NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

SYSTEMS ENGINEERING CAPSTONE REPORT

A SYSTEMS ENGINEERING ANALYSIS OF THE PESTONI PILLARS AS THEY APPLY TO USN SURFACE WARSHIPS

by

Daniel Bethancourt, Thomas H. Hatch, Shawn M. Nibert,
and Daniel J. Wirth

March 2021

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<tr><td colspan="3">REPORT DOCUMENTATION PAGE</td><td>Form Approved OMB No. 0704-0188</td></tr>
<tr><td colspan="4">Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC 20503.</td></tr>
<tr><td>1. AGENCY USE ONLY
(Leave blank)</td><td>2. REPORT DATE
March 2021</td><td colspan="2">3. REPORT TYPE AND DATES COVERED
Systems Engineering Capstone Report</td></tr>
<tr><td colspan="3">4. TITLE AND SUBTITLE
A SYSTEMS ENGINEERING ANALYSIS OF THE PESTONI PILLARS AS THEY APPLY TO USN SURFACE WARSHIPS</td><td rowspan="2">5. FUNDING NUMBERS</td></tr>
<tr><td colspan="3">6. AUTHOR(S) Daniel Bethancourt, Thomas H. Hatch, Shawn M. Nibert, and Daniel J. Wirth</td></tr>
<tr><td colspan="3">7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey, CA 93943-5000</td><td>8. PERFORMING ORGANIZATION REPORT NUMBER</td></tr>
<tr><td colspan="3">9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
N/A</td><td>10. SPONSORING / MONITORING AGENCY REPORT NUMBER</td></tr>
<tr><td colspan="4">11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.</td></tr>
<tr><td colspan="3">12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release. Distribution is unlimited.</td><td>12b. DISTRIBUTION CODE
A</td></tr>
<tr><td colspan="4">13. ABSTRACT (maximum 200 words)
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<tr><td colspan="3" rowspan="2">14. SUBJECT TERMS
future guided-missile frigate, FFG(X), PESTONI pillars</td><td>15. NUMBER OF PAGES
99</td></tr>
<tr><td>16. PRICE CODE</td></tr>
<tr><td>17. SECURITY CLASSIFICATION OF REPORT
Unclassified</td><td>18. SECURITY CLASSIFICATION OF THIS PAGE
Unclassified</td><td>19. SECURITY CLASSIFICATION OF ABSTRACT
Unclassified</td><td>20. LIMITATION OF ABSTRACT
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NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89)
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A SYSTEMS ENGINEERING ANALYSIS OF THE PESTONI PILLARS AS THEY APPLY TO USN SURFACE WARSHIPS

Daniel Bethancourt, Thomas H. Hatch, Shawn M. Nibert, and Daniel J. Wirth

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
March 2021

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ABSTRACT

This project develops a tool to better understand the impact of resource allocation on fleet readiness for the future guided-missile frigate, FFG(X). This project assesses the FFG(X) in terms of the PESTONI pillars (Personnel, Equipment, Supply, Training, Ordnance, Network, and Infrastructure). To use the PESTONI framework as a way to increase FFG(X) readiness, both a qualitative and a quantitative solution were developed. The qualitative solution is a series of failure propagation chain diagrams that represent how funding changes within one pillar affect the other pillars. The quantitative solution is the readiness model itself. The readiness model decomposes each pillar in a way that is relatable to the way the FFG(X) will operate when fielded. Once each pillar was independently constructed and tested, the pillars were interconnected in the same way they are presented in the failure propagation chain diagrams. The designed operation of the readiness model is to load the model with pertinent FFG(X) data that is then used in conjunction with both current and future funding allocations to estimate FFG(X) readiness. The readiness model is verified using multiple use case scenarios that demonstrate funding shifts cannot simply be equal across the PESTONI pillars, but they must be optimized to maximize FFG(X) readiness. The FFG(X) readiness model aims to present the user with objective information that will aid in producing the highest possible ship readiness.

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LIST OF ACRONYMS AND ABBREVIATIONS

AC	Active
ADT	Administrative Delay Time
A_o	Operational Availability
$A_{o,c}$	Operational Availability Current
$A_{o,f}$	Operational Availability Future
AMSRR	Aviation Maintenance Supply Readiness Reports
ANA	Authorization NAVSEA Allowance
ASW	Anti-Submarine Warfare
AAW	Anti-Aircraft Warfare
AW	Air Warfare
BUPERS	Bureau of Naval Personnel
CMP	Class Maintenance Plan
CNAF	Commander, Naval Air Forces
CNO	Chief of Naval Operations
Co	Current On
COB	Currently on Board
CSMP	Current Ships Maintenance Project
DOD	Department of Defense
DRRS-N	Defense Readiness Reporting System-Navy
EW	Electronic Warfare
FF	Frigate
FFG RET	FFG Requirements Evaluation Team
FFG(X)	Experimental Guided Missile Frigate
FOM	Figure of Merit
Gs	Skill Gap
Hq	Hand Quantity
IFOM	Infrastructure Figure of Merit
INCOSE	International Council on Systems Engineering

iNFADS	Internet Navy Facility Assets Data Store
LCS	Littoral Combat Ship
LDT	Logistics Delay Time
$\bar{M}$	Mean Active Maintenance Time
MDT	Maintenance Downtime
MFOM	Maintenance Figure of Merit
MOE	Measure of Effectiveness
MOP	Measure of Performance
MTTR	Mean Time To Repair
MTBF	Mean Time Between Failure
MTBM	Mean Time Between Maintenance
NALCOMIS	Naval Logistics Command/Manger Information System
NAVSEA	Naval Sea Systems Command
NEC	Navy Enlisted Certification
NFOM	Network Figure of Merit
NMET	Navy Mission-Essential Task
NSWC PHD	Naval Surface Warfare Center, Port Hueneme Division
NTA	Naval Tactical Task
NTIMS	Navy Training Information Management System
OFOM	Ordnance Figure of Merit
OPREP-5	Operations Summary Reports
OpsCon	Operational Concepts
PEO	Program Executive Office
PESTO	Personnel, Equipment, Supply, Training, Ordnance
PESTONI	Personnel, Equipment, Supply, Training, Ordnance, Network, Infrastructure
PFOM	Personnel Figure of Merit
PFOMc	Current Personnel Figure of Merit
PFOMf	Future Personnel Figure of Merit
RC	Reserve

