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Manpower systems integration factors for frigate design in the Turkish Navy

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NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

MANPOWER SYSTEMS INTEGRATION FACTORS FOR FRIGATE DESIGN IN THE TURKISH NAVY

by

Ismail Kilicaslan

December 2016

Thesis Advisor:	William Hatch
Thesis Co-Advisor:	Chad Seagren

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MANPOWER SYSTEMS INTEGRATION FACTORS FOR FRIGATE DESIGN IN THE TURKISH NAVY

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LIST OF ACRONYMS AND ABBREVIATIONS

CIS	Combat information system
CIWS	Close-in weapon system
CODAD	Combined diesel and diesel
CODAG	Combined diesel and gas turbine
CODOG	Combined diesel or gas turbine
FFGH	Frigate
HFE	Human factors engineering
HSI	Human Systems Integration
IHS	Information Handling Services
LCS	Littoral combat ship
MSA	Manpower systems analysis
NPS	Naval Postgraduate School
OLS	Ordinary least squares
OME	Optimal manning experiment
PCA	Principal Component Analysis
POE	Projected operational environment
ROC	Required operational capabilities
SAM	Surface-to-air missile
SHP	Ship horsepower
SMD	Ship manpower document
SSM	Surface-to-surface missile
SUW	Surface warfare
TF-2000	Turkish Frigate–2000
VDS	Variable depth sonar

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I. INTRODUCTION

The world's navies build or acquire frigates in support of their nations' maritime interests. Frigates are slightly larger than the off-shore patrol vessels and littoral combat ships (LCS), and smaller than the cruisers and destroyers. The intermediate size of frigates makes them appealing for many navies and suggests why frigates have such a wide usage by many nations. Frigates can be used not only in coastal littoral waters but also in the seas and oceans. The operational capabilities of navigating either independently or serving as part of a maritime task group paved the way for frigates' extensive usage. Although frigates took their unique place in many nations' navies with varying numbers, based on their threat definitions and economic powers, manning these vessels varies broadly by the number of navies using them. The key question in understanding the difference in manning of the same-type of naval vessels primarily lies at the intersection of manpower requirements and ship design capabilities. The general interest area of this thesis is to scrutinize the nexus of frigate design capabilities and manpower requirements onboard a frigate.

Frigates are considered as highly capable warships in terms of conducting the three main types of naval warfare: Surface warfare, anti-air warfare, and anti-submarine warfare. Besides, frigates, with some modifications, can even be used in mine warfare, maritime interdiction operations, or for special operations, serving as a platform for Navy Seals or unmanned vehicles. Determining the parameters of required operational capabilities (ROC) in the projected operational environment (POE) is a key stage in the design of a frigate (FFGH). Frigates with both surface-to-surface and surface-to-air guided missiles and helicopter platforms are the main focus of warships examined in this study. Analyzing the correlation between manpower requirements and design features requires a multi-disciplinary study using qualitative and quantitative techniques from various fields such as Manpower Systems Analysis (MSA), Systems Engineering, and Operations Research. Taking Human Systems Integration (HSI) domains into account is also a crucial element of the thoroughness of this research.

A. MOTIVATION

The correlation between frigate design characteristics and manpower requirements is a key consideration both in shipbuilding and the assignment of an optimal number of personnel to a warship in general, and to the frigate, in particular. Frigates are currently the primary platforms in the Turkish Navy and the warships on which I worked for four years at the beginning of my career. A new class of frigate, namely Turkish Frigate-2000 (TF-2000), is planned to be built in the near future. As a naval officer studying in the MSA program at the Naval Postgraduate School (NPS), I have chosen to undertake an in-depth analysis of the aforementioned correlation that may lead to sound managerial decisions in the development of the TF-2000 project. Examining a comprehensive list of frigates from major players in the international area and fitting a model to find the optimal number of crew complement based on the qualitative and quantitative analyses present a tough but worthwhile challenge. Many qualifications of the projected frigate still need to be determined, but studying other navies' frigates and at least having a range for the crew complement based on differing combat systems and international navies' own original approaches to manage the trade-offs in the HSI domains offers a broad perspective in the field of manpower systems analysis. The intent of this study is to apply the course contents and quantitative techniques learned throughout my education at NPS to an area useful in developing advanced manpower requirements of the TF-2000.

B. BACKGROUND

Human capital is to be considered as the most valuable asset in an organization and should be treated accordingly from the design and building of a warship to the end of its life cycle, which potentially implies a 40-year life span. However, the expensive nature of operating a warship necessitates the minimal manning of warships under increasing budget constraints, and especially in times of economic crises. Naval leadership all around the world strives for "paradigm shifts," such as technology leverage and workload transfer from ship to shore, to achieve the same mission goals with reduced manning (Douangaphaivong, 2004). These paradigm shifts also require some transformation within the organizational cultures of navies, including many key entities such as shipyards, fleets, training centers, etc. Along these lines, Thaveephone Douangaphaivong suggests refining the knowledge, skills, and abilities of the naval personnel and mentions a new concept of operations in his study on LCS:

> Through Spiral Development, LCS ships will: Leverage automation, "smart systems," and human systems integration principles in engineering, damage control, combat systems, ship control, messing, and other ship systems tied into an extensive local area network to optimize and integrate the capabilities of the ship and core crew. (2004)

A similar approach is absolutely needed and seems to be applicable in the design process of the TF-2000 project.

C. RESEARCH QUESTIONS

Research questions provide the guidelines to conduct the research and refine the thesis statement. Formulating the research questions is the starting point of a strong research.

1. Primary Questions

1. How do frigate design characteristics relate to manpower systems onboard a warship and manpower requirements?
2. How do specific relationships between ship design specifications and manpower requirements affect the optimal number of crew complement?
3. How can the specified relationships be incorporated into the design process of the Turkish Frigate-2000 (TF-2000)?

2. Secondary Questions

1. How can the HSI domains be utilized to estimate an optimal number of manpower requirements?
2. Can IHS Jane's data be used to incorporate the specified correlation between frigate design characteristics and manpower requirements into a frigate manpower systems integration model?

D. SCOPE AND LIMITATIONS

Providing an in-depth exploration of the correlations between frigate design characteristics and manpower requirements is the focal point of this research. Gathering sample data of 45 different frigates from 29 nations provides comprehensive sample size, especially for the qualitative analysis. However, the quantitative analysis comes with some limitations. Special attention must be paid to select frigates from international navies with similar characteristics such as a helicopter platform, surface-to-surface and surface-to-air guided missiles, and hull-mounted sonar. These specifications were purposefully taken into account as they would be the components of the TF-2000. However, due to the limited variation in the number of sensors or weapon systems, these dimensions were kept out of the regression analysis. Nevertheless, the number and type of sensors and weapons I have attempted to integrate into the study reflect their effects on manpower requirements.

This study is not a complete TF-2000 frigate manpower requirements analysis as the projected ship is still in a conceptual stage and many parameters such as radars, weapons systems, guided missiles, and many other sensors and devices still need to be determined. However, this study might be used as a good starting point in developing more advanced analyses. For instance, the Turkish Navy has Gabya-class frigates (ex-Oliver Hazard Perry class) in its inventory and an analysis of the Ship Manpower Document (SMD) of the Gabya-class frigates may provide the baseline requirements for the TF-2000 ships.

II. LITERATURE REVIEW

A. OVERVIEW

Based on a review of the literature, one of the ultimate goals of this study is to describe the needs to develop a Ship Manpower Document. The Department of the Navy's *U.S. Navy Total Force Manpower Policies and Procedures Instruction* lists the major determinants of an SMD:

- ROC/POE elements,
- Directed manpower requirements,
- Watch stations,
- Preventive Maintenance,
- Corrective Maintenance,
- Facilities Maintenance,
- Application approved staffing standards (when applicable),
- On-site workload measurement and analysis,
- Utility tasking (underway replenishment, flight operations, sea and anchor detail, etc.),
- Allowances (service diversions, productivity allowance, etc.),
- Development of officer requirements, and
- Fleet review of draft documents. (2002)

The same workload factors can be applied in the development process of TF-2000 ships' SMDs since the routines of sea life are very similar. The most critical element is the ROC/POE, which governs the types and numbers of all sensors and weapon systems, and consequently, the manpower requirements. Secondly, watch stations at sea are crucial and determined in accordance with the Conditions of Readiness levels, especially Conditions I, II, and III. Condition I dictates the battle readiness for 24 hours whereas Condition III is generally adopted in deployments longer than two weeks in the Turkish

Navy. Douangaphaivong summarizes the main criteria to be met by a warship in Condition I:

- Perform all offensive and defensive functions simultaneously,
- Keep all installed systems manned and operating for maximum effectiveness,
- Accomplish only minimal maintenance—that which is routinely associated with watch standing and urgent repairs,
- Perform self-defense measures, and
- Do not include evolutions, such as replenishment, law enforcement, or helicopter operations, unless the evolution stations are co-manned by staff from other battle stations. (2004)

Since Condition III is adopted for 60 days with eight hours of watch and eight hours of rest per day for crew, it lets department heads reduce manning to operate the necessary equipment and systems for navigation and engaging in sudden threats. Douangaphaivong also mentions two criteria for Condition III:

- Keep installed systems manned and operating as necessary to conform with prescribed ROCs in the POEs,
- Accomplish all normal underway maintenance, support, and administrative functions. (2004)

Another key aspect of preparing an SMD in the U.S. Navy is the standard workweek used to measure man-hours distributed to each job function such as watch-standing, doing all types of maintenance, utility tasking, training, etc. Although some differences, such as conscription, exist between the manpower of the U.S. Navy and the Turkish Navy, a similar approach can be adopted by the Turkish Navy to adjust the personnel costs. Even though the conscripted sailors in the Turkish Navy are provided limited salaries, they are still being accommodated, and these accommodations have significant costs for the Turkish Navy. Furthermore, the trend toward adopting a more professional approach in manning not only all naval vessels but also the entire military is inevitable in the very near future. After the workload onboard a warship is measured by the Manpower Analysis Center, workload hours are converted into requirements by rate/rating to display in the SMDs based on minimum skill, pay grade, and quantity to accomplish the mission within the defined framework of ROC/POE (Hatch, 2016). As an expert in manpower issues, U.S. Navy CDR William Hatch (RET) suggests that special care and attention are needed while determining the ROC elements. Because when the authorized number of ships and life expectancies of these warships are taken into account, very small differences in billets, which are comprised of requirements and authorized end strength, may equate to billions of dollars in extra personnel costs for a navy throughout a ship's life cycle. The U.S. Navy standard workweek is presented in Figure 1 as an exemplary measurement in determining manpower requirements.

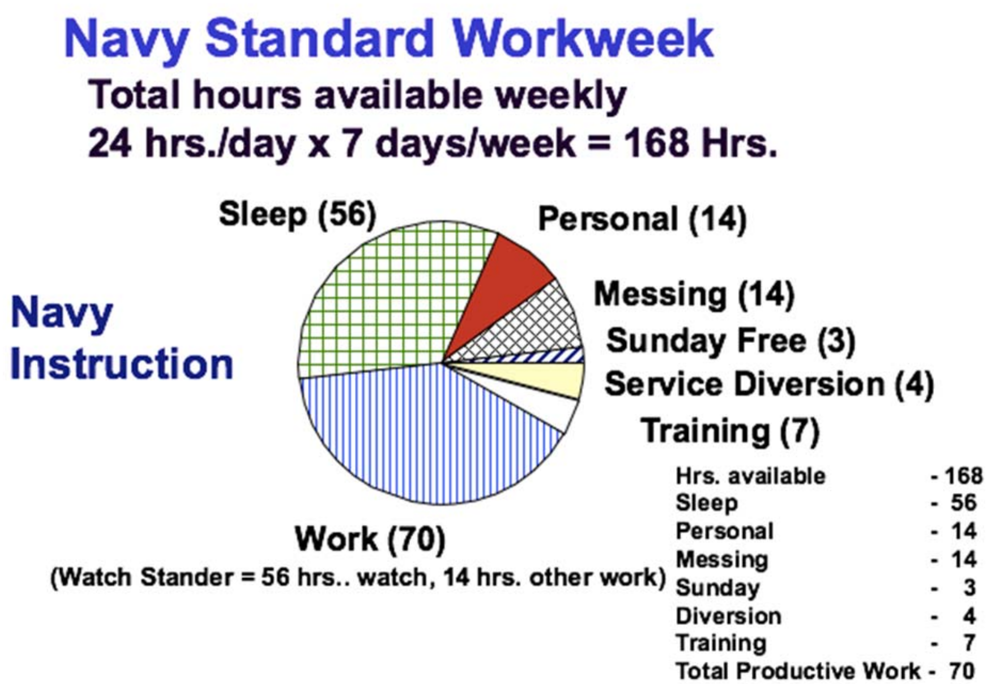

Figure 1. U.S. Navy Standard Workweek. Source: Hatch (2016).

