ship to be at sea at the same time. These ships must go through maintenance periods, training, and down time just like the Navy's warships. The author also writes that

MSC does not have any tankers in its reserve fleet and that the Navy would have to rely on the Voluntary Tanker Agreement (VTA) which is where civilian companies offer up their ships for the Navy during wartime. To add to the issue, the Navy only has six John Lewis Class oilers on contract to be constructed over the coming years. Additionally, there would likely be issues with maintenance due to increased operational tempo, there is a serious possibility of ships being sunk during conflict at sea, and the sheer amount of fuel that would be required to maintain warships and tankers on station would exhaust the MSC fleet. The article concludes that the U.S. needs to find balance in its spending for procurement of warships and the oilers that provide support for those warships to maintain station (Axe, 2021).

IV. METHODOLOGY

The purpose of this chapter is to discuss the methods used by the authors in conducting the analysis of this project. Specifically, this chapter addresses the type of data used, how the data was used for analysis, the approach of the analysis, and assumptions that were made.

A. DATA SOURCES

Much of the detailed information and statistics regarding consumption of naval fuel is classified so, for purposes of this analysis, this thesis analyzes publicly available information.

1. DLA Fact Books

The primary source of data for this analysis was DLA Energy Fact Books, dating back to FY 2010. At the time of release of this paper, the most recent DLA Fact Book was from FY 2020.The financial results section of DLA Fact Books lists several types of statistics for the given fiscal year including petroleum purchases by category, net sales by category, product cost, purchases by category, and worldwide bulk fuel inventory. These statistics were used for the analysis with a focus on the JP-5 and Distillates/Diesel categories because these are the two primary categories of fuel used by the U.S. Navy's surface fleet. Additionally, JP-5 is only used by maritime aircraft. The data were extracted from the Fact Books and transferred into several tables and graphs used for analysis. At times, conversions were made for the unit of measurement in the statistics. For example, some statistics listed fuel in thousands of barrels while others were in millions of barrels. For continuity, the data used in this project were converted to millions of barrels and millions of U.S. dollars.

2. Shipbuilding Plan

A major source of data for the analysis was the 30-year shipbuilding plan. Several years of this document were used to extract specific ship allocations in the fleet in previous years, as well as the future. As seen in Table 2, the shipbuilding plan breaks down the current and future fleet allocation by type of ship. This type of breakdown was used to determine the number of ships in the fleet using diesel fuel compared to those using nuclear propulsion.

Table 4. Force Structure of the U.S. Navy 30-Year Ship Building Plan. Source: "Congressional Budget Office" (2021b), p. 2.

The Navy's Inventory Goals, 2016 to 2021

	Number of Platforms					
	2016 Force Structure Assessment	2020 Future Naval Forces Study	2022 Shipbuilding Plan	Today's Fleet	Difference Between Today's Fleet and 2022 Shipbuilding Plan	Memorandum: Change From Today's Fleet to 2022 Shipbuilding Plan (Percent)
Aircraft Carriers	12	8 to 11	9 to 11	11	-2 to 0	-18 to 0
Light Carriers	n.a.	0 to 6	n.a.	0	n.a.	n.a.
Submarines						
Ballistic missile	12	12	12	14	-2	-14
Attack, guided missile, and large payload	66[a]	72 to 78[a]	66 to 72[b]	54	12 to 18	22 to 33
Large Surface Combatants	104	73 to 88	63 to 65	92	-29 to -27	-32 to -29
Small Surface Combatants and Mine Countermeasures Ships[c]	52	60 to 67	40 to 45	31	9 to 14	29 to 45
Amphibious Warfare Ships						
LHDs and LHAs	38[d] (LHDs and LHAs; LPDs and LSDs)	9 to 10	8 to 9	9	-1 to 0	-11 to 0
LPDs and LSDs		52 to 57[e] (LPDs and LSDs; Small amphibious warfare ships)	16 to 19	22	-6 to -3	-27 to -14
Small amphibious warfare ships	0		24 to 35	0	24 to 35	n.a.
Subtotal, combat ships	284	286 to 329	238 to 268	233	5 to 35	2 to 15
Combat Logistics Ships	32	69 to 87	56 to 75	29	27 to 46	93 to 159
Support Ships	39	27 to 30	27 to 29	34	-7 to -5	-21 to -15
Subtotal, logistics and support ships	71	96 to 117	83 to 104	63	20 to 41	32 to 65
Total Manned Battle Force Ships	**355**	**382 to 446**	**321 to 372**	**296**	**25 to 76**	**8 to 26**
Unmanned Surface Vessels	n.a.	119 to 166	59 to 89	0	59 to 89	n.a.
Unmanned Undersea Vessels	n.a.	24 to 76	18 to 51	0	18 to 51	n.a.
Total Unmanned Vessels	**n.a.**	**143 to 242**	**77 to 140**	**0**	**77 to 140**	**n.a.**
Total Manned Battle Force Ships and Unmanned Vessels	**355**	**525 to 688**	**398 to 512**	**296**	**102 to 216**	**34 to 73**

3. Pricing Data

This analysis uses results from a fuels project completed in 2021 that identifies that the price of JP-5 has previously been unaffected by changes in consumption and purchases. Over the last decade, JP-5 consumption has decreased and the standard price from DLA has decreased to a point that it is within pennies on the dollar to the price of F-76 (Camarata et al., 2021). If the pricing of JP-5 reverses course and increases drastically in relation to pricing of F-76, it would negatively affect the consideration of the SFC, and assumptions made in this analysis.

B. APPROACH

The overall approach to the analysis of this project is broken down into primary methods below.

1. Inflation Adjustments

Some of the data used in this project include monetary values spread over the course of several years. In any case where comparisons were made between years, the numbers were adjusted for inflation by using the consumer price index, thereby bringing all currency values to CY 2020 numbers.

2. Consumption/Spending Trends

Historic consumption and spending trends related to fuel products were created using Microsoft Excel. Specifically, the data analysis package was utilized to conduct regression analysis for accurate correlation calculations between data categories. The results of the regression analysis were used to calculate predicted consumption amounts for the future. The future allocation of ships was then added to the results to predict the effect of an increase in size of the fleet to the consumption of fuel. Additionally, Microsoft Excel was used in the creation of tables and graphs.

3. Cost Savings

After analyzing the results of regression analysis, the authors used the results of the 2021 fuel pricing thesis by Camarata et al. to determine potential cost savings in the fleet. The cost figures and standard pricing numbers were used to calculate future costs based on the predictions made in this thesis for future fuel consumption. The calculations also factored in the increase in size of the fleet over the next decade based on the shipbuilding plan.

4. Phased Rollout Plan

This analysis considered that there are 296 surface ships in the U.S. Navy's fleet, with Congress' goal of increasing the size of the fleet to between 398 and 512 manned and unmanned ships (Congressional Budget Office, 2021b). When considering the implementation of an SFC, a phased roll out approach was used and factored in this increase in size of the fleet while also considering decommissioning of ships over time.

C. ASSUMPTIONS

In the development of this project, several assumptions were made to narrow the focus of the analysis and ensure accuracy in reporting. The assumptions are listed to assist the reader in understanding the scope of the project.

1. DOD Consumption

Given that DLA purchased increasing amounts of each fuel type year over year, it is assumed that the DOD consumed most of the purchased fuel on an annual basis as opposed to storing large amounts of fuel. This assumption is made because it is unknown if the DOD is purchasing and storing various fuel types solely for long-term wartime reserves.