RCN	Rating Control Number
RFI	Request for Information
Rs	Skill Requirements
R3B	Resources and Requirements Review Board
SE	Systems Engineering
SECDEF	Secretary of Defense
SFOM	Supply Figure of Merit
SoS	System of Systems
SSCTF	Small Surface Combatant Task Force
SECNAV	Secretary of the Navy
SSC	Small Surface Combatant
SuW	Surface Warfare
TFIRM	Total Force Integrated Readiness Model
TFOM	Training Figure of Merit
TTRCE	Training Readiness Calculation Engine
T&E	Test and Evaluation
USC	Unmanned and Small Combatants
2-Kilos	Action Forms

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EXECUTIVE SUMMARY

FFG(X) is the notional designation of a new class of guided-missile frigates currently under development for the United States Navy (OPNAV N96E 2019). The FFG(X) will be an addition to the Small Surface Combatant (SSC) family of ships tasked with executing multiple types of missions. The FFG(X) will provide more offensive, defensive, and survivability capabilities than any other ship in its class. Ultimately, the FFG(X) will augment the Navy's forward presence and contact layer force (OPNAV N96E 2019).

For the FFG(X) to be successful once fielded, it is useful to assess how changes in programmatic funding affect the overall readiness of the frigate itself. Given the diverse set of capabilities the FFG(X) will have, comes an equally complex problem of understanding how resource allocation will impact frigate readiness. The purpose of this study was to examine the FFG(X) from a funding perspective and develop a tool that will aid the decision makers in allocating program resources in a way that maximizes FFG(X) readiness.

The resource allocation methodology this project analyzed was the PESTONI (Personnel, Equipment, Supply, Training, Ordnance, Network, and Infrastructure) pillars. The idea behind PESTONI is that any dollar spent on the FFG(X) would fall under one of the seven pillars of PESTONI. The simplicity of PESTONI as a resource allocation model is understandably attractive to most program offices. Unfortunately, there is very little guidance or documentation on what is contained within each pillar and even less information on how changes in one pillar will affect any of the other pillars. To use the PESTONI framework as a way to increase FFG(X) readiness, both a qualitative and a quantitative solution had to be developed.

The qualitative solution is a series of failure propagation chain diagrams that provide a visual representation of how funding changes within one pillar ripple out across the other pillars. These failure propagation chain diagrams also act as a quick reference to understanding why the FFG(X) cannot adjust the funding to one pillar without there being consequences across the rest of the pillars. Later, the development of the readiness model used the failure propagation chains as a roadmap to ensure the pillars were interconnected correctly.

The quantitative solution is the readiness model itself. The readiness model decomposes each pillar in a way that is relatable to the way the FFG(X) will operate when fielded. Each pillar's functional decomposition was structured in a way that coupled real-life scenarios with well-studied methods to populate the individual pillar's Figure of Merit (FOM). Pillars, such as equipment and supply, were populated with widely accepted concepts such as reliability, availability, and maintainability, while other pillars, such as personnel and training, used aspects of the Kirkpatrick model to develop that pillar's FOM. While methods used to decompose and populate each pillar were novel in the way they coupled various concepts to express readiness, each method used was extensively researched and documented. After each pillar was constructed, and prior to the pillars being interconnected, they were validated and verified to be accurate using previously substantiated models or information.

Once each pillar was independently constructed and tested, the pillars were interconnected much in the same way they are presented in the failure propagation chain diagrams. The method used to interconnect the pillars was developed in a way such that the project would be able to be completed, despite the lack of data available due to the ship not yet being fielded. The method uses a series of coefficients inserted throughout the model that relate changes in funding to changes in traditional readiness values such as Mean Time To Repair (*MTTR*) or Mean Time Between Failure (*MTBF*). The coefficients in the final model will be arbitrary until the FFG(X) is fielded and enough data is collected to make accurate correlations between funding and the calculated variables. The method of coefficients also allows for convenient changes in the future should those relationships change in any way.

The designed operation of the readiness model is to load the model with pertinent FFG(X) data that is then used in conjunction with both current and future funding allocations to estimate FFG(X) readiness. The model is equipped with ways to disperse equally the funding change or to change the funding of each pillar individually on the model's dashboard. The dashboard also contains each pillar's FOM as a quick reference to understanding the health of the pillar following the funding shift. The overall readiness of the FFG(X) is presented to the user as well as on the dashboard, in the form of the ship's Operational Availability (A_o). The readiness model is intended to aid in resource allocation whether there is a funding increase, decrease, or if the funding remains the same.

Efficacy of the readiness model is verified using multiple use case scenarios. Each scenario demonstrated that funding shifts cannot simply be equal across the PESTONI pillars, but they must be optimized in a way that maximizes the ship's readiness. While optimization of funds is not a new concept, a method that removes any conscious or subconscious bias and presents the user with objective information that will aid in producing the highest possible ship readiness has the potential to be extremely valuable to the Navy of tomorrow.