B. HUMAN SYSTEMS INTEGRATION DOMAINS

Given the interdisciplinary nature of this thesis, a brief description of the HSI domains is needed to elaborate on the manpower requirements' relationship with the ship design characteristics. The NPS website describes HIS as follows: "Human Systems Integration (HSI) emphasizes human considerations as the top priority in systems design/ acquisition to reduce life cycle costs and optimize system performance" (Naval

Postgraduate School, 2016). The major eight domains of the HSI are also listed on the NPS website:

- Human Factors Engineering
- System Safety
- Health Hazards
- Personnel Survivability
- Manpower
- Personnel
- Training
- Habitability (2016)

The analysis of the trade-offs among these areas of the HSI is crucial to have a deeper understanding of the correlation between the manpower requirements of a frigate and its design features. As an MSA student, my main focus of this research is on the manpower domain because the TF-2000 frigate project is still in the conceptual design stage. Human Factors Engineering (HFE) concentrates on the interfaces between humans and systems, including the hardware and software (Williams, 2012). Naval engineers and architects must address HFE, habitability, personnel survivability, and system safety domains. The personnel domain relates to the "faces" rather than the "spaces," and includes training and health hazards, which can be handled after the assignment of personnel (Hatch, 2016). Finally, the manpower domain of the HSI plays a pivotal role in the organization of this thesis. The quantifiable nature of manpower in terms of crew complement paves the way for making it the response variable among the other independent variables of ship specifications in the regression analysis. This aspect of the study is further explained in Chapter III.

C. NPS SYSTEMS ENGINEERING SHIP SYNTHESIS MODEL

The NPS Systems Engineering Ship Synthesis Model, which is primarily driven by operational requirements such as speed, endurance, radar range, number and types of guns, etc., is shown in Figure 2. The trade space is divided between the operational space and the physical space in this traditional model. The physical space is composed of architectural design parameters such as length, beam, displacement, cost, etc. This conventional synthesis model, however, seems to be lacking some important HSI domains according to Douglas Williams (2012).

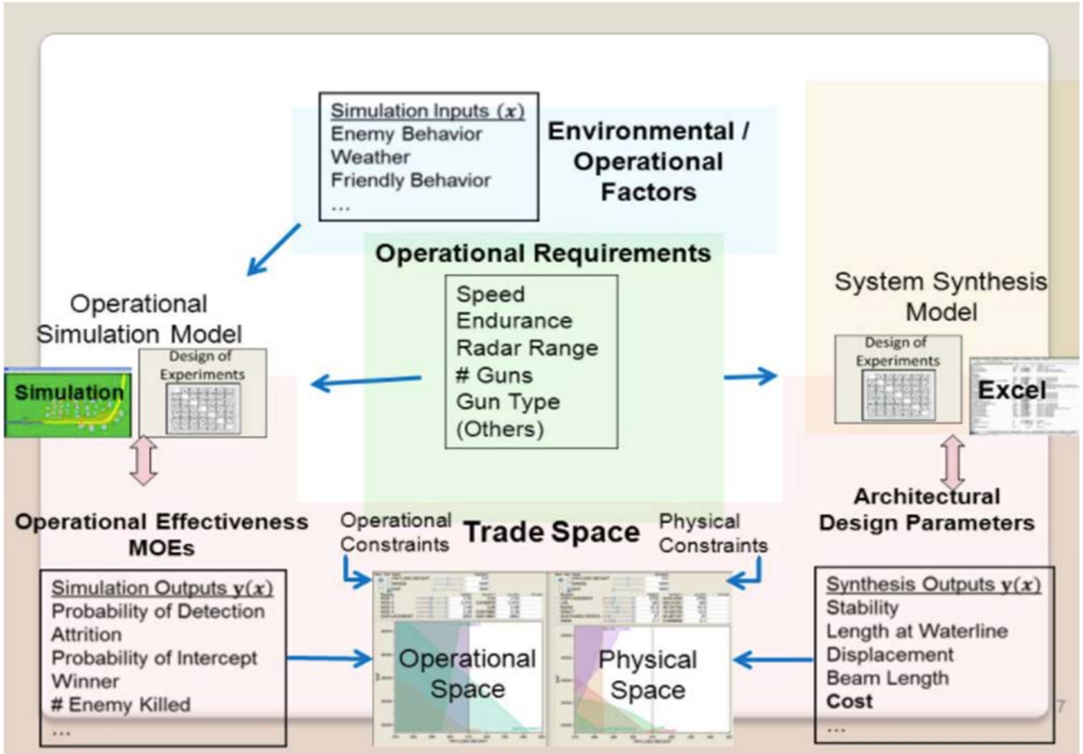

Figure 2. NPS Systems Engineering Ship Synthesis Model. Source: Williams (2012).

The operational requirements have a central role in this design model, and some straightforward questions arise related to those requirements:

> What are the anticipated types and quantities of equipment, software, personnel, facilities, etc., required, and where are they to be located? How is the system to be utilized, and for how long? What is the anticipated environment at each operational site (user location)? How is the system to be supported, by whom, and for how long? (Blanchard & Fabrycky, 2006)

D. INTEGRATION OF HSI DOMAINS AND SHIP DESIGN CHARACTERISTICS

In his master's thesis, Williams (2012) attempts to lay the groundwork for the integration of the HSI domains and ship design characteristics. This thesis, which was advised by Eugene Paulo, one of the founders of the NPS Systems Engineering Ship Synthesis Model, proposes an HSI Synthesis Manpower Model, which is shown in Figure 3, to expand on the previous NPS Systems Engineering Ship Synthesis Model to integrate the ship design characteristics and HSI domains.

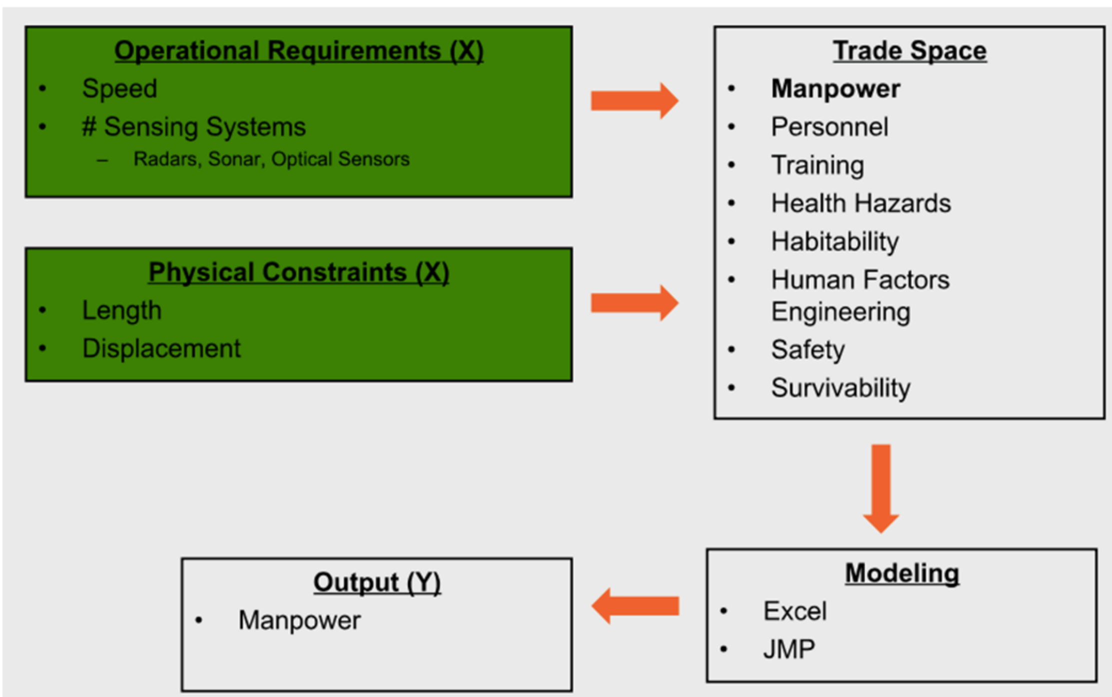

Figure 3. Proposed HSI Synthesis Manpower Model.
Source: Williams (2012).

This model is very similar to the model used in the next chapter with some differences. This model seeks to take "the operational requirements" such as speed or the number of sensors onboard a ship as inputs along with the ship design characteristics as "the physical constraints." These two categories of inputs are used in the trade space to estimate an optimal number of crew complement under the "Manpower" domain. The reason for the preference of the manpower domain over the other domains is that the crew complement is quantifiable. Thus, it can easily be used in the quantitative analyses such as the principal component analysis or the regression analysis.

1. Block Coefficient

Williams (2012) analyzes each ship design characteristic (ship speed, displacement, ship length and beam) and some specifications, such as the block coefficient and Froude number, which are calculated using specific formulas derived from the ship design features. Slade (1998) states that the "[b]lock coefficient is determined by taking a notional rectangular block, the length, width and depth of which are those of the ship in question. The volume of this block is then calculated. The actual volume of the ship hull in question is then assessed and expressed as a proportion of the volume of the block." In numerical form, the block coefficient is calculated with the following formula in Figure 4:

$$C_b = \frac{V}{LBT}$$

Figure 4. Block Coefficient. Source: Tupper & Rawson (2001, p. 12).

The values used in the formula can be described as follows:

- C_b = block coefficient
- V = displacement (volume of water displaced in tons)
- L = length (at waterline in feet)
- B = beam (at waterline in feet)
- T = draught (in feet)

The block coefficient also necessitates a comparison of shipbuilding costs versus operational costs resulting from machinery power, because when the values in the denominator of the formula are incremented, the shipbuilding costs also increase to adjust displacement increase and determine the optimal block coefficient. However, when characteristics such as length or draught are incremented, the reduction in the machinery power needs is achieved and money is saved from operational requirements throughout the life cycle of a ship. This trade-off calculation is crucial in determining the optimal ship design characteristics and also considered in the regression analysis in Chapter III.

2. Froude Number

Another important variable used in the regression analysis is the Froude number, which is calculated with the following formula shown in Figure 5:

$$Fr = \frac{V}{\sqrt{gL}}$$

Figure 5. Froude Number. Source: Tupper & Rawson (as cited in Williams, 2012).

The values used in the formula can be described as follows:

- Fr = Froude number
- V = Max Ship velocity (meters per second)
- g = gravity (9.81 meters per second^2)
- L= Ship length at the waterline (in feet)

Ship velocity or speed is an operational requirement, and ship length is a design characteristic. The relationship between these parameters is reminiscent of the relationship between HSI domains and ship design features because speed is achieved through the machinery propulsion. Consequently, the correlation between these ship design parameters and various HSI domains like manpower, systems safety, personnel, and training is to be scrutinized to better understand how ship design characteristics relate to the basic HSI areas, which is the essential research question of this thesis.

Williams (2012) states that "the optimum block coefficient is an indicator of ship sea-keeping and capacity to support systems that will require a larger shipping volume."

Figure 6 shows the relationship between the block coefficient and the Froude number, and the larger the number on the curve, the more the seakeeping capability of a ship increases. It is understood that frigates, which are the subject matter of this study, are at the far end of the curve. “A small block coefficient means less resistance and, consequently, the possibility of attaining higher ship speeds” (MAN Diesel & Turbo, n.d.). This statement probably explains the reason behind the frigates’ position at the end of the spectrum; high-seakeeping capability is a desirable factor in the design of the warships in general and frigates in particular.