2. DON F-76 Consumption

It is important to note that F-76 is used almost exclusively by the DON. The United States Marine Corp (USMC) exclusively uses JP-8 for ground vehicles and land-based aircraft (Kern et al., 2021). The United States Air Force (USAF) exclusively uses JP-8 for aviation operations (Speck, P. 2018). The United States Army (USA) like the USMC uses JP-8 for both battlefield vehicles and aviation fuel (Tegler, E. 2021). Since all other branches of the DOD use JP-8 the assumption is made that 100 percent of F-76 is being consumed by naval vessels. Although 100 percent was used for regression analysis there is a possibility that there might be a 10 percent difference since DLA Energy does not have a breakdown of F-76 like JP-5 and instead lists it as diesel/distillate. The small percent would be accounted for by the diesel/distillate being used for by other vehicles that use diesel other than naval vessels.

3. Future Fuel Purchases and Consumption

It is assumed that if the Navy moved forward with an SFC, it would need to produce enough JP-5 to cover the previous amount of F-76 being consumed. This assumption ensures that shifting to an SFC does not lead to a shortage in fuel required onboard ships; F-76 would be replaced by JP-5 on a 1:1 basis. Therefore, previous purchase and consumption numbers for F-76 were used to evaluate the future amount of production for JP-5 to maintain current operational tempo of the surface fleet.

4. Diesel/Distillate Fuel

It is important to note that DLA Fact Books report statistics for all DOD branches of service, not just DON. Additionally, one of the primary fuel categories used for this analysis is diesel/distillates. The statistics listed in Fact Books do not specify the type of diesel fuel. This analysis assumed that F-76 is the primary diesel/distillate fuel being measured by DLA. This major change in production of fuel will require years, so a rollout plan was developed to assess risk to force.

5. Burn Rate

In Jimenez et al., 2020 it was determined that there is a 3 percent efficiency difference between JP-5 and F-76. Efficiency is the conversion factor from the fuel source to power produced by the engine whereas burn rate is the factor of consumption of fuel source. There is no data suggesting that there is a burn rate (rate of consumption) difference between JP-5 and F-76. For purposes of this paper, an assumption was made that the burn rate (rate of consumption) of JP-5 will be comparable, with minimal differences, to that of F-76 in shipboard engines. Upon implementation of the SFC, further research would be required to determine the accuracy of this assumption.

6. Future Shipbuilding

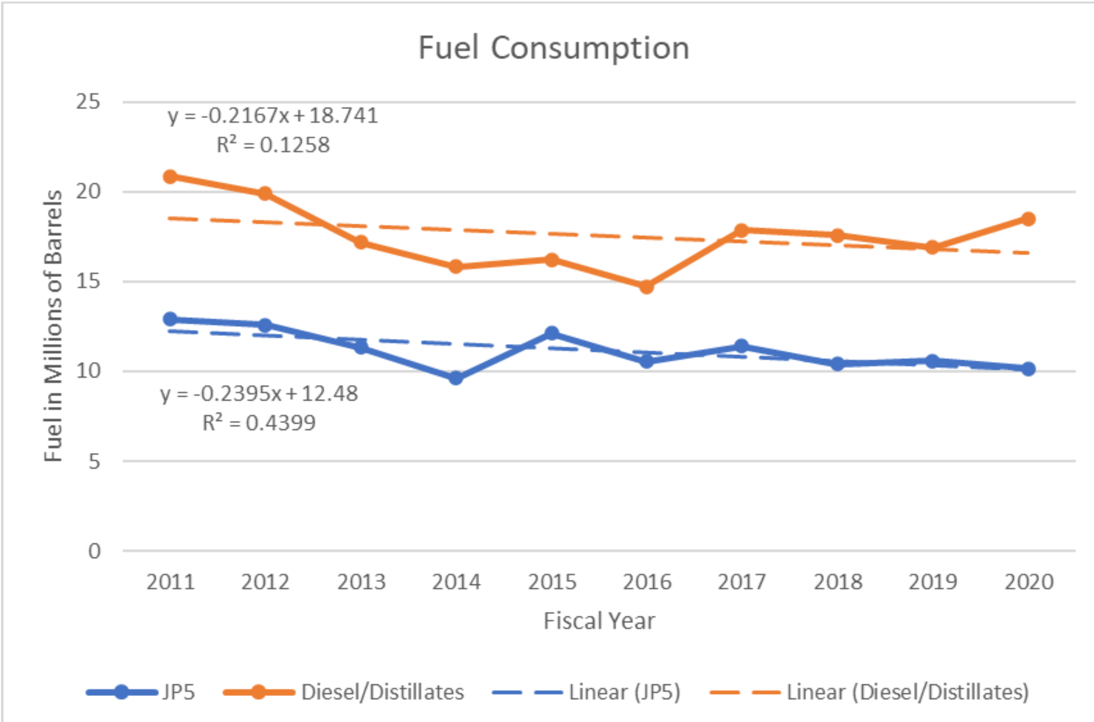
Although final shipbuilding plans for the U.S. Navy are not yet known, it is assumed that future classes of ships, including unmanned vessels, will be built with propulsion systems that are intended to consume F-76 and/or JP-5 rather than nuclear, steam, or other types of fuel. This allows the analysis to factor in these future classes of ships that are part of the 30-year shipbuilding plan. Table 4, displayed in the shipbuilding plan section, shows several categories of ships and the amount allocated to each category by year. These categories can be further broken down into classes of ships. For example, the Small Surface Combatant category includes current assets like Littoral Combat Ships (LCS) as well as future planned assets like Guided Missile Frigates (FFGs).

V. ANALYSIS

This chapter is an explanation of the analysis conducted based on the methodology discussed in Chapter IV. The analysis covers consumption data, regression analysis, future consumption predictions, transportation analysis, an SFC phased rollout plan, and a demonstration of cost savings.

A. CONSUMPTION DATA

The data collected from the 2010 to 2020 DLA fact books was extracted and transferred into tables to show the ending inventories and annual purchases of JP5 and diesel/distillate fuel for each fiscal year dating back to 2010. Purchase numbers were converted into millions of barrels of fuel to match the unit of measurement of ending inventories. These numbers were then used to convert into assumed consumption numbers for each fiscal year by taking year 1 ending inventory, adding year 2 purchases, and subtracting year 2 ending inventory. This results in an assumed consumption amount for the fiscal year and the term assumed is used simply because they are calculated numbers, not reported consumption by DLA. The calculations began with 2010 acting as year 1 and 2011 acting as year 2 in the calculation example above. This format was used for all subsequent years through 2020. The ending inventories and calculated consumption numbers for each fuel type were transferred into a chart for visual representation. Trend lines were superimposed on the consumption lines and linear equations were generated along with R-squared values, which represent the amount of the variation in fuel consumption (dependent variable), which is explained by the year value (independent variable) as seen in Figure 7.



Using DLA Energy data from 2010 to 2010.

Figure 7. Fuel Consumption of JP-5 and F-76 FY2010 to FY2020.

B. REGRESSION ANALYSIS

To identify the expected fuel consumption rates for F-76 and JP-5 over time, the following regression model was used

$$\text{Consumption}_t = \alpha + \beta \text{Year}_t + \varepsilon_t \qquad (1)$$

where *Consumption* $_t$ represents fuel consumption of either F-76 or JP-5 depending on which regression was run, $Year_t$ represents the variable *year*, and ε_t represents the error term. The regression analysis was run multiple times with slight variations in input and output. Separate regressions were run for Diesel/Distillate consumption and JP-5 consumption as related to time, with no other variable. These two regressions were repeated, but by adding the total number of ships per year as an additional variable. These ship numbers were input based on reported number of ships in each respective FY according to the 30-year shipbuilding plan.