Reference

Zvijac, David. 2017. *Risk and Reward in Investment Decisions.* Chicago: CNA Analysis and Solutions.

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ACKNOWLEDGMENTS

First, we would like to extend our gratitude to Professors O'Halloran and Beery for their patience and direction during this challenging process. Thanks for the feedback and support that you provided us. We would also like to thank our individual commands for sponsoring us and giving us the opportunity to attend Naval Postgraduate School.

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I. INTRODUCTION

The Missile Frigate FFG(X) is the notional designation of a class of guided-missile frigates for the United States Navy, which was contracted in 2020 (OPNAV N96E 2019). In July 2017, the Chief of Naval Operations (CNO) directed for the top-level requirements for the FFG(X) to be provided to industry through a Request for Information (RFI) (OPNAV N96E 2019). The FFG(X) will be incorporated into the SSC family of ships for lethal multi-missions to support Air Warfare (AW), Anti-Submarine Warfare (ASW), Surface Warfare (SuW), and Electronic Warfare (EW). Given the broad range of potential missions and associated demands for the FFG(X), this report develops an FFG(X) readiness model by gathering information input from the PESTONI pillars to estimate fleet readiness. The model was equipped with the functional decomposition diagrams that would provide a visual representation of the relationships between each pillar. The PESTONI pillars had a great influence on developing the FFG(X) readiness model when it explored and understood the interrelationships between the pillars. Having a better understanding of the pillars and how each pillar influence each other allowed senior leadership to have a better assessment concerning making better investment decisions (OPNAV N96E 2019).

A. BACKGROUND

In February 2014, the Secretary of Defense (SECDEF) gave direction to the Navy to conduct an analysis and submit proposals to procure an SSC that would have the capabilities to make it more lethal than the Littoral Combat Ship (LCS) (OPNAV N96E 2019). In December 2014, this plan was approved and by January 2015, the Secretary of the Navy (SECNAV) designated this ship as a Frigate (FF) (OPNAV N96E 2019). The CNO directed the Navy to conduct a follow-on study to the Small Surface Combatant Task Force (SSCTF) to ensure that there would be an increase in air defense and survivability beyond the FF. The outcome of this path was an FFG Requirements Evaluation Team (FFG RET) study that was conducted by requirement managers, acquisition professionals, cost estimators, naval architects, and fleet warfighters to look at various hull designs and potential improvements in air defense and vulnerability characteristics (OPNAV N96E

2019). In May 2017, the Resources and Requirements Review Board (R3B) reached a decision on the draft threshold capabilities for the FFG(X) would have (Hanley 2019). The CNO then directed that the top-level requirements be provided to industry by using an RFI on July 11, 2017, to have a better understanding of the competitive environment and to identify potential cost drivers (OPNAV N96E 2019). After getting input from industries, the top-level requirements were refined and then the CNO approved the top-level requirements for FFG(X). The FFG(X) will serve as an integral part of the Navy's validated Force Structure Assessment and Future Fleet Architecture requirements for SSCs (OPNAV N96E 2019).

B. SYSTEMS ENGINEERING METHOD

The systems engineering method that was chosen to execute this project is based on the Vee model presented in the *INCOSE Systems Engineering Handbook* (INCOSE 2015, 34) and shown in Figure 1. The Vee model was determined to be the best suited sequential method due to the model highlighting "the need for continuous validation with the stakeholders, the need to define verification plans during requirements development, and the importance of continuous risk and opportunity assessment" (INCOSE 2015, 34). With the intended flexibility of the frigate readiness model, the entire Vee sequence will be adhered to.

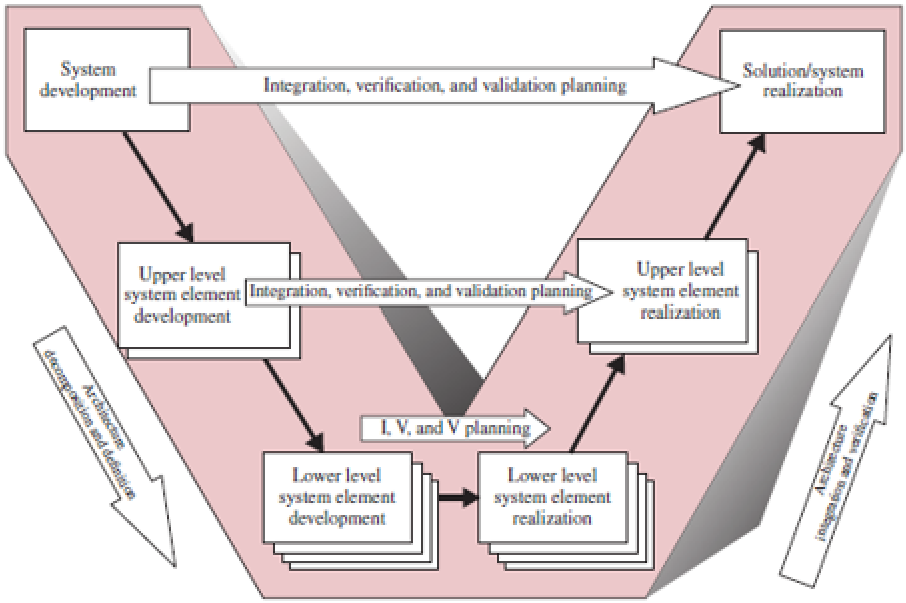

Figure 1. Vee Model. Adapted from INCOSE (2005, 41).

The Vee model was tailored according to (Van Bossuyt et al. 2019) which identifies a sequence of technical processes well suited to capstone studies. The capstone team analyzes and executes six of the technical processes during the duration of this capstone project. These processes are Mission analysis, Stakeholder Needs and Requirements, System Requirements Definition, Architecture Definition, Design Definition, and System Analysis.