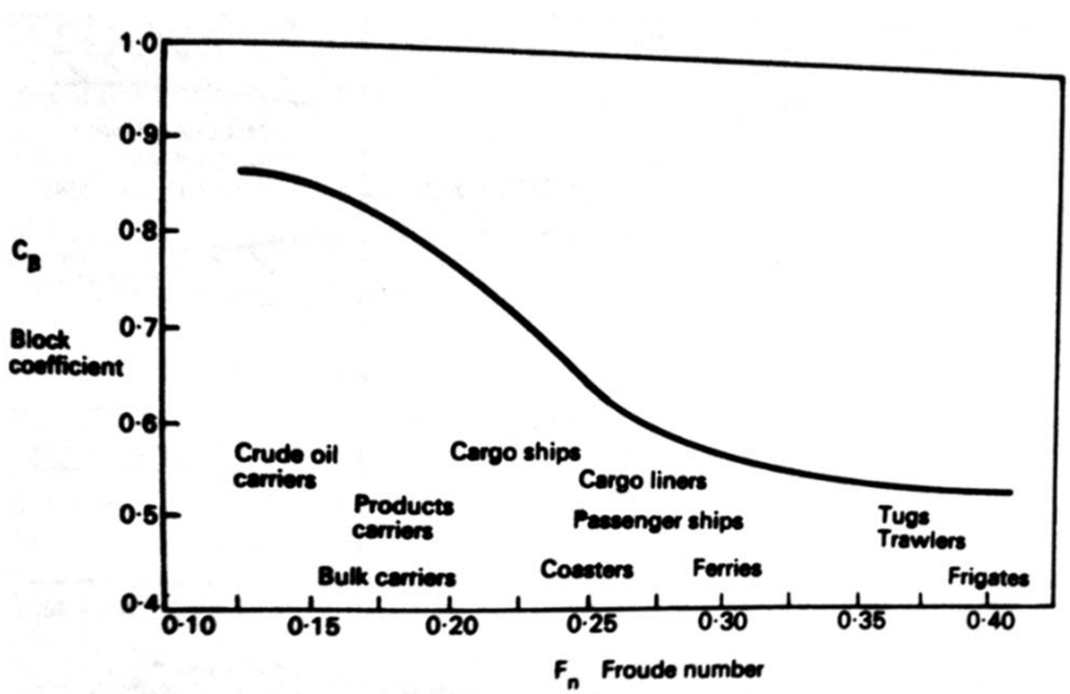

Figure 6. Optimum Block Coefficient over Froude Number Curve. Source: Williams (2012).

To provide a quick reference, Figure 7 shows the block coefficient over the Froude number from the sample data including frigates compiled from Information Handling Services (IHS) Jane’s Fighting Ships database. The trend on the graph seems to be in alignment with the general positioning of frigates in Figure 7, close to the range between 0.4–0.6.

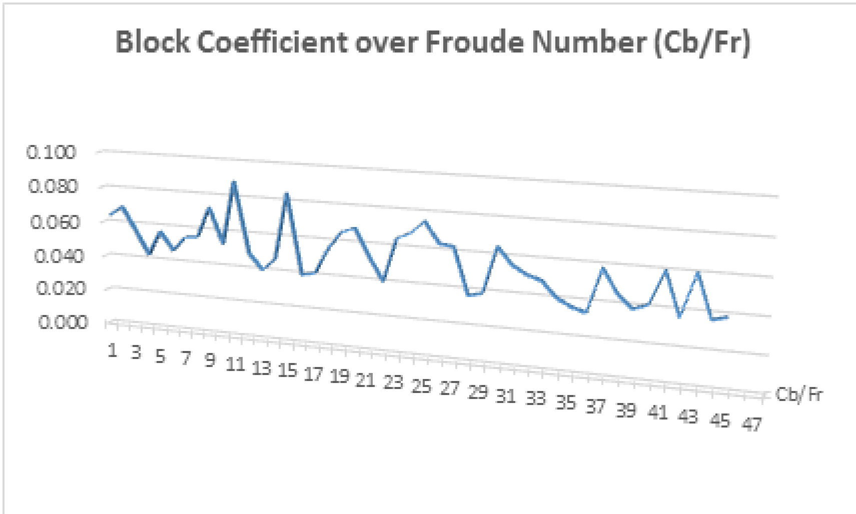

Figure 7. Block Coefficient over Froude Number from the Sample Data. Adapted from IHS Jane's Fighting Ships (2016).

E. LESSONS LEARNED FROM THE ANALYSIS OF THE LCS MANPOWER REQUIREMENTS

Operating warships with minimal manning is one of the latest necessities driven by budget constraints all over the world. Different nations find different solutions to this problem and that explains the varying crew complements from 100 to 292 in the same type of warship, that is, frigates. An exemplary study of manpower requirements analysis for the U.S. Navy's LCSs is Douangaphaivong's (2004) master's thesis. The thesis focuses on two channels to accomplish minimal manning: Paradigm shifts and reduced manning initiatives.

Paradigm shifts center on changes in the policy and culture. The first change occurs in the Composite Sailor concept, which aims to compound the maintenance and operator jobs for applicable duties such as the Nixie or some engine technician jobs. Similar attempts have also been applied to Fire Control operators and repairmen in the Turkish Navy. The Composition concept paves the way for reducing manpower requirements by 50 percent, along with providing operators a better understanding of the systems, which results from operators doing the maintenance and repairs themselves. The second paradigm shift relates to Technology Leverage, which provides taking advantage of current technological advancements for all systems onboard a ship whenever applicable. This concept is highly important, especially in jobs such as log keeping, because when such a job is automated, the data is gathered more accurately and manpower needs can be reduced significantly. The third concept is the Workload Transfer from ship to shore. This shift enables labor-intensive jobs and maintenance to be done regularly at the shore facilities, freeing the ship's crew to focus on operating the systems effectively and efficiently.

Reduced manning initiatives have also been derived from other successful experimental initiatives tried on different types of warships and can be transferred to other types of warships. The first one is the Smart Ship initiative, which aimed to integrate systems to provide information to the watch-standers more effectively. The second initiative is the Fleet Optimal Manning Experiments (OME), which successfully reduced the manning requirements within the U.S. Navy. A brief sample depiction of the Composite Sailor and the OME is shown in Table 1.

Table 1. An Example of the Reduced Manning Initiative and the Paradigm Shift in the U.S. Navy. Source: Douangaphaivong (2004).

Legacy Rate Composition From OME	
Before	**After**
Quartermaster	Bridge Specialist
Signalman	
NIXIE Operator	NIXIE Operator/Repairman
NIXIE Repairman	
Operator	Operator/Monitor
Monitor	

F. IMPLICATIONS OF THE DEFENSE PERSONNEL TRENDS

The technology leverage concept is supported by many recent studies. A Rand Corporation study of defense personnel trends by Dr. Harry J. Thie (2009) compares the crew complements of various naval platforms in historical perspective and indicates that the number of personnel per tonnage of a warship decreases over time. For instance, although the crew complement size for a Perry-class frigate was around 72 per 2,000 tons for these warships between 1975 and 1991, it is only around 47 for a San Antonio-class Land Platform Dock after 1995 as shown in Figure 8 (Thie, 2009). It is crystal clear that technology changes the manpower needs.

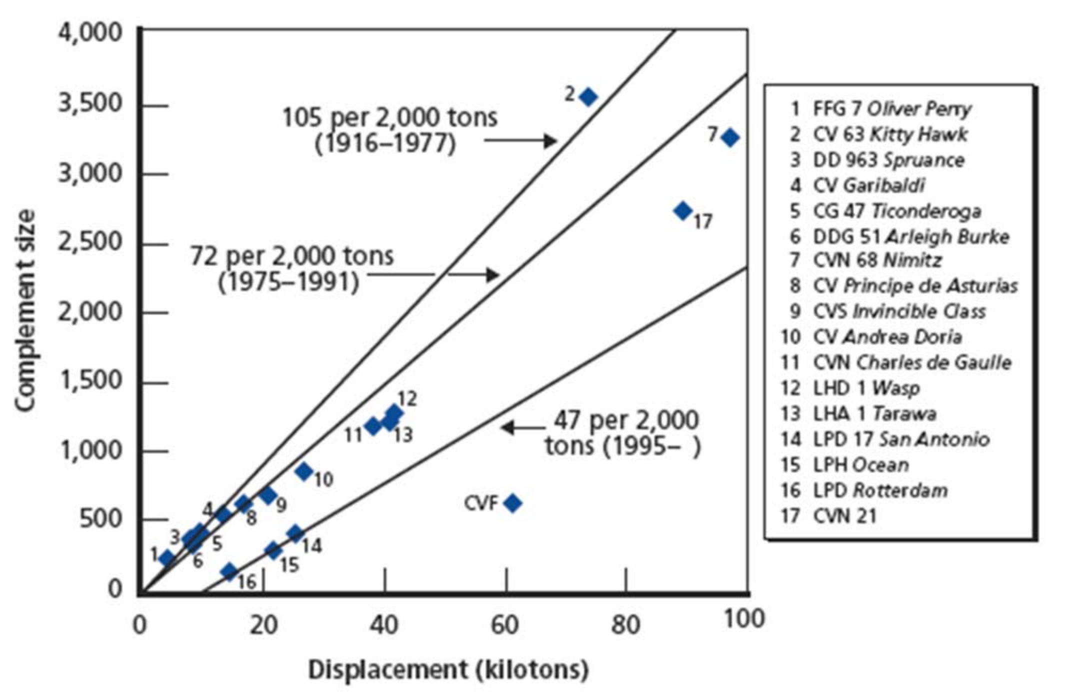

Figure 8. A Historical Comparison of Crew Complement Sizes vs. Displacement. Source: Thie (2009).

Militaries all around the world have been changing at an overwhelming pace, and many external factors affect the manpower needs and human capital outcomes. The Rand Corporation study by Thie (2009) on the defense personnel trends affecting the U.S. military lists some of these factors as follows:

- Qualified and available population
- Civil-military relations (general attitude towards military)

- Geographic and economic factors
- Employment trends
- Changing world views of new generations
- Changed education patterns
- War for talent and emphasis on performance
- Changes in the roles of officers, enlisted personnel, and civilians
- Rise of mobility among employees
- Changes in the operational tempo and increasing reliance on contractors

All these factors significantly affect the accessions into the military, training needs, and professional development areas such as fitness reports and promotions. Likewise, developing new standard operating procedures for the retention of the skilled workforce is crucial in this era of talent warfare. At the same time, the distribution of funds among the armed services and branches must be reviewed and re-evaluated based not only on the need to recruit and retain skilled personnel, but also on national or organizational security strategies. Considering the separation and retirement procedures and assisting the military personnel in their transition into the civilian life is also a key step in managing the human capital in a sustainable way.

G. CHAPTER SUMMARY

The literature review shows the necessity of adopting a standard workweek by the Turkish Navy to measure the man-hours required to develop an SMD for the TF-2000 frigates. The workload factors such as ROC/POE elements, watch stations, all types of maintenance, etc., for the TF-2000 frigates should also be integrated with the previously described HSI domains to determine the manpower requirements. The NPS Systems Engineering Ship Synthesis Model and Williams' (2012) proposed HSI Synthesis Manpower Model are also key models evaluated in this research to integrate the manpower systems analyses into the Turkish Navy frigate design process. Moreover, the invaluable lessons learned such as the Technology Leverage, Optimal Manning Experiments, and Workload Transfer from ship to shore from the LCS manpower requirements analysis are central in achieving the desired reduced manning levels. Finally, the latest defense personnel trends, such as the civil-military relations and the employment trends in the Turkish society, along with the other economic and geographical factors are crucial considerations for the available manpower pool in manning of the TF-2000 frigates in particular for the Turkish Navy and in general for the Turkish military.

III. METHODOLOGY

A. SAMPLE DATA DESCRIPTION

The sample data consists of 45 different frigates from 29 different countries. The data used for this study was gathered from the Information Handling Services (IHS) Jane's Fighting Ships database, which is a reliable and unclassified military intelligence source. As an NPS student, this researcher has free access through the Dudley Knox Library to "the world's most comprehensive and reliable open-source naval reference resource available, covering the navies and coast guards of 165 nations worldwide and providing detailed information on war ships, aircraft, weapon and sensor systems in service and under construction" (IHS Jane's, 2016, para. 1). The IHS Jane's database provides "detailed platform and subsystem technical data (with) vessel photographs, drawings and silhouettes" (IHS Jane's, 2016, para. 2).

1. Research Methodology

The research methodology used in collecting the data can be called "judgment sampling" as the ships and their characteristics were chosen through purposive sampling (Dudovskiy, 2016). This method seemed to be cost-effective and time-effective as well as the only appropriate method available because of the limited data sources that might contribute to the study. The limited sample may be vulnerable to the typical disadvantages of judgment sampling, but special attention was paid to the data to be inclusive of all the prominent frigates existing in the international arena.