1. Diesel Regressions

The results of the regression for diesel consumption as a function of time can be seen in Table 5. The regression analysis does not yield a statistically significant result (p = 0.31) for a statistical relationship between time and consumption of diesel fuel. Figure 8 provides a visual of the relationship between the actual consumption numbers compared to the predicted values of the regression. Figure 9 is a linear representation of the predicted diesel consumption from year 1 (2011) through year 20 (2031).

Table 5. Diesel Consumption as a Function of Time.

Diesel Consumption as a Function of Time								
Regression Statistics								
Multiple R	0.354709571							
R Square	0.12581888							
Adjusted R Square	0.01654624							
Standard Error	1.834369899							
Observations	10							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	1	3.874433482	3.874433	1.151422	0.314549945			
Residual	8	26.91930342	3.364913					
Total	9	30.7937369						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	18.741	1.253113203	14.95555	3.94E-07	15.85131577	21.630684	15.8513158	21.6306842
Year	-0.216709091	0.201957479	-1.07304	0.31455	-0.68242387	0.2490057	-0.68242387	0.24900569

Using DLA Energy data from 2010 to 2010.

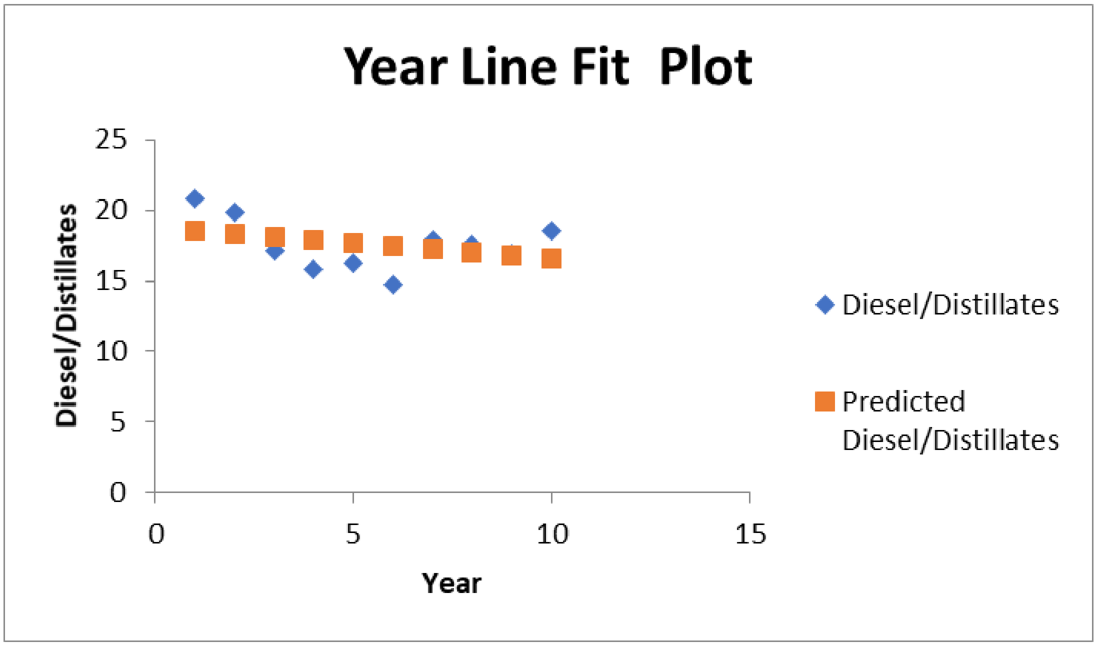


Figure 8. Consumption of Diesel/Distillates vs. Predicted Consumption.

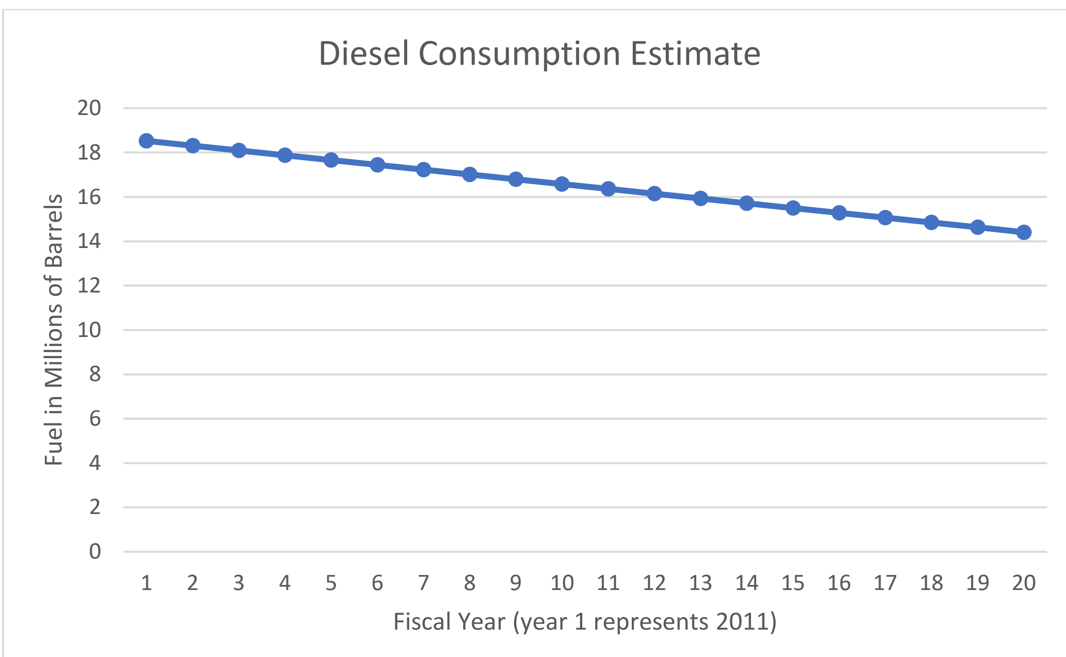


Figure 9. Diesel Consumption Estimate.

When the number of ships in the fleet are added to the regression analysis by year, there is an improvement in the statistical significance of the relationship between the data. While not recognized as a high level of statistical significance, there is a more significant relationship between diesel fuel consumption over time when the total number of ships is added, and this model will be used for the prediction of consumption for F-76. The results in Table 6 show that for every addition of one ship, fuel consumption increases by 0.1328 million of barrels of fuel per year with a p-value of 0.1178.

Table 6. Diesel Consumption as a Function of Time and Total Ships.

Diesel Consumption as a Function of Time and Total Ships								
Regression Statistics								
Multiple R	0.6315559							
R Square	0.3988628							
Adjusted R Square	0.2271093							
Standard Error	1.6261814							
Observations	10							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	2	12.2824762	6.141238	2.322298	0.168425408			
Residual	7	18.5112607	2.644466					
Total	9	30.7937369						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-18.53499	20.93452007	-0.88538	0.405338	-68.03726121	30.96728652	-68.03726121	30.96728652
Year	-0.295573	0.184418711	-1.60273	0.153029	-0.731653775	0.140508136	-0.731653775	0.140508136
Total Ships	0.1327808	0.074465772	1.783111	0.117758	-0.043302804	0.308864338	-0.043302804	0.308864338

Using data from DLA Energy (2010 – 2020), Congressional Budget Office Shipbuilding Plan (2016, 2017, 2019, 2020, 2022), Naval History and Heritage (2017), and Congressional Research Service (2018).