1. Stakeholder Needs and Requirement Process

According to the *INCOSE Handbook*: "the purpose of the Stakeholder Needs and Requirements Definition process is to define the stakeholder requirements for a system that can provide the capabilities needed by users and other stakeholders in a defined environment" (INCOSE 2015, 42). The stakeholder needs and requirements process includes preparation for the definition process, the development of Operational Concepts (OpsCon), and the development of measures of effectiveness (MOE). To initiate the Stakeholder Needs and Requirements Definition process, the team elicits the stakeholder needs from the participating identified stakeholders, then refines and transforms them into prioritized stakeholder requirements. The team accomplishes this by conducting Q&A sessions with the project stakeholders. The team then develops the OpsCon and considers other Life Cycle Concepts. In accordance with INCOSE, an OpsCon describes how the system works from the operators' perspective; it delves into the operational environment, providing a lower-level view of the system.

2. System Requirements Definition Process

According to the *INCOSE Handbook*: "the purpose of the System Requirements Definition process is to transform the stakeholder, user-oriented view of desired capabilities into a technical view of a solution that meets the operational needs of the user" (INCOSE 2015, 42). The system requirements definition process includes preparation for the system requirement definition and the development of measures of performance (MOP). The team prepares for system requirement definition by developing a sound understanding of the stakeholders' needs and the concept of operations from the stakeholder needs and requirement process. System requirement definition involves the identification of critical quality characteristics relevant to the system. The team accomplished this by researching the functionality of the FFG(X), as well as the top-level functionality of the PESTONI pillars. The pairing of stakeholder requirements with system requirements enabled a higher degree of traceability for the team and facilitated the establishment of requirements records. Development of MOPs ensured the system requirements are satisfied. This process leads to the architecture definition process.

3. Architecture Definition Process

According to the *INCOSE Handbook*: "the purpose of the Architecture Definition process is to generate system architecture alternatives, to select one or more alternatives that frame stakeholder concerns and meet system requirements, and to express this in a set of consistent views" (INCOSE 2015, 47). The architecture definition process includes the development of architectural viewpoints, models, and definitions of interfaces. The team identifies necessary technical, business, and operational information that allows the development of architectural viewpoints. The development of models and views describes interactions of the system entities with one another and defines the system interfaces. The interfaces between the architectural elements are defined to ensure that the data elements necessary for the system to work are available. The team assesses the identified architectural candidates using system analysis and risk analysis processes.

4. Design Definition Process

According to the INCOSE Handbook, "the purpose of the Design Definition process is to provide sufficient detailed data and information about the system and its elements to enable the implementation consistent with architectural entities as defined in models and views of the system architecture" (INCOSE 2015, 49). System design supplements the system architecture providing information and data useful and necessary for the implementation of the system elements (INCOSE 2015, 49).

5. System Analysis Process

According to the *INCOSE Handbook*, "the purpose of the System Analysis process is to provide a rigorous basis of data and information for technical understanding to aid decision-making across the life cycle" (INCOSE 2015, 56). Throughout the system analysis process, action items are determined along with corresponding scheduling and budget estimates to fulfill the requirement at hand. "It validates that all activities are operating from the same set of requirements, agreements, and design iteration. It also evaluates the outputs of the other activities and conducts independent studies to determine which of the alternate approaches is best suited to the application" (Center 2005, 57). By analyzing cost, viability, technical risk, effectiveness, along with other essential quality attributes, the team can then perform quantitative evaluations and approximations. "The results of analyses and estimations, as data, information, and arguments, are provided to the decision management process for selecting the most efficient alternative or candidate" (INCOSE 2015, 56).

C. TEAM STRUCTURE AND SOFTWARE SELECTION

The structure of the FFG(X) team was created to provide clear and defined roles throughout the capstone project. Determining these roles helped improve team coordination and choose software to use for this project. Software selection is a key factor in any project. The selected software accommodated the long-term decisions about the stakeholders' needs. Making these decisions the correct way can help avoid costly implementation mishaps throughout the duration of any project.

The team separated participants into major functional areas as graphically shown in Figure 2. The structure assigns a team member to each function while giving the team the responsibilities to ensure project continuity in case of any member absence due to required work travel or uncontrollable events. The team consists of four major roles, a team lead, and designated communicator as shown in Figure 2. The roles consist of Program Archiver, Program Scheduler, Program Editor/Publisher, and Project Modeler. Additionally, each team member will help fill all roles when necessary to even out the workload throughout the duration of this project.

Figure 2. Team Organizational Structure

1. Project Roles and Participants

Each team member performs their assigned functions as needed. They also contribute to other functional areas when their expertise, interests, and the needs of the project require it. Table 1 shows the functional area of the assigned team member.

Table 1. Team Member Assignments

Functional Area	**Team Member**
Team Lead	Daniel Wirth
Program Archiver	Thomas Hatch
Program Communicator	Daniel Bethancourt
Program Editor/Publisher	Daniel Wirth
Project Modeler	Daniel Bethancourt
Program Scheduler	Shawn Nibert

Team Lead (Wirth): Responsible for the overall forward momentum of the project. The team lead will delegate tasks not already assigned herein.

Program Archiver (Hatch): Responsible for collecting, storing, and compiling all data derived throughout the capstone project.

Program Communicator (Bethancourt): Responsible for the timely and professional communication to all outside entities and acts as a single point of contact for reaching the team.

Program Editor/Publisher (Wirth): Performs final review of deliverables for content and formatting and is responsible for the submission.