2. Assumptions and Limitations

A brief evaluation of the sample characteristics seemed to be compulsory to both better understand and analyze the data and reinforce the quantitative analysis. This evaluation is necessary because the regression analysis lacks some important ship characteristics, such as sensors and weapon systems, which may be highly correlated with the crew complement. The reason behind why these important factors were not included in the Excel sample data is that the variations would disappear if they were quantified.

Nearly all of the frigates gathered for the analysis are considered to be "FFGH" and all of them have a similar number of radars, sonars, optical sensors, and weapons systems, namely SSMs (surface-to-surface missiles) and SAMs (surface-to-air missiles), CIWSs (close-in weapon systems), and guns. A minimal number of frigates may not have SAMs, but other than that, the number of sensors and weapons seems to be identical. The difference in the types of the sensors and weapon systems are to be analyzed qualitatively due to the limitation of the quantitative techniques. A typical FFGH used in the sample has the following number of sensors and weapons shown in Table 2, with varying brands of warfare systems, ranges, weapons control systems, etc.

Table 2. Typical FFGH's Firepower. Source: IHS (2016).

FIREPOWER	
Missiles:	**SSM:** 8 Boeing Harpoon [Ref 1]; active radar homing to 130 km *(70 n miles)* at 0.9 Mach; warhead 227 kg. **SAM:** Eurosam SAAAM; 2 octuple Sylver A 43 VLS; 2 octuple Sylver A 50 VLS [Ref 2] for MBDA Aster 15; command guidance active radar homing to 15 km *(8.1 n miles)* anti-missile and to 30 km *(16.2 n miles)* anti-aircraft. 32 missiles.
Guns:	1 Oto Melara 3 in *(76 mm)* /62 Super rapid [Ref 3]; 120 rds/min to 16 km *(8.7 n miles)* ; weight of shell 6 kg. 2 M134D 7.62 mm miniguns.
Torpedoes:	6-324 mm (2 triple (recessed)) [Ref 4] tubes. Eurotorp A 244/S Mod 3; anti-submarine; active/passive homing to 7 km *(3.8 n miles)* at 33 kt; warhead 34 kg (shaped charge).
Physical countermeasures:	**Decoys:** 3 EADS NGDS 8-barrelled chaff [Ref 5], IR and anti-torpedo decoy launchers.
Electronic countermeasures:	**ESM:** RAFAEL C-PEARL-M; intercept.
Radars:	**Air/search:** Thales Herakles 3-D radar multifunction [Ref 7]; E/F-band. **Surface search/Navigation:** 2 Terma Scanter 2001 [Ref 8]; I-band.
Sonars:	EDO 980 ALOFTS VDS; low frequency (2 kHz).
Weapon control systems:	2 EADS Nagir 2000 optronic directors [Ref 6].
Helicopters:	1 S-70B Seahawk [Ref 9].

3. Sample Characteristics

The distribution of the frigates in the sample is shown in Figure 9, with their names on the vertical axis and the number of frigates per class on the horizontal axis.

Most countries have up to eight or ten frigates in their fleets. Some countries like Great Britain and Canada have slightly more than ten frigates to cover their interest areas in the seas and oceans based on their threat evaluations and economic power. China has the largest fleet of frigates. For the most part, the Jiangkai II class-frigates were built in the last decade. Twenty-two of them are in active service, three of them are still being built, and five of them are planned to be transferred to other nations. Chinese military armament has reached worrying levels for the United States, especially with the aircraft carrier, three nuclear submarines, guided missile destroyers, and many other weapon systems still being built (LaGrone & Majumdar, 2014). With a population of more than 1.3 billion, China seems to be manning its ships without a severe problem.

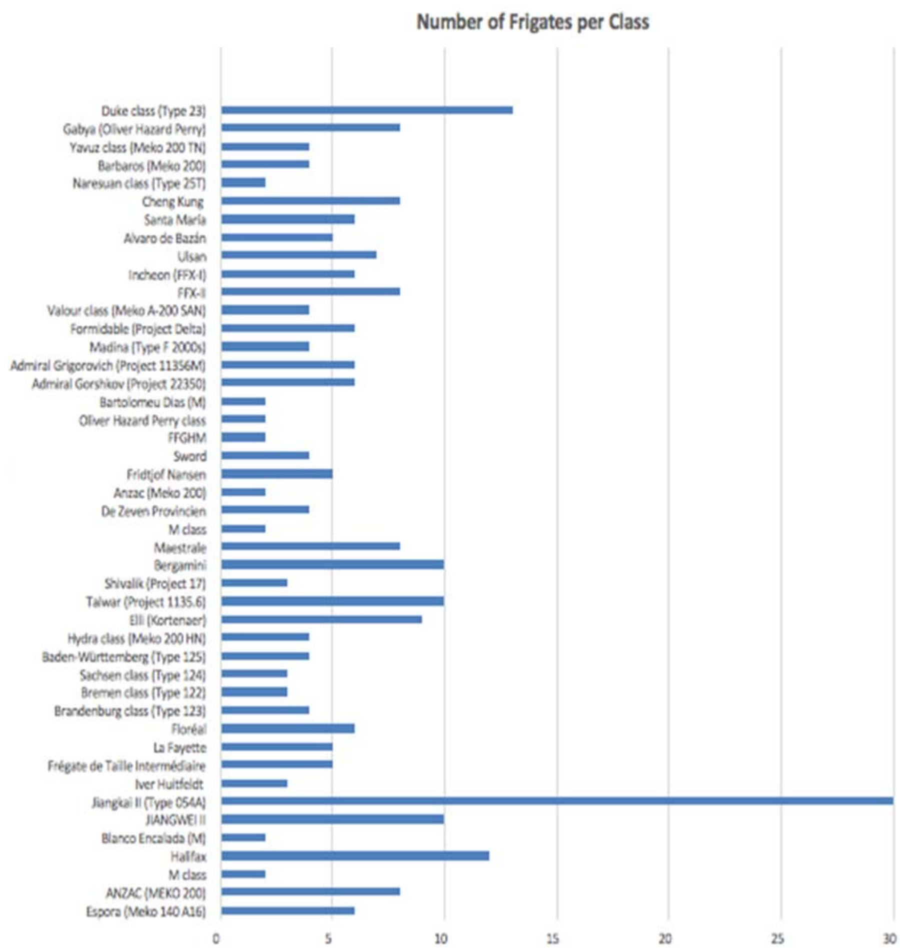

Figure 9. Distribution of the Frigates per Class. Adapted from IHS Jane’s (2016).

The U.S. Navy has been decommissioning its Perry-class frigates for a while and building LCSs for the same purposes—to protect littoral waters—with a slightly different purpose for doing it and with less personnel onboard. Sam LaGrone and Dave Majumdar (2015) report that Secretary of the Navy Ray Mabus announced some plans to "change the hull designation of the LCS class ships to FF. It will still be the same ship, the same program of record, just with an appropriate and traditional name." The U.S. Navy attempted to resolve the confusion of the LCSs' association with amphibious ships in the last batch of the 20 LCSs. The U.S. Navy also transferred some of the decommissioned Perry-class frigates to other navies. For instance, eight of them are in active service in the Turkish Navy with a new name, Gabya class, and modernized Combat Information System, namely Genesis. Likewise, German-made frigates called Meko class are in service in many nations' fleets with different names, such as Yavuz and Barbaros classes in the Turkish Navy, Valour class in the South African Navy, Hydra class in the Hellenic Navy, Anzac class in the Australian Navy, and Espora class in Argentina's Navy.

The crew complements by ship class are shown in Figure 10. Navies all over the world have their own organizational cultures and many different aspects affect their manning decisions to balance the trade-offs among HSI domains. The numerical range for the crew complements is between 100 and 292. Denmark and Singapore are the two countries positioned at the low end of the spectrum. Many reasons may contribute to their maintaining such minimal manning levels, but the foremost reason seems to be associated with their population size of around six million. Similarly, the Dutch Navy is facing some difficulties in recruitment of military personnel and has eliminated traditional maps for navigation on warships and solely depends on the multiple Electronic Chart Display and Information Systems on the bridge. By contrast, Shivalik-class Indian frigates with 292 personnel onboard have the largest crew complements. India is the second most populous country in the world, just after China, and manpower costs do not seem to be very expensive for the Indian Navy. A Shivalik-class frigate (F-49) laden with the crew on open decks for a special occasion is shown in Figure 11.

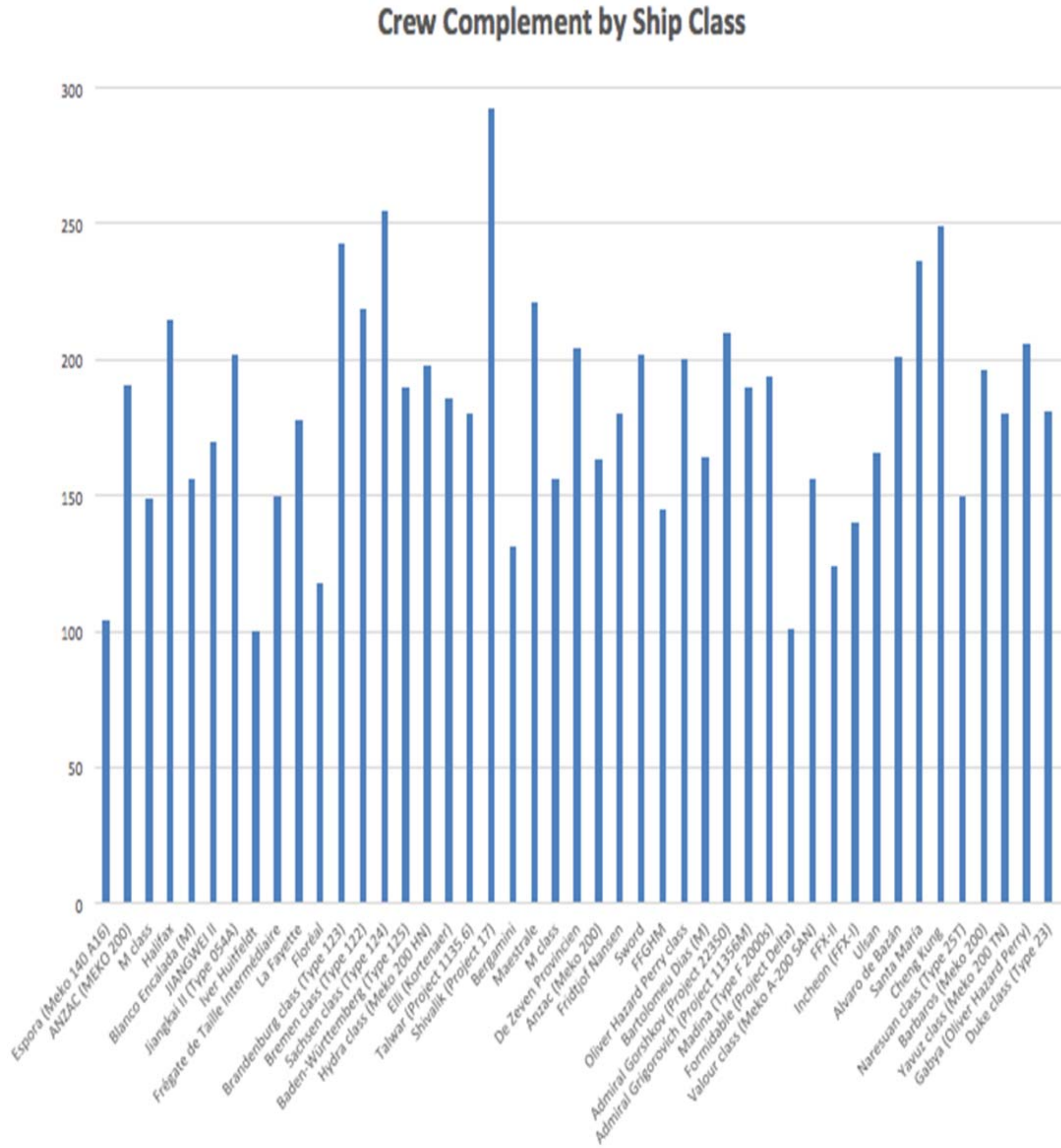

Figure 10. Personnel Numbers by Ship Class. Adapted from IHS Jane's (2016).