2. JP-5 Regressions

The results of the regression for JP-5 consumption as a function of time can be seen in Table 7. The regression analysis yields a statistically significant result at the standard 5% level ($p = 0.0365$) for a relationship between time and consumption of JP-5 which makes these figures a good predictor for future consumption of JP-5. Figure 10 provides a visual of the relationship between the actual consumption numbers compared to the predicted values of the regression. Figure 11 is a linear representation of the predicted JP-5 consumption from year 1 (2011) through year 20 (2031).

Table 7. JP-5 Consumption as a Function of Time.

JP-5 Consumption as a Function of Time								
Regression Statistics								
Multiple R	0.6632679							
R Square	0.4399243							
Adjusted R Square	0.3699149							
Standard Error	0.8677056							
Observations	10							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	1	4.731142936	4.731143	6.283784	0.03655568			
Residual	8	6.023303964	0.752913					
Total	9	10.7544469						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	12.48	0.592755766	21.0542	2.72E-08	11.11310275	13.84689725	11.11310275	13.84689725
Year	-0.2394727	0.095531242	-2.50675	0.036556	-0.459768166	-0.019177289	-0.45976817	-0.01917729

Using DLA Energy data from 2010 to 2010.

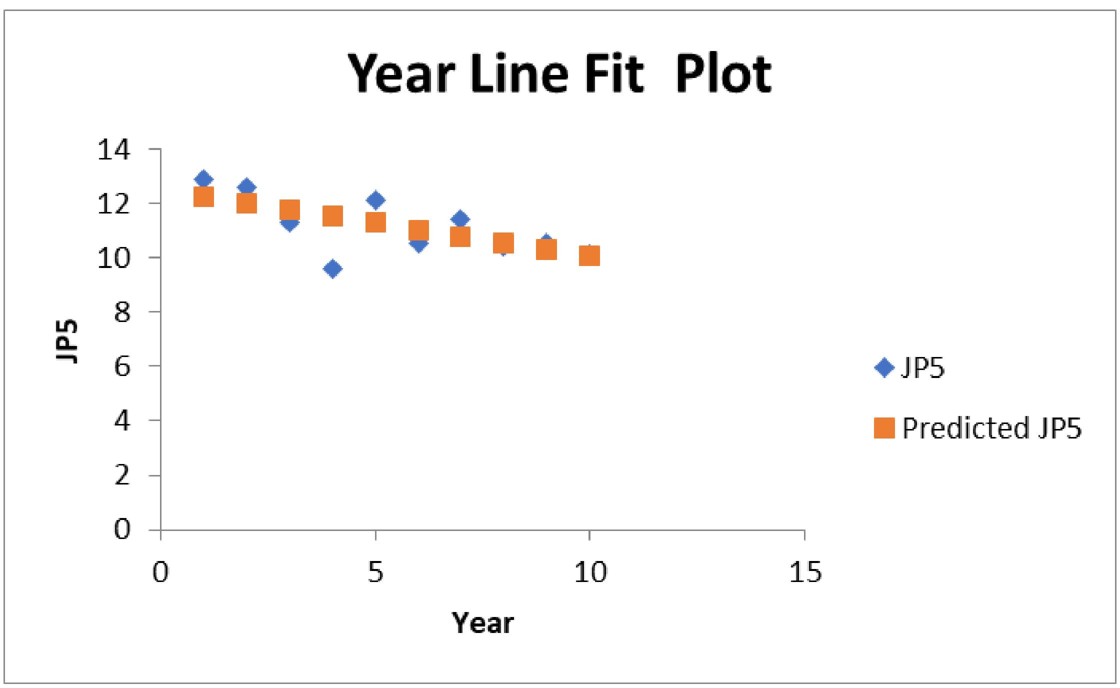


Figure 10. Consumption of JP-5 vs. Predicted Consumption.

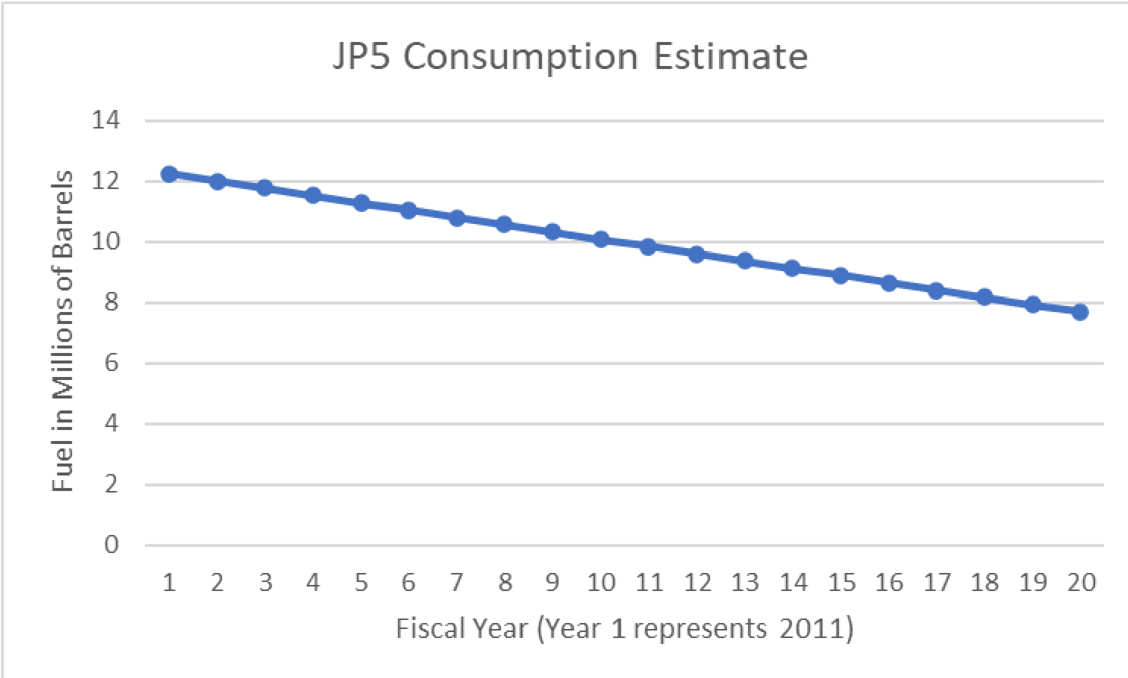


Figure 11. JP-5 Consumption Estimate for 2011 to 2031.

When the number of ships in the fleet are added to the regression analysis by year (see Table 8), there is a large decrease in the statistical significance of the *Year* variable in the results, and the *Total Ships* variable is not at all significant, ($p = 0.5465$). This result indicates that consumption of JP-5 is not related directly to the number of ships in the fleet; rather, the number of maritime aircraft would be expected to be a better predictor of JP-5 consumption. Maritime aircraft are not permanently assigned to ships, instead they belong to an aircraft squadron or air wing that will rotate deployments on various ships. Aircraft Carriers (CVN), as the name suggests, carry significantly more aircraft than most other ships. In general, a CVN carries between seventy and ninety aircraft while the Navy's small and large surface combatants typically carry only two aircraft on deployments. This may help explain the insignificant relationship between number of ships and consumption of JP-5 as found in the regression analysis. Further research would be required to determine the relationship between number of aircraft and current JP-5 consumption. Another possibility is that including the number of ships in the regressions introduces a multicollinearity concern between the variables *Year* and *Total Ships* and may be leading to inconsistency in the results. Due to these possibilities, the regression for JP-5 consumption as a function of time will be used to predict future JP-5 consumption.