Program Modeler (Bethancourt): Responsible for the management of the model development and end-product functionality.

Program Scheduler (Nibert): Responsible for scheduling milestones, deliverable dates, and for keeping the teams' members well informed of upcoming tasks.

2. Software Selection

The team utilizes the MBSE tool *Innoslate* to represent all system models to stakeholders and all other relevant parties. *Innoslate* was the tool chosen due to its accessibility, collaborative ability, and overall effectiveness in illustrating SE models. For the actual development of the FFG(X) Reliability Model, Microsoft Excel will be used to perform all calculations and functionality of the actual model. The primary reference document used during the system engineering (SE) process of this capstone project is the International Council of Systems Engineering (INCOSE) Handbook (2015).

D. BENEFIT OF STUDY

Understanding the purpose of research behind the FFG(X) was beneficial to the project team, stakeholders, and everyone involved with this capstone project. It assisted with the intellectual vitality, creativity, and shape of the project. Benefits of study are used to recognize whom the project is for, to improve learning, and to hone skills.

The project develops an FFG(X) Readiness Model tailored to support ongoing readiness analysis taking place at the Naval Sea System Command (NAVSEA), Program Executive Office (PEO) Unmanned and Small Combatants (USC) Frigate Program Office (PMS 515). The Stakeholders in this project are Naval Sea Systems, PEO USC/PMS 515, and FFG(X) Operators. Recall that the FFG(X) will supplement the fleet's capabilities, operations, and overall system. The FFG(X) will also take the place of large surface combat ships from strenuous missions other than wartime operations. For the FFG(X) to be effective in its desired roles, the overall readiness impacts of the fleet must be understood. This project develops a qualitative and quantitative model of PESTONI pillars to assist with resource allocation decisions and improve the overall readiness of the FFG(X).

The tool will collect pertinent information from each PESTONI pillar and evaluate the collected data to provide unbiased information to the decision makers as to the end effect on fleet readiness. The tool will also include graphical representations of how the PESTONI pillars interact with one another to provide additional information regarding the causal relationships between the pillars.

II. PRELIMINARY SYSTEM DEFINITION

The preliminary system engineering definition will define the needs and scope of the project. This chapter goes into detail on how the stakeholders worked with the project team to ensure the model being created was best suited for the FFG(X). It will discuss who, where, and what different commands do in support of the FFG(X) as well as the fleet itself while giving some requirements that were agreed upon during the SE process. The project scope, assumptions, data inputs, and boundaries were also identified and discussed in more detail.

A. NEEDS ANALYSIS

The Needs analysis is an assessment of the "what" and "how" the stakeholders want the project. It helped discover gaps that could have prevented the project from reaching its desired goals. With the help and continuous communication between the project stakeholders, sponsors, and capstone team, the team was able to come up with certain guidelines that were used to complete this capstone project. As the first step in preliminary system design, stakeholder needs are assessed.

1. Stakeholder Identification

The team identified stakeholders that may be directly impacted by the FFG(X) project. NAVSEA is responsible for engineering, building, buying, and maintaining the U.S. Navy's ships (NAVSEA n.d). PEO USC "designs, develops, builds, maintains, and modernizes the Navy's expanding family of unmanned maritime systems, mine warfare systems and small surface combatants" (NAVSEA n.d). PMS 515 is an executive office that manages the FFG(X) program. The FFG(X) Naval Operators will operate the ship and be affected by the capstone project. Naval Surface Warfare Center, Port Hueneme Division (NSWC PHD) is a tenant command located at Naval Base Ventura County in Port Hueneme, California. They played a major role in determining the requirements and giving feedback along with direction for the entire FFG(X) capstone project. The table below lists the stakeholders and a description of their role with the FFG(X).

Table 2. NPS Stakeholders

	Stakeholder	Description
1	NAVSEA	"Design, build, deliver and maintain ships and systems on time and on cost for the U.S. Navy" (NAVSEA, n.d).
2	PEO USC	"PEO Unmanned and Small Combatants designs, develops, builds, maintains, and modernizes the Navy's expanding family of unmanned maritime systems, mine warfare systems, and small surface combatants" (NAVSEA, n.d).
3	PMS 515	Frigate Program Executive Office for PEO USC
4	FGG(X) Operators	System Operation
5	NSWC PHD	Center of excellence for engineering, testing, training, and evaluation for new U.S. Navy capabilities

Conversations with the project sponsors helped identify the current capability assessment, identify major stakeholders, define the problem statement, develop the Concept of Operations and scope, and consider assumptions and constraints for the future of the FFG(X).

2. Stakeholder Analysis

The identification and engineering process of stakeholder needs is a fundamental requirement for systems engineering processes. Stakeholders are personally responsible for the project results. Assessing each individual stakeholder need directly correlates to the inputs that will be used for the project model. By completing this assessment, the capstone team will guarantee that the stakeholder needs and requirements are fulfilled.

One of the stakeholders' needs that the team addressed was how the FFG(X) will serve as an inherent part of the Navy's force alongside the SSC. The team addressed this need by providing support on how to define and develop a Frigate System of Systems (SoS) effectiveness model. This would help determine what was needed for the FFG(X) to be a successful and fully operational asset to the fleet. To better address this need, the team evaluated readiness and availability to developed requirements for stakeholders to inform the use of the FFG(X). A PESTONI model was created to better understand the system sustainment for the FFG(X). The model was focused on the PESTONI pillars to help guide the stakeholders in the right direction for future use and assessment of the FFG(X). The following requirements were discussed and agreed upon with the project stakeholders:

- The model shall allow for top-to-bottom resource allocation.
- The model shall allow for resource allocation optimization.
- The model shall receive inputs requisite inputs from outside sources to populate each pillar.
- The model shall present qualitative data in the form of risk to fleet readiness.
- The model shall be modular and expandable after delivery to the customer.
- The model shall be provisioned for a method to insert/adjust sensitivity within each pillar.
- The model shall be capable of being used in a non-classified NMCI environment and include a "user manual" to facilitate model use and understanding of structure and logic.