Figure 11. A Shivalik-class Frigate (F-49) Laden with Crew on the Open Decks. Source: IHS Jane's (2016).

The average crew complement on a frigate is 181, with a standard deviation of 41. The minimum number for the total personnel onboard a frigate is 100 and the maximum is 292. This gives a rough picture of the manning approaches of the frigates in different navies. Having decided on the specific sensors, weapon systems, machinery configuration, and so forth, the Turkish Navy can take advantage of this baseline study to determine the optimal number of personnel to assign to TF-2000 frigates. Many parameters, such as the manpower costs, technological leverages, and capabilities for reduced manning initiatives, and availability of shore facilities like recruitment and training centers and shipyards, exist in determining the optimal manning of the ships. Even some cultural aspects such as how food is served—either self-serve as implemented in the U.S. Navy or by (enlisted) sailors in some traditional navies—may affect the crew complements, or might explain the differences in manning of the frigates in different navies.

Figure 12 shows the frigates' full displacement in tons by ship class. It is intuitive that larger or heavier ships are expected to be manned with larger crew complements. The relationship between the independent variables and the ship characteristics is further discussed in Chapters IV and V. The average tonnage of the frigates is around 4,500 tons, and some frigates are significantly larger than the average displacement. For instance, the Baden-Wurttemberg-class (Type 125) frigates in the German Navy replaced the old type of destroyers and that partly explains the larger size, which exceeds most of the frigates in the sample. Likewise, Alvaro de Bazan-class frigates in the Spanish Navy and Fridtjof Nansen-class frigates in the Norwegian Navy are equipped with the Aegis combat system for the latest technology in air-defense, making them weigh more than the average frigates in the sample. Comparably, the Alvaro de Bazan frigates have a crew complement of 201; whereas, the Fridtjof Nansen-class frigates operate with 180 personnel. Thus, manpower cost savings in the Norwegian Navy might be significant over the life cycle of the frigates in their fleet compared to Spanish Navy, assuming the effectiveness of both frigates is more or less the same.

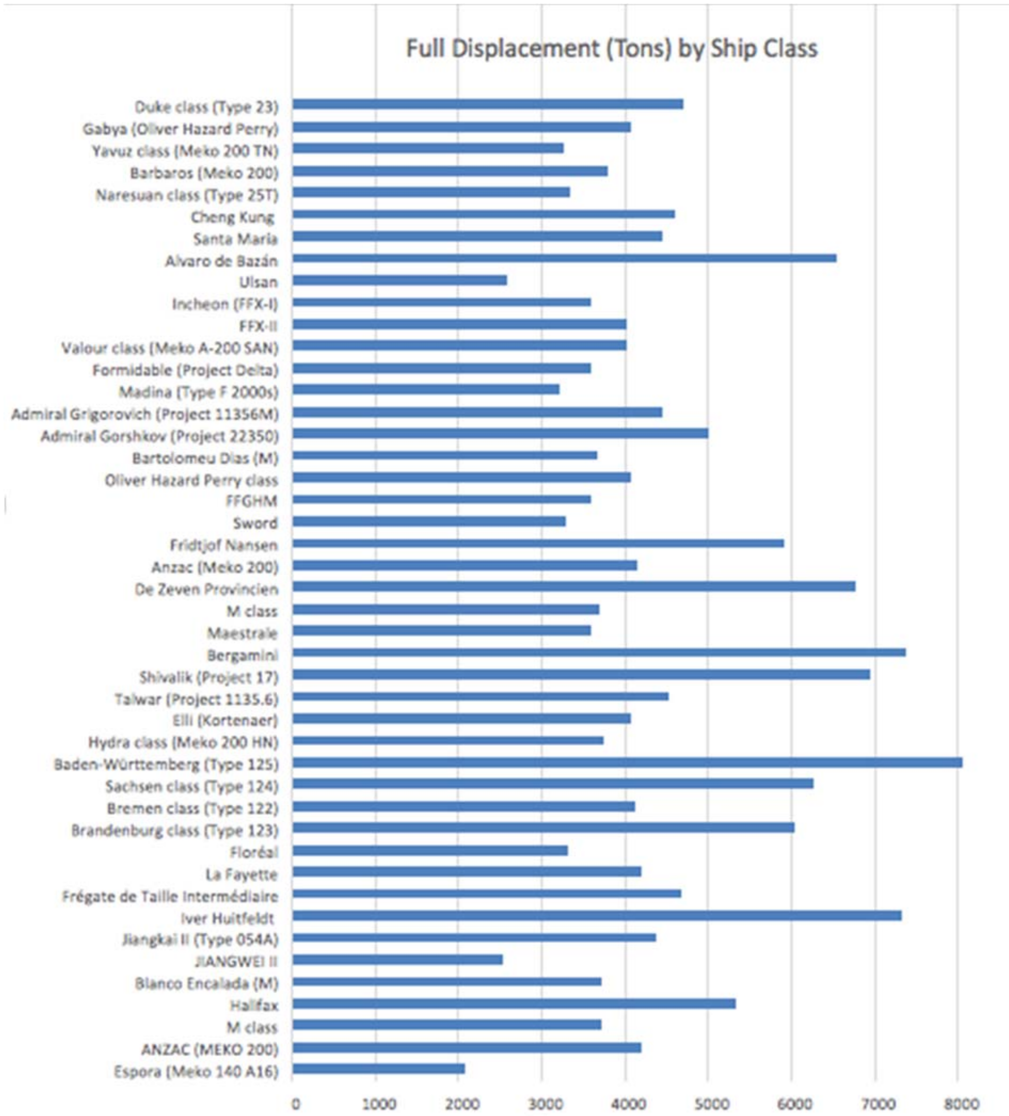

Figure 12. Full Displacement in Tons by Ship Class. Adapted from IHS Jane’s (2016).

The machinery configuration of the frigates is as important as the other ship design features and choice of sensors and weapons systems. Actually, deciding on a CODAD (Combined Diesel and Diesel), CODOG (Combined Diesel or Gas Turbine), or CODAG (Combined Diesel and Gas Turbine) configuration significantly affects the overall displacement, maximum speed, or many other characteristics of a warship. Figure 13 shows the machinery powers of the frigates by ship class in the sample. Having a gas turbine significantly increases the horsepower and maximum speed capabilities of a frigate, but it also touches upon the other elements of the HSI domains such as manpower, personnel, training, habitability, etc.

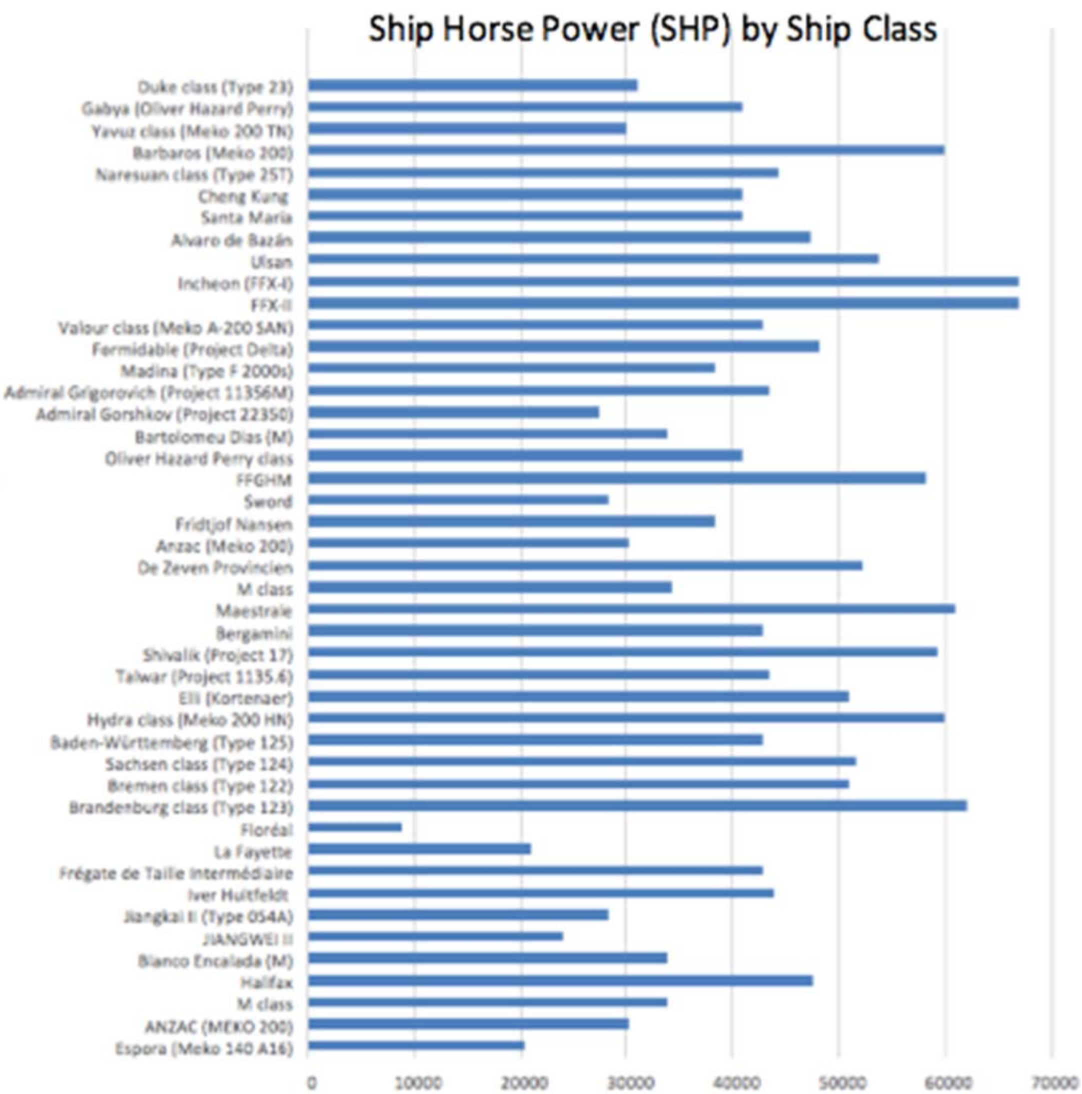

Figure 13. Ship Horsepower (SHP) by Ship Class. Adapted from IHS Jane’s (2016).

The average SHP of the sample data is 42,211 HP, with a standard deviation of 13,131 HP. Figure 14 shows the relationship between the SHP and the crew complements. It is hard to comment on the nature of the relationship between the SHP and crew complement due to the scattered plot in Figure 14. Nevertheless, some striking points exist in the sample. For instance, Halifax-class frigates in the Canadian Navy have a CODOG configuration, while the Iver Huitfeldt-class frigates in the Danish Navy have only diesel machines for propulsion. The Halifax frigates have a crew complement of 215, while Denmark's frigates are operated by only 100 personnel. The Iver Huitfeldt-class frigates were commissioned after 2010, which implies overwhelming technological leverage in comparison to the Halifax frigates commissioned in the 1990s. Besides, Denmark's relatively very low population might also be contributing to this very minimal manning other than the lack of gas turbine propulsion and the latest technological advantages.