Table 8. JP-5 Consumption as a Function of Time and Total Ships

JP-5 Consumption as a Function of Time and Total Ships								
Regression Statistics								
Multiple R	0.6857816							
R Square	0.4702964							
Adjusted R Square	0.3189526							
Standard Error	0.9021141							
Observations	10							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	2	5.057778009	2.528889	3.107469	0.108172071			
Residual	7	5.696668891	0.81381					
Total	9	10.7544469						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	19.827052	11.6132961	1.707272	0.131531	-7.634029686	47.28813352	-7.634029686	47.28813352
Year	-0.223929	0.102305144	-2.18883	0.06479	-0.465842007	0.017984443	-0.465842007	0.017984443
Total Ships	-0.026171	0.041309429	-0.63353	0.546519	-0.123852205	0.071510348	-0.123852205	0.071510348

Using data from DLA Energy (2010 – 2020), Congressional Budget Office Shipbuilding Plan (2016, 2017, 2019, 2020, 2022), Naval History and Heritage (2017), and Congressional Research Service (2018).

The output from these regression analyses were used to predict future consumption of both F-76 and JP-5. The consumption predictions for diesel/distillate can then be used to determine the amount of fuel that will need to be replaced by JP-5 for the SFC. These numbers can then be added to the predicted consumption values of JP-5 to have a total value for future needs of JP-5 production for the fleet. These calculations are covered in detail in the Consumption Predictions section.

C. TRANSPORTATION EXPENSES

Regression analysis was also performed for transportation expenses as reported by DLA. Figure 12 provides a visual representation of the transportation expenses reported per fiscal year as extracted from DLA Fact Books. The regression analyses performed provided no statistically significant relationship for transportation expense as a function of time or number of ships for either JP-5 or F-76. This is likely due to the expense reflecting

DLA's costs incurred from refinery to DLA facilities prior to sale to the end consumer, rather than the added cost that would be incurred by moving the fuel product from storage to the end user (ship).

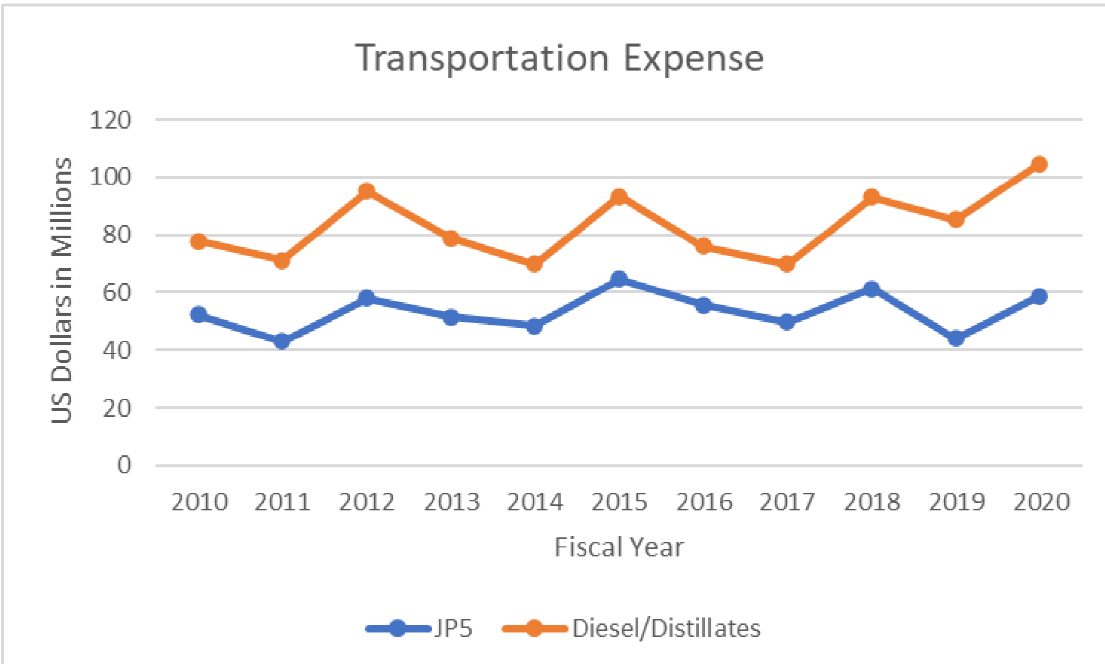


Figure 12. Transportation Expense by Fiscal Year.

D. CONSUMPTION PREDICTIONS

The regression analysis results were used to predict future consumption of diesel and JP-5. The figures and tables used to make consumption predictions were based on the regression analysis that yielded the highest level of significance. For diesel consumption, the regression analysis that included both year and number of ships was used. The coefficient values for intercept, year, and total ships from Table 6 were used as the measures of prediction in Equation 2.

$$\text{Consumption}_{\text{Diesel}} = -18.53499 + (-0.295573 \times \text{Year}) + (0.1327808 \times \#\text{ of Ships}) \quad (2)$$

where *Year* represents the fiscal year (year 1 represents 2011, year 20 represents year 2030) and *Number of Ships* represents the number of ships in the fleet in the given fiscal year.

The values for *Number of Ships* were derived from the 30 Year Shipbuilding Plan, which lists a range of ships to be produced over the next 30 years. The difference between the current allocation of ships and the low-end range from the 30-year shipbuilding plan was calculated, and then was divided by 30 to determine the number of ships per year increase at the low end. This was also done for the high-end of the range. To clarify, the 30-year shipbuilding plan lists the total number of ships in 30 years as a range of 398 to 512. On the low-end, this is an increase of 102 ships from today's 296, or an average annual increase of 3.4 ships added to the fleet per year. The same calculation was done for the high-end with an increase of 216 ships from today's 296, resulting in an average annual increase of 7.2 ships added to the fleet per year. These per year increase numbers were used to project the number of ships in the fleet for year 2021 to 2030, as seen in Table 9.

The results of the analysis for the next ten years of diesel consumption are shown in Table 9 and Figure 13. In Table 9, years 1 through 10 represent years 2011 through 2020 with the corresponding number of ships for each historical year in the left two columns. The consumption output for these years represents what the model predicted would have been the consumption. Years 11 through 20 represent future consumption broken down into low and high predictions based on the corresponding low and high number of ships expected in each year. The consumption numbers listed in the table and chart are in millions of barrels.

Table 9. 10-Year Diesel Consumption Prediction.