These requirements list what the model needed to be able to do to provide a useful and reliable tool for the future of the FFG(X). As with any systems engineering project, stakeholders' needs ultimately drove the FFG(X) recommended design, model, and solution. They helped identify and communicate their individual needs. The project team was then able to better identify the stakeholders' needs as the systems engineering analysis progressed.

By keeping the project's sponsors and stakeholders directly involved with the project model and pillar decomposition, the project team gained constant knowledge and insight throughout the project. This was extremely important as the project team continued to make interpretations and revisions to each pillar decomposition.

B. PROJECT SCOPE

The purpose of this study is to design a tool that illustrates the effects of allocated resources amongst the FFG(X) to increase its overall readiness and the readiness of the fleet as a whole. Our team defined the scope of this project with the project's stakeholders to establish deliverables for the FFG(X) readiness model. The team and the stakeholders agreed that using coefficients would eliminate the need for large-scale data collection. This would simplify the readiness model refinement when additional data would become available.

1. FFG(X) Project Assumptions

The FFG(X) capstone team will work under specific project assumptions to effectively create a readiness model that meets stakeholder needs.

a. Input Data

All data used to supply the FFG(X) readiness model will be arbitrary. Actual NAVSEA data pertaining to the PESTONI pillars will be withheld from the capstone team to maintain a degree of confidentiality. Note that the model will be able to accept actual data from the program decision makers once the model is transferred to project stakeholders. At the time of this capstone report, the FFG(X) is not yet implemented as part of the Navy's Fleet. This resulted in a lack of historical data of the systems to be reported on.

b. Fleet Data

The capstone team will operate under the assumption that the data inputted into the FFG(X) readiness model, as well as data output, will be representative of the entire fleet, rather than from the perspective of singular frigates

c. Accurate and Not Intervene

The capstone team will assume that any individual adding data to the model will do so accurately to the best of their knowledge.

2. Lack of Knowledge/Access to Training Data

One of the project constraints that the capstone team initially experienced was the lack of experience dealing with the FFG(X) systems. There was a lack of knowledge from previous work on the PESTONI pillars. Without having real-life data to input to the pillars it made it difficult to get measurable data. The team had to get familiarized with the PESTONI pillars and come up with failure propagation models in order to see how each pillar affected each other.

3. Problem Boundary

Based on stakeholder input and feedback, the team identified three primary focus areas for the project and the associated readiness tool. That assessment suggests that it is important that the project develop a tool that:

- collects information from each PESTONI pillar
- provides fleet readiness information to the decision makers from data collected
- graphically represents the pillar's interaction with one another and their relationships

Graphically representing the interactions between all the pillars is a key focus area, because one of the key requirements from the project's stakeholders is to see the effect on pillar X when action is taken on pillar Y. Taking into consideration that this aspect of the tool will be the most challenging to represent, this justified the capstone team determination that it would be the primary focal point for our project.

4. Model Boundary

To effectively bound the creation of the FFG(X) Readiness Model, the team created a graphical Input-Output Diagram (Figure 3). That diagram highlights the data elements that must be accepted by the model as well as the data elements that should be produced by the model. Note that the User Interface is described, which will be consistent with the stakeholder considerations described previously.

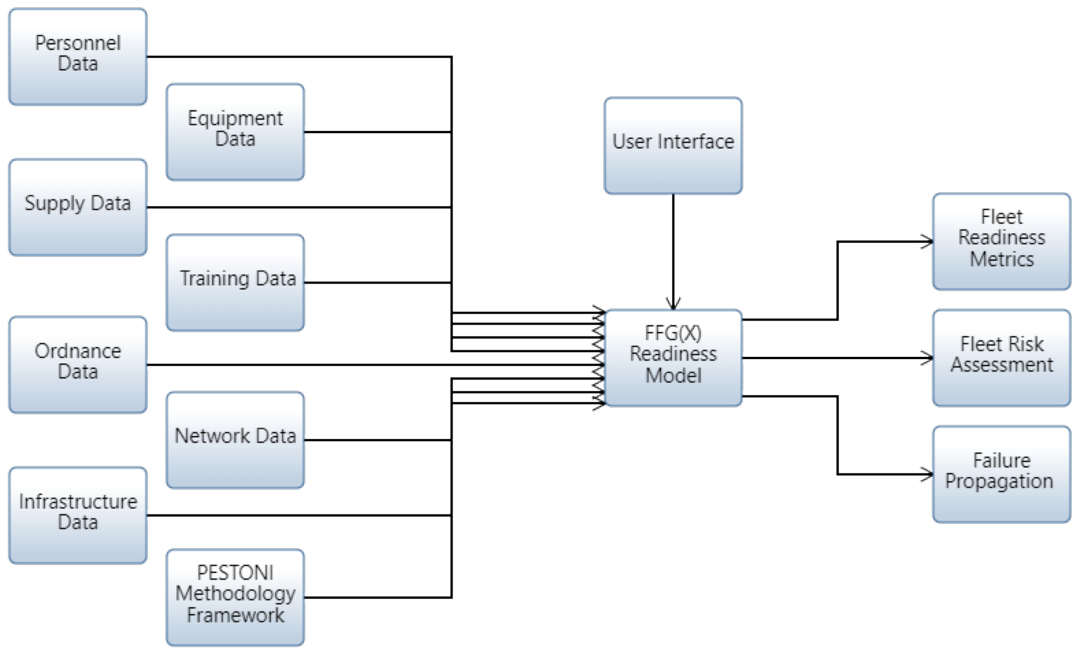

Figure 3. Input and Output

C. FUNCTIONAL ANALYSIS

Performing a functional analysis of the system requirements is accomplished by first establishing how the system will perform its objectives within a specified design. After analyzing the system requirements that help identify top-level system functionality, a functional architecture can be identified. In terms of developing the architecture, the capstone team received input from individuals who would be hands-on with the team's final deliverable. This ensured continuity of architectural expectations between both parties.