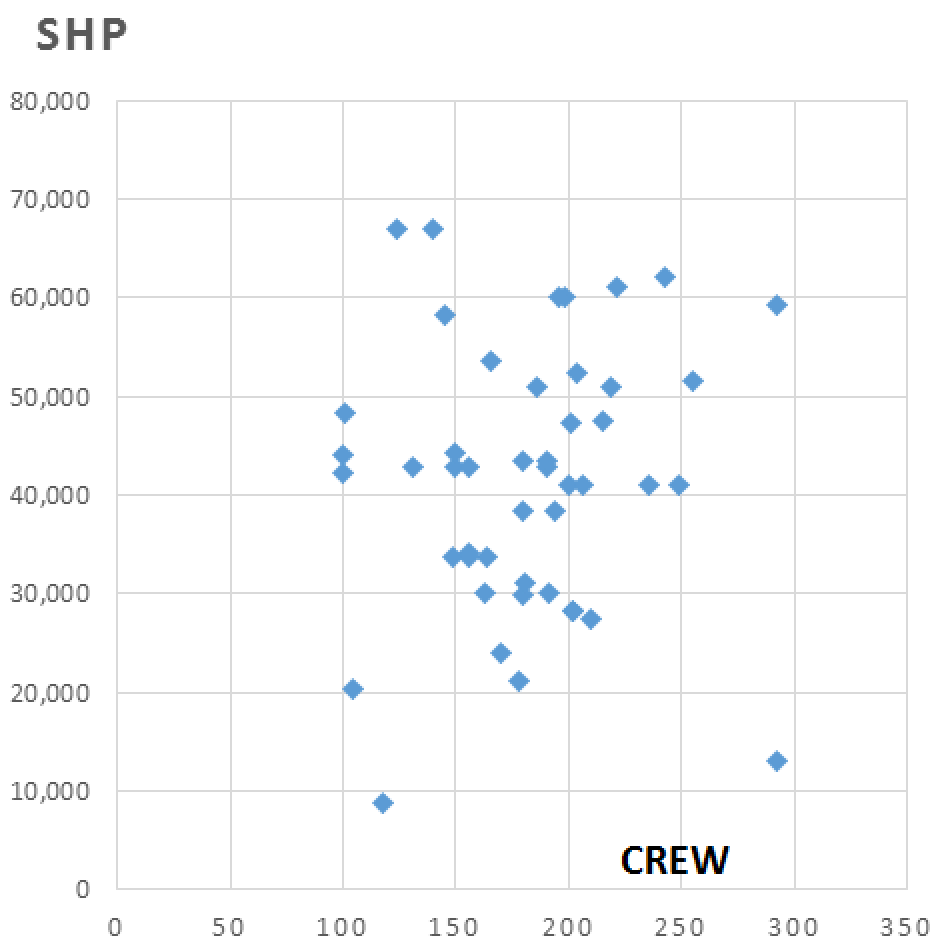

Figure 14. The SHP vs. Crew Complement Diagram. Adapted from IHS Jane's (2016).

B. DATA COLLECTION

The data inclusive of 45 frigates from 29 nations used in this thesis was collected using a method similar to the one used by Williams (2012) in his master's thesis on the offshore patrol vessels. Within the IHS Jane's Aerospace, Defense, and Security Database, the author clicked on "Fighting Ships" and searched for "frigate.." Initially, 73 different frigates were exported into an Excel file and then 45 frigates either in service and/or under construction were sorted into a new spreadsheet. The data used both in qualitative and quantitative analyses are shown in the Appendix. The following ship features were collected for each frigate in the sample data:

- Nation and ship class name
- Crew complement
- Displacement
- Length
- Beam
- Draught
- Max Speed
- Shaft Horsepower
- Number of ships in class

The block coefficient and Froude number were calculated in Excel using the formulas discussed in Chapter II. The needed conversions for the parameters, such as kt or lb, were converted in Excel using the "Convert" formulas of Excel.

C. METHOD OVERVIEW

The data for this study is compiled from the database of Jane's Fighting Ships. The gathered information is analyzed both in Excel and JMP Pro 12. The collected data is unclassified and does not include human subject research. The design characteristics for quantitative analyses were determined based on the conclusions from the literature review.

Having finished the literature review to gain in-depth knowledge of the correlations between frigate design characteristics and manpower requirements, my first step was to complete the data collection and then enter them into an Excel spreadsheet. The data is initially analyzed in Excel to get useful graphs and have a deeper understanding. Later on, the Excel data is transferred into the JMP Pro 12 data analysis program to conduct the regression analysis and other appropriate quantitative methods. Finally, based on the research findings from the analyses, the answers to the research questions are reevaluated and implications of the study are compared to the possible usage areas in the TF-2000 design project.

D. DESCRIPTION OF THE VARIABLES

The regression analysis includes a response (also called the dependent) variable and eight explanatory (or independent) variables. The variables used in the quantitative analyses conducted in both Excel and JMP Pro 12 are described as follows:

1. Response Variable

Crew complement was chosen as the response variable in the analysis because one of the key questions of this study is to find the optimal number of manpower in a newly designed frigate, namely the TF-2000. It also allows for the quantitative analysis as it corresponds to the ship design characteristics and the key HSI area, manpower, that is quantifiable.

2. Explanatory Variables

The explanatory variables were purposely chosen from the IHS Jane’s Fighting Ships database. These are some of the quantifiable ship characteristics collected for each frigate in the sample data from the Jane’s database, but admittedly, this data lacks some key parameters such as combat systems or radars that are extremely hard to quantify, or even if quantified, it lacks the variance required for the regression. For instance, the number of sensors such as radars, sonar, and electronic and physical countermeasures could be quantified and included in the sample data. However, most frigates, if not all, have a surface radar, an air surveillance radar, a hull-mounted sonar, or a VDS (variable depth sonar), and so forth. Similarly, the total number of weapons is a crucial factor affecting the crew complement, but nearly all the frigates (FFGH) have an SSM, a SAM, a 127mm or 76 mm or a similar gun, etc. When these weapon systems or sensors are quantified, the variance needed for the quantitative analysis is lost. Thus, this is a shortcoming of the quantitative analysis used in this thesis, and throughout the study, the qualitative analyses attempt to incorporate the differing ship characteristics, such as the Aegis radar system or having a gas turbine propulsion, to compensate for the excluded explanatory variables. The following independent variables are either directly collected from the IHS Jane's database for each ship or calculated based on the formulas discussed in Chapter II.

- X1 = Full Displacement
- X2 = Length
- X3 = Beam
- X4 = Draught
- X5 = Speed
- X6 = Shaft Horsepower
- X7 = Block Coefficient
- X8 = Froude Number

E. CHAPTER SUMMARY

The methodology for the collection of the data consisting of the 45 frigate classes from 29 countries and analysis of the sample is discussed in this chapter. Typical FFGH specifications are explained in detail, and ship design characteristics such as Aegis combat system and machinery configurations of various frigates from the data are clarified as well. The proposed change of hull designation for the LCS class ships to FF in the U.S. Navy is also highlighted for the expected continuing role of frigates. The difference in the manning of the same class of warships, namely frigates, is clarified through the qualitative analyses. Finally, the variables of the regression analysis explained in Chapter IV are described in this chapter.

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IV. RESULTS

A. PRINCIPAL COMPONENT ANALYSIS

The Excel file shown in detail in the Appendix is opened in JMP Pro 12 to conduct the Principal Component Analysis (PCA), which explains the direction of the variation among the independent variables, as shown in Figure 15. PCA is mainly used to eliminate the redundant explanatory variables that would not account for the variance in the dependent variable.

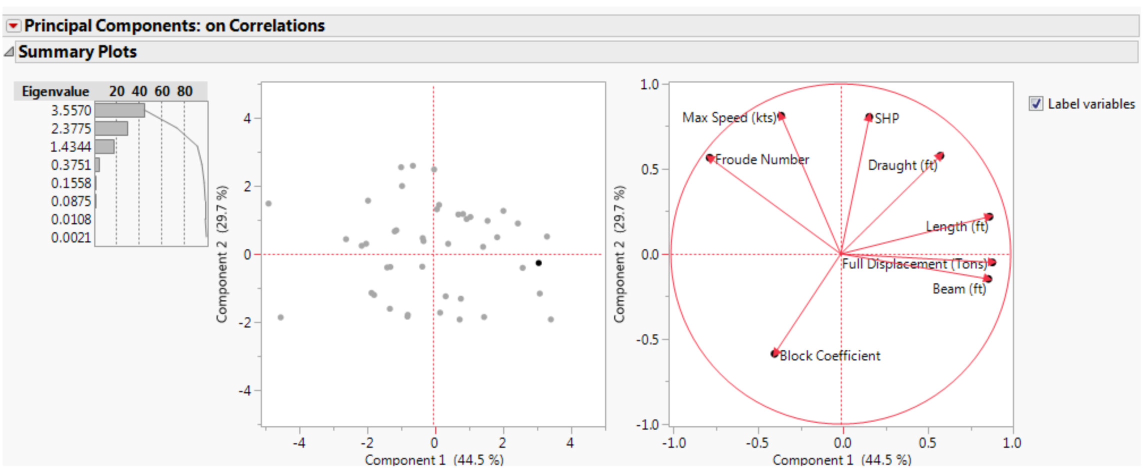


Figure 15. Principal Component on Correlations. Adapted from IHS Jane's Fighting Ships (2016).

The correlation matrix shown in Figure 16 indicates that some level of correlation among some of the independent variables exists. More specifically, the correlated pairs are: {Displacement, Length}, {Displacement, Beam}, {Length, Draught}, and {Max Speed, Froude Number}. Some of these explanatory variables are retained for the regression analysis based on the power of the correlation, and some of them are kept out of the fitted model to prevent from multicollinearity.

Principal Components: on Correlations

Correlations

	Full Displacement (Tons)	Length (ft)	Beam (ft)	Draught (ft)	Max Speed (kts)	SHP	Block Coefficient	Froude Number
Full Displacement (Tons)	1.0000	0.8367	0.9126	0.2934	-0.1968	0.2546	-0.0160	-0.6035
Length (ft)	0.8367	1.0000	0.7129	0.5145	0.0251	0.2766	-0.3423	-0.5179
Beam (ft)	0.9126	0.7129	1.0000	0.2237	-0.3077	0.1762	-0.0478	-0.6408
Draught (ft)	0.2934	0.5145	0.2237	1.0000	0.0485	0.3699	-0.9094	-0.2495
Max Speed (kts)	-0.1968	0.0251	-0.3077	0.0485	1.0000	0.6213	-0.0954	0.8385
SHP	0.2546	0.2766	0.1762	0.3699	0.6213	1.0000	-0.2614	0.3807
Block Coefficient	-0.0160	-0.3423	-0.0478	-0.9094	-0.0954	-0.2614	1.0000	0.1274
Froude Number	-0.6035	-0.5179	-0.6408	-0.2495	0.8385	0.3807	0.1274	1.0000

Figure 16. PCA Correlations Matrix. Adapted from IHS Jane's Fighting Ships (2016).

The interpretation of the Eigenvalues is crucial in understanding how much of the variation is dependent on the explanatory variables. The first three principal components (PC1 is the Full Displacement, PC2 is the Length, and the PC3 is the Beam) cumulatively account for the 92% of the total variation in the dependent variable of the crew complement, as shown in Figure 17. PC1 accounts for the 44% of the total variance, and this is in accordance with the expectation that larger warships will have more manpower requirements personnel onboard. PC2, accounting for nearly 30% of the total variance, can be interpreted in a similar way since the longer ships are generally designed and built to be heavier and larger. "According to Marascuilo and Levin (1983), eigenvalues over 1.0 should be considered for retaining among those variables analyzed" (Williams, 2012, p. 52). Thus, PC1, PC2, and P3 with eigenvalues over 1.0 are retained for the future regression analysis.

The scree plot shown in Figure 17 also helps in the interpretation of the relationship between the eigenvalues and principal components to determine the number of explanatory variables to include in the future regression analysis. The negative slope on the plotted line starts to flatten while approaching to zero after the third dot. The scree plot also shows in a graphical way that three of the PCs should be kept for the regression analysis.