10 Year Diesel Consumption Prediction				
# Ships Low	# Ships High	Year	Consumption Low	Consumption High
284	284	1	18.87917769	18.87917769
287	287	2	18.98194717	18.98194717
285	285	3	18.42081282	18.42081282
289	289	4	18.65636306	18.65636306
273	273	5	16.23629797	16.23629797
272	272	6	15.80794439	15.80794439
279	279	7	16.44183694	16.44183694
285	285	8	16.94294872	16.94294872
290	290	9	17.31127974	17.31127974
296	296	10	17.81239152	17.81239152
299.4	303.2	11	17.96827331	18.47284022
302.8	310.4	12	18.1241551	19.13328893
306.2	317.6	13	18.28003688	19.79373763
309.6	324.8	14	18.43591867	20.45418633
313	332	15	18.59180046	21.11463504
316.4	339.2	16	18.74768225	21.77508374
319.8	346.4	17	18.90356404	22.43553244
323.2	353.6	18	19.05944583	23.09598115
326.6	360.8	19	19.21532762	23.75642985
330	368	20	19.37120941	24.41687856

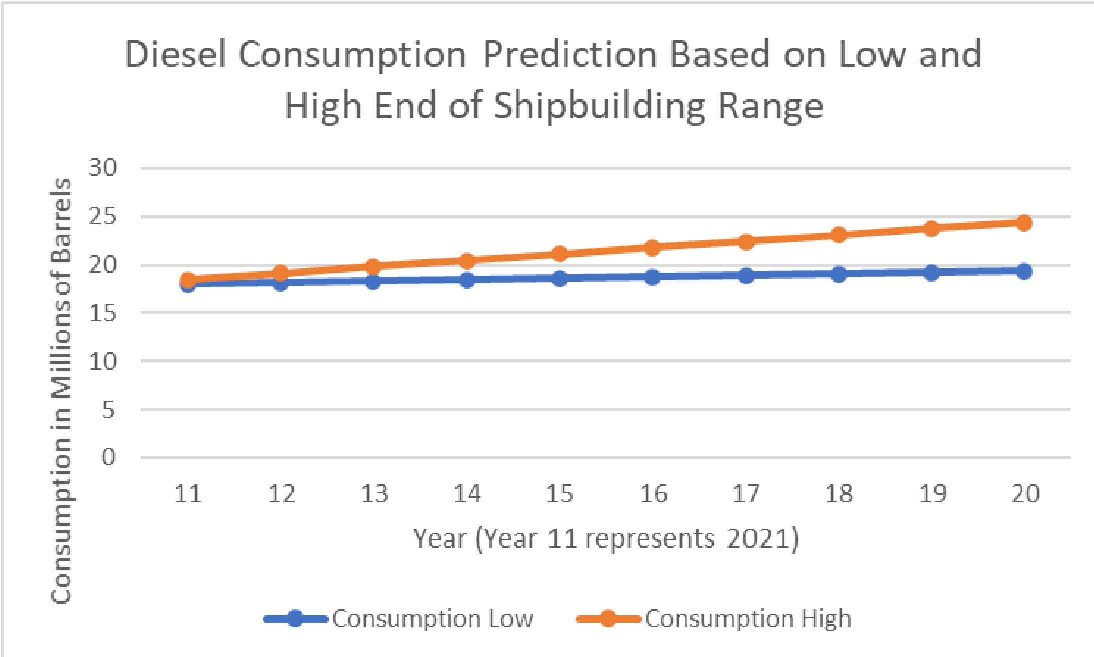


Figure 13. Diesel Consumption Based on Shipbuilding Range

For JP-5 consumption, the regression analysis that included consumption as a function of time was used because the other JP-5 regression analysis showed that there was no significant relationship between JP-5 consumption to the number of ships. The coefficient values for intercept and year from Table 7 were used as the measures of prediction in Equation 3.

$$\text{Consumption}_{\text{JP-5}} = 12.48 + (-0.2394727 \text{ x Year}) \quad (3)$$

in Equation 3 *Year* represents the fiscal year (year 1 represents 2011, year 20 represents year 2030). The predicted consumption output of JP-5 for the next 10 years is shown in Table 10. These values were added to the predicted consumption values from Table 9 to determine the total amount of JP-5 that would need to be produced to keep up with demand for fuel under the SFC. Table 11 shows high end and low-end values for fuel based on the low- and high-end numbers of ships that will be produced over the next 10 years. Additionally, Table 11 shows the percentage increase in JP-5 production necessary based on using the 2020 JP-5 purchase amount of 10.133 million barrels as a base year.

Table 10. 10-Year JP-5 Consumption Prediction.

Year	Consumption
1	12.24052727
2	12.00105455
3	11.76158182
4	11.52210909
5	11.28263636
6	11.04316364
7	10.80369091
8	10.56421818
9	10.32474545
10	10.08527273
11	9.8458
12	9.606327273
13	9.366854545
14	9.127381818
15	8.887909091
16	8.648436364
17	8.408963636
18	8.169490909
19	7.930018182
20	7.690545455

Table 11. Total JP-5 Production Required for SFC.

Total JP-5 Production Needed for SFC				
Year	**Consumption Low**	**Consumption High**	**% Increase Low**	**% Increase High**
11	27.81407331	28.31864022	274.49%	279.47%
12	27.73048237	28.7396162	273.67%	283.62%
13	27.64689143	29.16059218	272.84%	287.78%
14	27.56330049	29.58156815	272.02%	291.93%
15	27.47970955	30.00254413	271.19%	296.09%
16	27.39611862	30.4235201	270.37%	300.24%
17	27.31252768	30.84449608	269.54%	304.40%
18	27.22893674	31.26547206	268.72%	308.55%
19	27.1453458	31.68644803	267.89%	312.71%
20	27.06175486	32.10742401	267.07%	316.86%

E. COST SAVINGS

If the purchase and sales prices of JP-5 remain the same for DLA upon implementation of the SFC, there is potential for substantial savings for the government. Table 12 from the 2021 thesis written by Camarata et al., lists the purchase costs and standard sales prices for JP-5 and F-76. These prices are listed per gallon and, according to DLA, 42 gallons is equal to 1 barrel of fuel (2020 DLA Factbook, pg. 20). The cost and sales price figures were used to calculate potential savings from a shift to the SFC. Figures for year 11 through 20 for predicted JP-5 and F-76 were used to calculate the estimated purchase costs and sales costs for fuel under the current two-fuel concept. Then the predicted consumption figures for an SFC were used to predict the total fuel cost of JP-5 for years 11 through 20 as a single fuel in the fleet. As will be discussed in the next section, it is unlikely to make a complete switch to the SFC in an immediate timeframe, but for purposes of this analysis, the cost savings calculations were run as if a complete shift happened on day one.

Table 12. Data Characteristics for JP-5 and Diesel Bulk Fuel Data from FY2009 to FY2020. Source: Camarata et al. (2021), p. 10.

Table 1: Data Characteristics for JP5 and Diesel Bulk Fuel Data from FY2009 through FY2020

Prices per Gallon	Diesel	σ	JP5	σ	p-value
Purchase Cost*	$2.548	$0.738	$2.519	$0.749	<0.001
Standard Sales Price*	$3.321	$0.612	$3.310	$0.571	<0.001
Transportation Cost	$0.123	$0.016	$0.123	$0.016	<0.001
Average Volumes (Millions of Barrels per Year)	**Diesel**	**σ**	**JP5**	**σ**	**p-value**
Purchased Volume	17.8558	2.0490	11.4778	1.2003	0.019
Net Sales Volume	18.7125	1.5932	10.1023	0.6900	<0.001
Bulk Ending Inventory	0.0096	0.0010	0.0149	0.0005	0.636

*Partial correlation coefficient determined controlling for the price of crude oil over the same period

**All prices adjusted for inflation using CPI-U correction factor to Jan CY20 Dollars

***Volumes are Millions of Barrels

The cost savings for each scenario (low end vs. high end of 30-year shipbuilding plan) can be seen in Tables 13 through 16. Tables 13 and 14 show tables for DLA purchase costs, which are costs incurred to buy the fuel from the refinery. Tables 15 and 16 show the breakdown of DLA sales price and corresponding cost to the end user, the U.S. Navy.