The goal of a system's architecture is to ensure that all subsystems are able to operate harmoniously by forming a top-level design of the system. A critical component of this system design is to address the needs of the stakeholders. The system architecture also illustrates any trade-offs necessary to meet the needs of the stakeholders. *INCOSE Handbook* defines systems architecture as, "The fundamental and unifying system structure defined in terms of system elements, interfaces, processes, constraints, and behaviors." It is pertinent that the architecture of the FFG(X) Readiness Model be planned with significant detail and accuracy. This requirement is driven by the intricacies relating to each of the PESTONI pillars.

The basic architecture of the FFG(X) readiness model will be built around the Microsoft Excel platform. This is to ensure usability across the largest audience. Using Microsoft Excel also will deliver the highest level of operational familiarity to the model's user, due to its widespread use across NAVSEA. The PESTONI pillars are to be modeled in individual worksheets within an Excel workbook. All data pertaining to a given pillar will reside in its respective worksheet. Summary data received from each pillar will be pulled and distributed to the summary sheet, or "dashboard," at the front of the workbook. The dashboard takes all the results from the selected figures of merit equations and normalizes them into a digestible format that can be used for comparison across all pillars.

D. SYSTEM DESIGN PROCESS

With the stakeholders' needs understood and the project bounded appropriately. The team was ready to begin the work of creating the system. Before the team was able to start work, a system design process had to be laid out. Understanding what must be done, and in what order, allowed the team to plan accordingly and ensure the project as a whole would meet the required deadlines.

The first step was to collect all related information and the current capabilities of the PESTONI pillars. This would ensure the team was not unnecessarily duplicating work that had already been completed and gain an understanding of the current state of the art. Next, the Concept of Operations (CONOPS) was drafted. This outlined exactly how the readiness model was intended to be utilized. Examples of "real-life" scenarios were hypothesized in which the readiness model was being used to allocate resources in a way that was markedly superior to the current methods.

Each pillar was then decomposed to understand what information and equations should be included from the pillar in the readiness model. The pillar decomposition also resulted in the decision of the FOM for each pillar that will provide the user with a high-level representation of the health of each pillar. Once decomposed, failure propagation chains were developed for each pillar to provide a visual representation of how funding changes in one pillar will ripple out and affect the other pillars within the model. The chains would also act as a guide to how each pillar is interconnected with the other pillars to bring the entire readiness model together.

Once constructed, the model was subjected to multiple validation and verification tests. These tests were not only intended to prove the model was built correctly and functions as intended but served to prove the model would be a valuable tool in resource allocation. Since the developers and the users of the model are not one and the same, a user guide was developed to supplement the model to provide the user with information related to how the model functioned at a much lower level than is appropriate for this report.

III. PESTONI EXISTING CAPABILITIES

There are authoritative databases and sources that support the values that are displayed in five of the PESTONI pillars. The five PESTONI pillars with authoritative databases are referred to as the PESTO pillars: Personnel, Equipment, Supply, Training, and Ordnance. The goals for the PESTO pillars are to provide the commanders with reporting readiness insight into their underlying resource conditions at the task and capability level and to provide the various concerned enterprises with a unit's resource readiness in a capability and task construct. The team will expand the current analysis capability by including the network and infrastructure pillars. Prior to that discussion, the current capability for each pillar is discussed.

A. EXISTING CAPABILITY

Within the following sections, each of the PESTO pillars is going to be explored to see how they currently aid commanders by reporting readiness insight. There will be a better understanding of the PESTO pillars and how they interact within the Defense Readiness Reporting System-Navy (DRRS-N).

1. Personnel Existing Capability

The Personnel (P) pillar represents and captures the skills of individuals that affect the ability of a unit to perform its mission (Olanowski et al. 2017). Currently, the biggest impact for the Personnel pillar is that the bulk of unit-level personnel data will be fed directly from the Bureau of Naval Personnel (BUPERS). This will provide greater visibility to how much manning impacts operational readiness. Within the Personnel pillar, it is seen how it pulls school's requirements and accomplishment information from Fleet Training Management Planning System (FLTMPS) as a contributor to individual training readiness.

The Personnel Figure of Merit (PFOM) is calculated for each Navy Mission-Essential Task (NMET) then averaged to provide a PFOM score for each capability area (Olanowski et al. 2017). The PFOM is a formula that is composed of required skills and skill gaps. Those areas where required skills and skill gaps are taken into consideration are

"Active (AC) and Reserve (RC) Component officer and enlisted Rating Fit, AC and RC Navy Enlisted Classification (NEC) Fit, Government Civilian Fit, and T&E school requirements" (Olanowski et al. 2017).