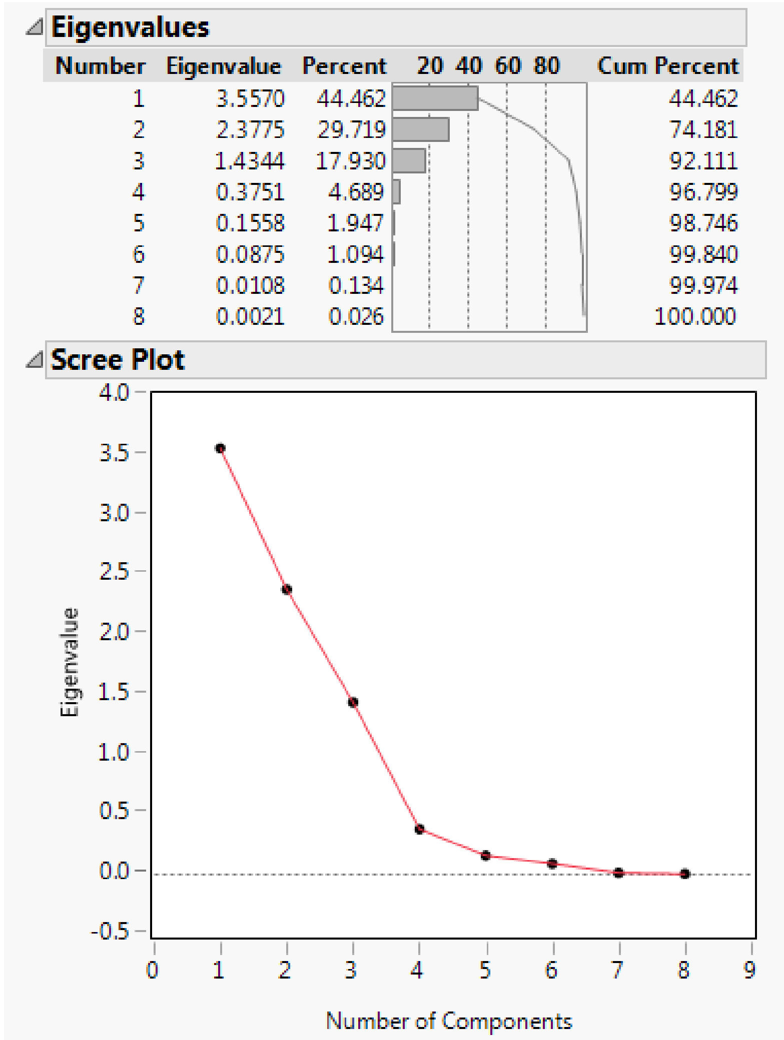
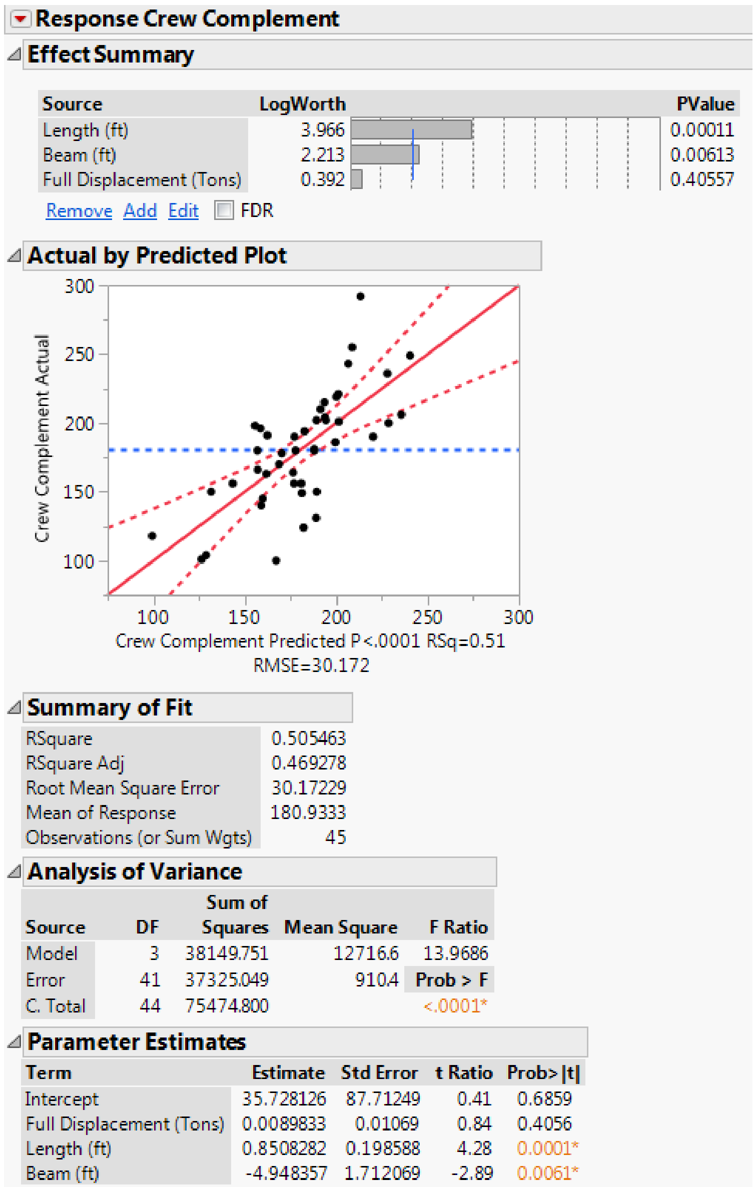


Figure 17. Eigenvalues of the Explanatory Variables and the Scree Plot. Adapted from IHS Jane's Fighting Ships (2016).

B. ORDINARY LEAST SQUARES (OLS) REGRESSION ANALYSIS

The sample Excel data are opened within the JMP Pro 12 and the three explanatory variables determined by the PCA are picked along with the crew complement as the response variable to construct the model. Having fitted the model, the results shown in Figure 18 indicate an R^2 of 0.50 and adjusted R^2 of 0.47. This analytic model explains the 50% of the variance in the crew complement mentioned earlier. Although this R^2 might be considered as low, it still indicates the existing relationship between the explanatory variables and the response variable. In other words, the correlation between the ship design characteristics and the number of personnel is highlighted by the quantitative analysis. The qualitative analyses in Chapter II attempted to explain the other half of the variance. The mean of the response variable is around 181 for the 45 frigates in the sample.



Source	LogWorth	PValue
Length (ft)	3.966	0.00011
Beam (ft)	2.213	0.00613
Full Displacement (Tons)	0.392	0.40557

RSquare	0.505463
RSquare Adj	0.469278
Root Mean Square Error	30.17229
Mean of Response	180.9333
Observations (or Sum Wgts)	45

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	38149.751	12716.6	13.9686
Error	41	37325.049	910.4	Prob > F
C. Total	44	75474.800		<.0001*

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	35.728126	87.71249	0.41	0.6859
Full Displacement (Tons)	0.0089833	0.01069	0.84	0.4056
Length (ft)	0.8508282	0.198588	4.28	0.0001*
Beam (ft)	-4.948357	1.712069	-2.89	0.0061*

Figure 18. Actual by Predicted Plot of the Fitted Model. Adapted from IHS Jane’s Fighting Ships (2016).

The fitted OLS regression analysis shows the length and beam as significant parameters with p-values less than 0.01. To validate the model, the residuals are to have the following specifications:

- Normal distribution
- Being independent or uncorrelated (no significant autocorrelation)
- Constant variance

The validation of the model is basically needed to "separate the signal from the noise" as described by Abma (1995). The residuals meet all the criteria by satisfying all the required assumptions. The residuals seem to be normally distributed as shown in Figure 19.

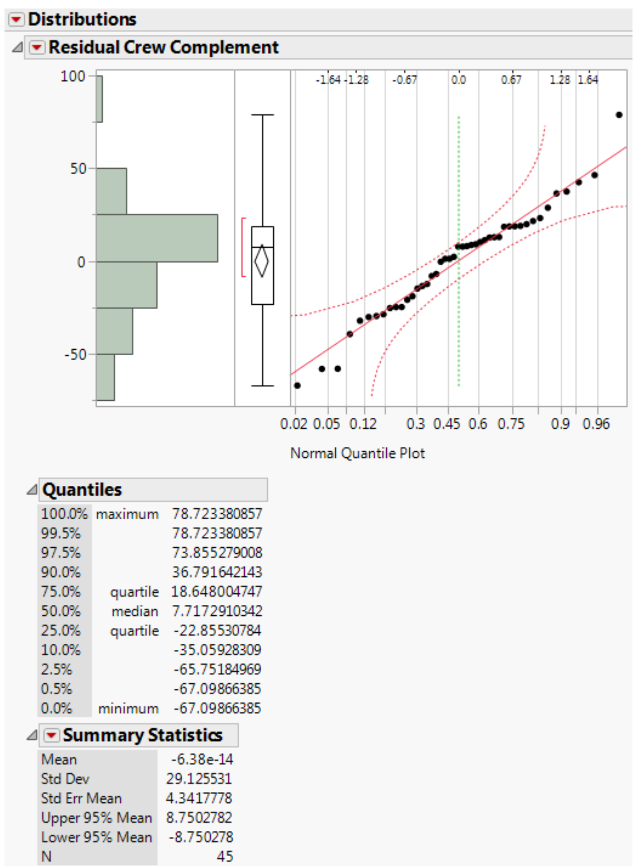


Figure 19. Normal Quantile Plot. Adapted from IHS Jane's Fighting Ships (2016).

The residuals show a shotgun blast pattern in Figure 20, which is a good indication of the constant variance. No specific funneling pattern is an exhibition of the homoscedasticity and the lack of autocorrelation. Therefore, all the required assumptions are met and the OLS regression analysis model is validated.

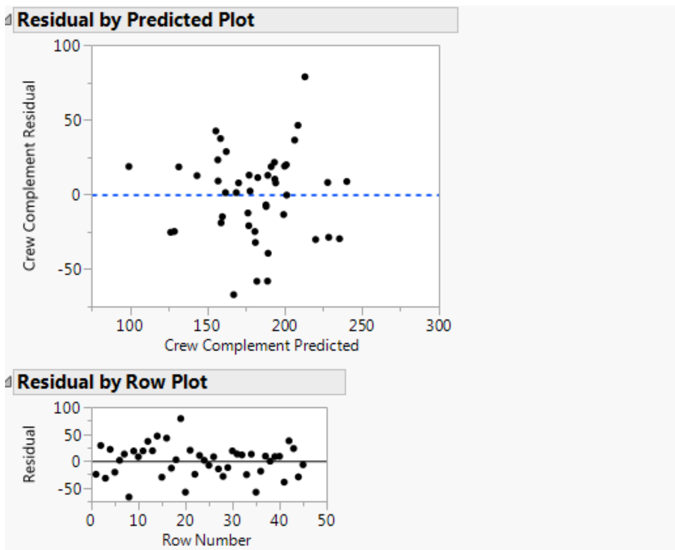


Figure 20. Residual by Predicted Plot of the Fitted Model. Adapted from IHS Jane's Fighting Ships (2016).

C. CHAPTER SUMMARY

PCA is conducted to determine the significant explanatory variables to retain for the OLS regression analysis. The principle principal components of Full Displacement, Length, and Beam are kept for the OLS regression analysis based on the justifications of the eigenvalues and the scree plot. The validated OLS regression analysis of the fitted model results in an R^2 of 0.50 for the variance in the response variable of crew complement. The correlation between the ship design characteristics and the manpower requirements is supported by the quantitative analysis. The qualitative analyses in Chapter II contributed to the explanation of the other half of the variance in crew complement.

V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A. SUMMARY

Frigates have been used by many prominent navies around the world for decades due to their convenient operability in multi-threat environments in a relatively cost-efficient way compared to other types of warships. Based on a four years of experience on two types of Turkish Navy frigates, the researcher examined the difference in manpower requirements of the 45 frigates (FFGHs) from 29 nations. The data gathered from the IHS Jane's Fighting Ships database include nearly all the prominent frigates built or under construction. The access to the unclassified intelligence database enabled the researcher to collect the data shown in the Appendix using the judgment sampling method and to analyze it through the qualitative and quantitative techniques learned at NPS throughout the 18-months' long study in the MSA curriculum. The combination of the fleet frigate experience and the newly learned skills, such as the regression analysis using JMP Pro 12, supported this research.

Frigates are generally designed and built for a life cycle of 40 years and redundancies in personnel costs might equate to billions of dollars of waste in those time periods, especially considering the total number of ships in a frigate-class. Many professional navies have already started taking precautions against the surplus of manning due to the increasing budget constraints in these times of severe economic crises. For instance, the U.S. Navy prioritizes Human Systems Integration as a top consideration, even in the design and acquisition stages:

> Skilled manpower is an indispensable factor in the successful deployment of new ships, aircraft, equipment, and most other new hardware systems. The human element must be an integral part of system design and logistic support at the earliest acquisition phase. Although there is considerable uncertainty early in the acquisition process, every effort shall be made to use the best available data and techniques in developing manpower estimates. These estimates shall be continuously refined, as the system progresses, to form the basis for operational and maintenance manpower requirements' descriptions, personnel selection and training, training

> devices and simulator design, and other planning related to Manpower, Personnel, and Training (MPT). (U.S. Department of the Navy, 2002)

The correlation between the frigate design characteristics and manpower requirements therefore plays a pivotal role in achieving the desired reduced manning levels. One of the main benefits of this research is to provide a deeper understanding of the correlation between frigate design specifications and manpower requirements and to use this knowledge in the TF-2000 project design process. Furthermore, the Human Resources and Surface Warfare communities can benefit from the study to readjust their numbers of crew complement onboard frigates based on the research findings. The evaluated paradigm shifts or transformations in the organizational cultures and mindsets require a holistic approach to align all entities such as fleets, shipyards, training facilities, etc., in a navy with strategic manpower goals.