The far-right column of each table, titled 'difference', represents the savings possible per year and in total for 10 years of switching to the SFC compared to the current system. Based on these calculations, DLA can procure JP-5 as a single fuel for $227M to $262M less over the next decade. Additionally, the USN would subsequently save between $86M and $99M over the next decade by switching to JP-5 as a single fuel.

Table 13. DLA Purchase Costs Current System vs. SFC (Low Ship #).

DLA Purchase Costs: Current System vs. SFC (Low Ship #)					
Year	**Purchase Cost F-76**	**Purchase Cost JP-5**	**Total Purchase Cost**	**SFC Purchase Cost**	**Difference**
11	$ 1,922,892,736.25	$ 1,041,665,948.40	$ 2,964,558,684.65	$ 2,942,673,327.76	$ 21,885,356.89
12	$ 1,939,574,581.76	$ 1,016,330,212.80	$ 2,955,904,794.56	$ 2,933,829,573.65	$ 22,075,220.91
13	$ 1,956,256,427.28	$ 990,994,477.20	$ 2,947,250,904.48	$ 2,924,985,819.55	$ 22,265,084.93
14	$ 1,972,938,272.79	$ 965,658,741.60	$ 2,938,597,014.39	$ 2,916,142,065.45	$ 22,454,948.94
15	$ 1,989,620,118.30	$ 940,323,006.00	$ 2,929,943,124.30	$ 2,907,298,311.34	$ 22,644,812.96
16	$ 2,006,301,963.82	$ 914,987,270.40	$ 2,921,289,234.22	$ 2,898,454,557.24	$ 22,834,676.98
17	$ 2,022,983,809.33	$ 889,651,534.80	$ 2,912,635,344.13	$ 2,889,610,803.13	$ 23,024,541.00
18	$ 2,039,665,654.85	$ 864,315,799.20	$ 2,903,981,454.05	$ 2,880,767,049.03	$ 23,214,405.02
19	$ 2,056,347,500.36	$ 838,980,063.60	$ 2,895,327,563.96	$ 2,871,923,294.92	$ 23,404,269.04
20	$ 2,073,029,345.88	$ 813,644,328.00	$ 2,886,673,673.88	$ 2,863,079,540.82	$ 23,594,133.06
Total	$ 19,979,610,410.61	$ 9,276,551,382.00	$ 29,256,161,792.61	$ 29,028,764,342.88	**$ 227,397,449.73**

Table 14. DLA Purchase Costs Current System vs. SFC (High Ship #).

DLA Purchase Costs: Current System vs. SFC (High Ship #)					
Year	**Purchase Cost F-76**	**Purchase Cost JP-5**	**Total Purchase Cost**	**SFC Purchase Cost**	**Difference**
11	$ 1,976,889,469.21	$ 1,041,665,948.40	$ 3,018,555,417.61	$ 2,996,055,498.22	$ 22,499,919.39
12	$ 2,047,568,047.69	$ 1,016,330,212.80	$ 3,063,898,260.49	$ 3,040,593,914.58	$ 23,304,345.91
13	$ 2,118,246,626.17	$ 990,994,477.20	$ 3,109,241,103.37	$ 3,085,132,330.94	$ 24,108,772.43
14	$ 2,188,925,204.65	$ 965,658,741.60	$ 3,154,583,946.25	$ 3,129,670,747.30	$ 24,913,198.95
15	$ 2,259,603,783.13	$ 940,323,006.00	$ 3,199,926,789.13	$ 3,174,209,163.66	$ 25,717,625.48
16	$ 2,330,282,361.61	$ 914,987,270.40	$ 3,245,269,632.01	$ 3,218,747,580.01	$ 26,522,052.00
17	$ 2,400,960,940.09	$ 889,651,534.80	$ 3,290,612,474.89	$ 3,263,285,996.37	$ 27,326,478.52
18	$ 2,471,639,518.57	$ 864,315,799.20	$ 3,335,955,317.77	$ 3,307,824,412.73	$ 28,130,905.04
19	$ 2,542,318,097.05	$ 838,980,063.60	$ 3,381,298,160.65	$ 3,352,362,829.09	$ 28,935,331.56
20	$ 2,612,996,675.53	$ 813,644,328.00	$ 3,426,641,003.53	$ 3,396,901,245.45	$ 29,739,758.08
Total	$ 22,949,430,723.71	$ 9,276,551,382.00	$ 32,225,982,105.71	$ 31,964,783,718.35	**$ 261,198,387.36**

Table 15. End User Cost (Low Ship #).

End User Cost (DLA Sales Price): Current System vs. SFC (Low Ship #)					
Year	Purchase Cost F-76	Purchase Cost JP-5	Total Purchase Cost	SFC Purchase Cost	Difference
11	$ 2,506,250,697.44	$ 1,368,763,116.00	$ 3,875,013,813.44	$ 3,866,712,471.17	$ 8,301,342.27
12	$ 2,527,993,401.11	$ 1,335,471,617.45	$ 3,863,465,018.57	$ 3,855,091,658.91	$ 8,373,359.65
13	$ 2,549,736,104.78	$ 1,302,180,118.91	$ 3,851,916,223.69	$ 3,843,470,846.65	$ 8,445,377.04
14	$ 2,571,478,808.45	$ 1,268,888,620.36	$ 3,840,367,428.82	$ 3,831,850,034.39	$ 8,517,394.43
15	$ 2,593,221,512.12	$ 1,235,597,121.82	$ 3,828,818,633.94	$ 3,820,229,222.13	$ 8,589,411.81
16	$ 2,614,964,215.79	$ 1,202,305,623.27	$ 3,817,269,839.07	$ 3,808,608,409.87	$ 8,661,429.20
17	$ 2,636,706,919.46	$ 1,169,014,124.73	$ 3,805,721,044.19	$ 3,796,987,597.60	$ 8,733,446.59
18	$ 2,658,449,623.13	$ 1,135,722,626.18	$ 3,794,172,249.32	$ 3,785,366,785.34	$ 8,805,463.97
19	$ 2,680,192,326.80	$ 1,102,431,127.64	$ 3,782,623,454.44	$ 3,773,745,973.08	$ 8,877,481.36
20	$ 2,701,935,030.48	$ 1,069,139,629.09	$ 3,771,074,659.57	$ 3,762,125,160.82	$ 8,949,498.75
Total	$ 26,040,928,639.58	$ 12,189,513,725.45	$ 38,230,442,365.03	$ 38,144,188,159.96	**$ 86,254,205.07**

Table 16. End User Cost (High Ship #).