This research reviewed some of the best practices such as the latest status of the U.S. Navy's standard workweek, NPS Systems Engineering Ship Synthesis Model, Williams' (2012) HSI Synthesis Manpower Model, a Rand Corporation study on the recent defense personnel trends, which enabled this author to analyze how frigate design characteristics correlate with the manpower needs. Additionally, the general attitude towards the military and changing worldviews of the new generation add new dimensions to the manpower domain of the HSI. Choosing the specific types of combat systems, machinery configuration, and other ship specifications for the TF-2000 frigates is an enormous project and can only be achieved with a dedicated workforce. The results of the quantitative analyses in Chapter IV also complement the qualitative analyses to understand the optimal manning of frigates based on ship design characteristics and aforementioned specifications. This research should complement more advanced analyses of the manpower requirements for the TF-2000 project.

B. CONCLUSIONS AND RECOMMENDATIONS

Research Question 1: *How do frigate design characteristics correlate with manpower systems onboard a warship and manpower requirements?*

Conclusion: The OLS regression analysis conducted in JMP Pro 12 supports the intuitive logic that larger ships necessitate larger crew complements. Moreover, the qualitative analyses discussed in Chapter III suggest paying attention to details in determining many ship specifications, from radars to weapon systems and machinery configuration.

Recommendation: Manpower analysts and/or HSI professionals not only in the Turkish and the U.S. navies but also other nations' navies can develop more advanced models for the integration of the manpower domain with the rest of the HSI domains into the ship design processes and reach to more comprehensive syntheses in this field of endeavor.

Research Question 2: *How do specific relationships between ship design specifications and manpower requirements affect the optimal number of crew complement?*

Conclusion: Having reviewed 45 different frigate classes from 29 nations, the author's major conclusion from the sample data is the range of 100–292 manpower requirements for the response variable of crew complement with a mean of 181 and standard deviation of 41.

Recommendation: Finding ways to include weapon systems, radars, and features of the machinery configurations can pave the way for more sophisticated models with more accuracy to find optimal crew complements for a given frigate with certain specifications.

Research Question 3: *How can the specified relationships be incorporated into the design process of Turkish Frigate-2000 (TF-2000)?*

Conclusion: This research provides a range of 100–292 manpower requirements for the crew complements of the reviewed frigates in this research by explaining the reasons for the difference in manning of those frigates by different navies based on the specific relationships between the ship design specifications and manpower requirements. Likewise, reviewed studies in the Chapter II offers some best practices that can be incorporated into the design process of TF-2000.

Recommendation: Personnel in charge of the TF-2000 project in the Turkish Navy can take advantage of the research findings by incorporating them into the TF-2000 project for the realization of this project in a near future.

Research Question 4: *How can the Human Systems Integration (HSI) domains be utilized to estimate an optimal number of manpower requirements?*

Conclusion: Reviewing the HSI domains and applying a multi-disciplinary approach to this research enabled a better understanding of the determinants of manpower needs onboard frigates.

Recommendation: The data sample can be used as a stepping stone to take advantage of the best practices of the international navies within the framework of the HSI domains, can be very helpful in the development of the TF-2000 project and determining the optimal manning onboard these frigates.

Research Question 5: *Can the IHS Jane's data be used to incorporate the specified correlations between frigate design characteristics and manpower requirements into a frigate manpower systems integration model?*

Conclusion: The sample data can be considered as very comprehensive due to the wide-ranging characteristic with the inclusion of the many prominent navies' frigates from countries like the United States, United Kingdom, China, Russia, South Korea, Germany, Japan, Germany, France, Turkey, etc. This broad list includes nearly all types of technologies from the Aegis weapon system to Smart-S radars, from Rolls-Royce gas turbines to the LM2500 gas turbines, etc.

Recommendation: The Turkish Navy should supplement forecasting manpower requirements for the TF-2000 frigates based on the analyses of this research in determining the specifications of prototype ships.

C. FURTHER RESEARCH

Future studies might examine all HSI domains while developing their quantitative models. This research primarily used the crew complement as the response variable. Additionally, adding new independent variables, such as the ship specifications excluded from this research, should be considered to explain the variance of the manpower requirements more fully by increasing the R^2 in their regression analyses. Future researchers may also combine the data from different ship classes to increase the validity of their models. Finally, integration of the other workload factors or navy standard workweek requirements may further improve the accuracy and quality of the future research.

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APPENDIX. THE DATA GATHERED FROM THE IHS JANE'S FIGHTING SHIPS DATABASE. ADAPTED FROM IHS JANE'S (2016).

1	Nation	Ship Class Name	Crew Complement	Full Displacement (Tons)	Displacement (lbs	Length (ft)	Beam (ft)	Draught (mt)	Draught (ft)	Max Speed (kts	Max Speed (m/s	SHP	Block Coefficient	Froude Number	# of ships
2	Argentina	Espora (Meko 140 A16)	104	2,072.3	4,144,600	299.2	36.4	3.41376	11.2	28	14.4	20,400	0.017	0.266	6
3	Australia	ANZAC (MEKO 200)	191	4,199.8	8,399,600	387.1	48.6	4.35864	14.3	27	13.9	30,172	0.016	0.225	8
4	Belgium	M class	149	3,718.1	7,436,200	406.2	47.2	4.29768	14.1	30	15.4	33,800	0.014	0.244	2
5	Canada	Halifax	215	5,342.9	10,685,800	441.9	53.8	7.10184	23.3	29	14.9	47,494	0.010	0.227	12
6	Chile	Blanco Encalada (M)	156	3,718.1	7,436,200	401.2	47.2	4.29768	14.1	30	15.4	33,800	0.014	0.246	2
7	China	JIANGWEI II	170	2,519.9	5,039,800	366.5	40.7	4.78536	15.7	27	13.9	24,000	0.011	0.232	10
8	China	Jiangkai II (Type 054A)	202	4,368.5	8,737,000	439.6	52.5	4.99872	16.4	27	13.9	28,200	0.012	0.212	30
9	Denmark	Iver Huitfeldt	100	7,324.9	14,649,800	455.1	65	6.30936	20.7	28	14.4	44,000	0.012	0.216	3
10	France	Frégate de Taille Intermédiaire	150	4,684.8	9,369,600	401.1	58.1	3.8	12.5	27	13.9	42912	0.016	0.221	5
11	France	La Fayette	178	4,200.0	8,400,000	407.5	50.5	5.7912	19	25	12.9	21107	0.011	0.203	5
12	France	Floréal	118	3,303.6	6,607,200	306.8	45.9	4.29768	14.1	20	10.3	8,820	0.017	0.188	6
13	Germany	Brandenburg class (Type 123)	243	6,048.4	12,096,800	455.7	54.8	6.79704	22.3	29	14.9	62,070	0.011	0.223	4
14	Germany	Bremen class (Type 122)	219	4,121.5	8,243,000	426.5	47.6	6.49224	21.3	30	15.4	51,000	0.010	0.239	3
15	Germany	Sachsen class (Type 124)	255	6,272.2	12,544,400	469.2	57.1	6.88848	22.6	29	14.9	51,642	0.010	0.220	3
16	Germany	Baden-Württemberg (Type 12!	190	8064.5	16,129,000	490.5	61.7	4.99872	16.4	26	13.4	42,920	0.016	0.193	4
17	Greece	Hydra class (Meko 200 HN)	198	3,752.3	7,504,600	383.9	48.6	6.00456	19.7	31	15.9	60,000	0.010	0.260	4
18	Greece	Elli (Kortenaer)	186	4,065.3	8,130,600	428.1	47.9	6.18744	20.3	30	15.4	50,880	0.010	0.238	9
19	India	Talwar (Project 1135.6)	180	4,519.5	9,039,000	409.4	49.9	4.69392	15.4	32	16.5	43,448	0.014	0.260	10
20	India	Shivalik (Project 17)	292	6,943.5	13,887,000	469.2	57.4	5.30352	17.4	30	15.4	59,200	0.015	0.227	3
21	Italy	Bergamini	131	7,385.5	14,771,000	472.1	63.6	5.39496	17.7	27	13.9	42,912	0.014	0.204	10
22	Italy	Maestrale	221	3,583.6	7,167,200	402.6	42.3	4.60248	15.1	32	16.5	61,000	0.014	0.262	8
23	Netherlands	M class	156	3,681.7	7,363,400	406.2	47.2	6.18744	20.3	29	14.9	34,200	0.009	0.236	2
24	Netherlands	De Zeven Provincien	204	6,773.7	13,547,400	473.1	61.7	5.21208	17.1	28	14.4	52,300	0.014	0.211	4
25	New Zealand	Anzac (Meko 200)	163	4,143.6	8,287,200	387.1	48.6	4.38912	14.4	27	13.9	30,172	0.015	0.225	2
26	Norway	Fridtjof Nansen	180	5,924.9	11,849,800	437	55.1	4.90728	16.1	26	13.4	38,352	0.015	0.204	5
27	Pakistan	Sword	202	3,284.9	6,569,800	403.5	43.3	3.81	12.5	29	14.9	28200	0.015	0.237	4
28	Philippines	FFGHM	145	3,583.6	7,167,200	375	45.9	3.99288	13.1	30	15.4	58200	0.016	0.254	2
29	Poland	Oliver Hazard Perry class	200	4,074.1	8,148,200	444.9	44.9	7.49808	24.6	29	14.9	41,000	0.008	0.226	2
30	Portugal	Bartolomeu Dias (M)	164	3,659.7	7,319,400	401.2	47.2	6.4008	21	29	14.9	33,800	0.009	0.238	2
31	Russian Federatior	Admiral Gorshkov	210	5,015.5	10,031,000	442.9	53.8	4.38912	14.4	29	14.9	27,500	0.015	0.226	6
32	Russian Federatior	Admiral Grigorovich	190	4,447.8	8,895,600	409.4	49.9	4.60248	15.1	32	16.5	43,488	0.014	0.260	6
33	Saudi Arabia	Madina (Type F 2000s)	194	3,214.3	6,428,600	377.3	41	4.90728	16.1	30	15.4	38,400	0.013	0.254	4
34	Singapore	Formidable (Project Delta)	101	3,583.6	7,167,200	374	52.5	4.99872	16.4	27	13.9	48,276	0.011	0.229	6
35	South Africa	Valour class (Meko A-200 SAN)	156	4,021.2	8,042,400	397	53.8	6.18744	20.3	28	14.4	42,922	0.009	0.231	4
36	South Korea	FFX-II	124	4,023.4	8,046,800	400.6	46.6	7.40664	24.3	30	15.4	67,040	0.009	0.246	8
37	South Korea	Incheon (FFX-I)	140	3,583.6	7,167,200	374	45.9	7.40664	24.3	30	15.4	67,040	0.009	0.255	6
38	South Korea	Ulsan	166	2,576.1	5,152,200	334.6	37.7	3.5052	11.5	34	17.5	53,640	0.018	0.305	7
39	Spain	Alvaro de Bazán	201	6,555.4	13,110,800	480.3	61	7.19328	23.6	28	14.4	47,328	0.009	0.210	5
40	Spain	Santa María	236	4,445.6	8,891,200	451.8	46.9	7.49808	24.6	29	14.9	41,000	0.009	0.224	6
41	Taiwan	Cheng Kung	249	4,597.7	9,195,400	453.1	44.9	7.49808	24.6	29	14.9	41,000	0.009	0.224	8
42	Thailand	Naresuan class (Type 25T)	150	3,337.8	6,675,600	393.7	42.7	3.81	12.5	32	16.5	44,250	0.016	0.265	2
43	Turkey	Barbaros (Meko 200)	196	3,785.3	7,570,600	387.1	48.6	6.4008	21	32	16.5	60,000	0.010	0.267	4
44	Turkey	Yavuz class (Meko 200 TN)	180	3,269.5	6,539,000	378.9	46.6	4.1148	13.5	27	13.9	29,940	0.014	0.228	4
45	Turkey	Gabya (Oliver Hazard Perry)	206	4,074.1	8,148,200	453.1	44.9	7.49808	24.6	29	14.9	41,000	0.008	0.224	8
46	United Kingdom	Duke class (Type 23)	181	4,703.6	9,407,200	436.4	52.8	7.3152	24	28	14.4	31,100	0.009	0.220	13

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