End User Cost (DLA Sales Price): Current System vs. SFC (High Ship #)					
Year	Purchase Cost F-76	Purchase Cost JP-5	Total Purchase Cost	SFC Purchase Cost	Difference
11	$ 2,576,628,699.86	$ 1,368,763,116.00	$ 3,945,391,815.86	$ 3,936,857,363.68	$ 8,534,452.18
12	$ 2,668,749,405.96	$ 1,335,471,617.45	$ 4,004,221,023.41	$ 3,995,381,443.93	$ 8,839,579.48
13	$ 2,760,870,112.06	$ 1,302,180,118.91	$ 4,063,050,230.96	$ 4,053,905,524.18	$ 9,144,706.78
14	$ 2,852,990,818.15	$ 1,268,888,620.36	$ 4,121,879,438.51	$ 4,112,429,604.43	$ 9,449,834.09
15	$ 2,945,111,524.25	$ 1,235,597,121.82	$ 4,180,708,646.06	$ 4,170,953,684.68	$ 9,754,961.39
16	$ 3,037,232,230.34	$ 1,202,305,623.27	$ 4,239,537,853.61	$ 4,229,477,764.93	$ 10,060,088.69
17	$ 3,129,352,936.44	$ 1,169,014,124.73	$ 4,298,367,061.16	$ 4,288,001,845.17	$ 10,365,215.99
18	$ 3,221,473,642.53	$ 1,135,722,626.18	$ 4,357,196,268.71	$ 4,346,525,925.42	$ 10,670,343.29
19	$ 3,313,594,348.63	$ 1,102,431,127.64	$ 4,416,025,476.26	$ 4,405,050,005.67	$ 10,975,470.59
20	$ 3,405,715,054.72	$ 1,069,139,629.09	$ 4,474,854,683.81	$ 4,463,574,085.92	$ 11,280,597.89
Total	$ 29,911,718,772.94	$ 12,189,513,725.45	$ 42,101,232,498.39	$ 42,002,157,248.01	**$ 99,075,250.38**

F. ROLLOUT PLAN

Based on the significant increase in the amount of JP-5 that would be necessary to implement the SFC, we recommend a phased rollout. This will allow time for adjustments to the supply system as well as allow time to assess unforeseen effects of an SFC on ships. The rollout plan consists of 3 phases held over the course of the next several years in an effort to conduct analysis, allow government-used refineries time to shift production to JP-5, and mitigate risks associated with unforeseen damages possible to ships after the switch to JP-5.

Phase 1. DOD works with DLA Energy and commercial refineries to determine the timeline necessary to shift production to JP-5. Immediately begin the shift of one quarter of the F-76 refinery capacity to produce JP-5. DON begins using F-76 reserve fuel as needed for ships in CONUS and use other diesel/distillate fuel available in foreign AORs as needed.

Phase 2. DOD identifies any factors that may prevent MSC from shifting to an SFC to provide the fleet support. This phase should include fuel tank reconfiguration in at least one oil tanker in 5th, 6th, and 7th fleet areas of operations, while beginning the reconfiguration of fuel tanks for any tanker currently in a major maintenance availability.

Phase 3. Introduce the SFC to a limited number of DDGs and CGs across the fleet for two full years. This timeframe was selected based on a typical ship cycle between maintenance yard periods being about two years. We suggest implementing the SFC on all CGs and the aging DDGs to mitigate risk of unknown damages to equipment or maintenance requirements from introduction. Specifically, it would be beneficial to implement the plan on ships set to decommission within 10 years. Upon implementation, all these ships should be closely monitored for increases in maintenance costs, reports of engine breakdown, changes in fuel consumption, and changes to corrosion or filth levels inside ship storage tanks. These figures should be compiled and analyzed in depth at the end of two years of implementation when the ships enter their scheduled maintenance availabilities. By the end of this phase, at least half of the oil tankers in operation should be reconfigured to support JP-5 as a single fuel, with all remaining tankers reconfiguring during their next major maintenance availability.

Phase 4. Introduce the SFC to all remaining DDGs. Also implement the SFC on all other diesel-operated ships commissioned in the fleet to include: DDGs, CGs, LHDs, LHAs, LPDs, LSDs, LCS, and all logistics support ships. Monitor these ships for negative effects for two years following implementation and examined thoroughly upon scheduled maintenance periods.

Phase 5. If there are still limited negative effects and cost impacts to the fleet from the introduction of SFC, introduce full-scale production and implementation of the SFC across the entire fleet, including all new ships being commissioned. This phase would begin at the start of year five, after analysis has been conducted on the ships operating on JP-5 from the previous phases. We would recommend keeping reserves in place during the previous phases of the rollout to SFC until ultimately replacing these reserves with JP-5.

Distillate fuels similar to F-76 are readily available across the world and used by other militaries as well as merchant ships. The U.S. could use these other replacement fuels as an emergency source of fuel if JP-5 as a single fuel is disrupted in the future. However, the most important fuel to protect for future operations is JP-5 given that it is the sole fuel used in our maritime aircraft.

VI. CONCLUSION AND RECOMMENDATIONS

This chapter concludes the paper and provides recommendations for follow-on research into the SFC to further develop the need for a shift in the Navy's fuel supply.

A. CONCLUSION

This paper takes a historical look at consumption and pricing trends to determine future fuel consumption in the Navy. The analysis conducted shows the trends of the Navy's maritime fuel consumption and the impacts associated with increasing the size of the fleet over the next ten years in accordance with the 30-Year Shipbuilding Plan. The shift to an SFC would lead to an increase of over three times the current refinery production of JP-5 for the fleet. This will take time to implement, so the phased rollout plan provides a basic framework for the Navy to begin the SFC while considering risks to the fleet. Furthermore, the analysis demonstrates that based on current cost and pricing figures for F-76 and JP-5, there is room for substantial savings for DOD by shifting to the SFC. With this analysis in mind, the Navy should begin making the transition to an SFC by beginning the phased rollout of JP-5 to existing fleet assets. Shifting to the SFC over time will allow the supply chain time to adjust to the new demands put on refineries. In the event of an interruption of JP-5 supply in the future, the shift to an SFC opens doors for deeper supply banks of the Navy's fuel for both ships and maritime aircraft. The Navy can always shift ships back to F-76 or use other commonly available distillate fuels around the world, but the Navy cannot quickly replace the need for JP-5 for maritime aircraft; further justifying the need to expand the production and availability of JP-5 in the Navy.

B. RECOMMENDATIONS FOR FURTHER RESEARCH

Although there have been multiple research papers written on the SFC, there is still more analysis to be conducted to prove that an SFC would benefit the Navy. The authors recommend the following topics for amplifying research:

1. We recommend conducting research into the need to increase the size of the U.S. Navy's refueling fleet to support the increase in size of the fleet.

The 30-year shipbuilding plan lists a small increase in fleet logistics ships, but it might not be enough to support the increased fleet size in a contested environment. Additionally, we recommend adjusting the analysis to demonstrate the improved efficiency that is possible by utilizing the SFC on tankers.

2. To fully implement the SFC, the costs associated with the transition to SFC should be examined. These costs include things such as tank cleanouts onboard ships, reconfiguration of piping systems and storage tanks, changes to distribution of fuel onboard MSC ships, and aspects of the transition that cannot be easily monetized such as unforeseen maintenance from long-term use of JP-5 on equipment previously run-on F-76.

3. Fuel blending is an area of research that might help increase availability of JP-5 without completely ceasing F-76 production. Research should be conducted on both the feasibility and cost impacts of doing some ratio of a fuel blend. This would provide the Navy with an alternate to the current fuel set up or the SFC.

4. Refineries will have to significantly increase JP-5 production to keep up with the demand from implementing an SFC. Therefore, research should be conducted into the feasibility, timeline, and costs associated with commercial refineries making the switch from diesel fuel to JP-5, as well as how these factors would affect the timeline for implementing an SFC. Additionally, any risks involved in this change to the supply chain should be examined.

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