The following variables in equation 1 are broken up into skill requirements (Rs) and skill gaps (Gs). The variable Rs measures officers, Rating Control Number (RCN), NEC, T&E (Test and Evaluation), while the variable Gs measures officer manning, enlisted skills, and T&E completions.

$$PFOM = ((Rs - Gs)/Rs)\ 100 \tag{1}$$

With the capability metric being defined it will be divided into three categories. Those three categories are Ready (Green), Qualified Ready (Yellow), or Not Ready (Red). If the values are between 80 and 100 it would be considered in the green section, between 60 and 79 would be considered in the yellow section, and less than 60 would be considered in the red section. The example PFOM calculation compares requirements (Rs) and (Gs). The result of the calculation is an integer which is normalized to a whole number. If a unit does not pose one of the requirements, then it is left blank. The following table demonstrates an example of PFOM being calculated and having a score of 79.

Table 3. PFOM Example Calculation. Adapted from Matthews (2012).

Skill	NEC	ENL	OFF	CIV	T&E	Total	PFOM
Rs	66	235	41	0	0	342	79
Gs	13	55	4	0	0	72	

2. Equipment Existing Capability

The Equipment (E) pillar represents the equipment material condition on how it is performing for each assigned NMET and capability (Olanowski et al. 2017). The Maintenance Figure of Merit (MFOM) "calculates values for equipment material condition readiness based on input from the Current Ships Maintenance Project (CSMP)" (Olanowski et al. 2017). CSMP "is a database of maintenance Action Forms called (2-Kilos)"

(Olanowski et al. 2017). Accuracy of the equipment pillar relies on encrypted information that is present in individual 2-Kilos.

A numeric value and color indication will be used as a display for the DRRS-N to provide "each resource category with a FOM value for each NMET assigned to each unit" (Olanowski et al. 2017). These two indicators will demonstrate "the equipment material condition for each NMET assigned to each unit as computed by the maintenance FOM" (Olanowski et al. 2017). Where there are tasks where equipment is required, the system will be weighted by major components and sub-components and are mapped to those tasks.

The MFOM puts together task-to-equipment mappings and generates maintenance FOM data for DRRS-N. The MFOM "material readiness 'algorithm' rolls up Parent and Child systems that will map to a Naval Tactical Task (NTA)" (Olanowski et al. 2017). The "NTAs all map to capability areas, which are two variations within the rollup calculation: The first variation is (all non-critical items – simple weighted average) and the second variation is (at least one critical item – modified weighted average)" (Olanowski et al. 2017). Equation 2 displays how the MFOM is calculated. The three sections that the formula is broken up into are equipment operating capability, system impact, and time accelerator. The following tables demonstrate the three sections broken up.

$$MFOM = [100 - 100(1 - EOC) System\ Impact\ Time\ Accelerator] \qquad (2)$$

Table 4. Equipment Operating Capability. Adapted from Olanowski et al. (2017).

Equipment Operating Capability
From 2-Kilo (work Candidate):
1. If STATUS is blank then disregard 2K 2. If APL/AEL reads NA then disregard 2K 3. If SERIAL Number reads 1 or 2 (CRITICAL/SERIOUS) then EOC =.2 4. If SAFETY reads 3 (MODERATE) then EOC = 0.4 5. If SAFETY reads 4,5 (MINOR/NONE) or is blank then go to STATUS 6. If STATUS reads 1 (OPERATIONAL) then EOC = 0.9 7. If STATUS reads 2 (NON-OP) then EOC = .2 8. IF STATUS reads 3 (REDCAP) then EOC = 0.75 9. If STATUS reads 0 (N/A) Then EOC = 1.0

Table 5. System Impact. Adapted from Olanowski et al. (2017).

System Impact
1. Based on Parent-Child Relationship from Readiness Model) 2. Warfare Ranking * Impact form model system rollup * Functional Area Ranking * Priority 3. CSMP PRIORITY CODE (2K – Blk 41) 4. PRI 1- Mandatory (C-4) 5. PRI 2 Essential (C-3) 6. PRI 3 – Highly Desirable (C-2) 7. PRI 4 – Desirable

Table 6. Time Accelerator. Adapted from Olanowski et al. (2017).

Time Accelerator
1. Formula Range (0 - 100), 100 is good and 0 is bad. 2. Unit Value * Weeks (Until the mission is in the right hand of standard distribution curve)

3. Supply Existing Capability

For each NMET and capability, the Supply (S) pillar "represents the availability of necessary supplies" (Olanowski et al. 2017). The Supply Figure of Merit (SFOM) will calculate "the values that are displayed in the S pillar of DRRS-N" (Olanowski et al. 2017). Within the S pillar, the main objective is to get equipment back in the hands of warfighters faster and more efficiently by simplifying logistics and proactively getting the right parts, on time, to the right locations.

The S Pillar "represents supply data generated by the aircraft carrier which is imported into the DRRS-N by the carrier readiness team ashore" Table 1. (Olanowski et al. 2017). The information supplied from the carriers is displayed in four sections, which are R-Supply Database, Naval Logistics Command/Manager Information System (NALCOMIS) Database, Aviation Maintenance Supply Readiness Reports (AMSRR), and Operations Summary Reports (OPREP-5) Feeders. Equation 3 displays how the SFOM is calculated. With this equation the supply pillar inputs its data into the DRRS-N via the web input tool, which is managed by Commander, Naval Air Forces (CNAF) Force Supply who receives inputs from the carriers R-supply Database, NALCOMIS database, AMSRR Reports, and OPREP-S Feeders (Olanowski et al. 2017). The metrics in the supply FOM are the same for every CVN class but are broken up into two groups. Those two groups are Force Level and Unit Level Supply. The measurements differ from each other but are consistent with Class Maintenance Plan (CMP) reporting requirements.

$$SFOM = (A + RP + F + P)/4 \tag{3}$$

4. Training Existing Capability

The Training (T) pillar represents "the performance and experience of the CVN for performing each assigned NMET and capability" (Olanowski et al. 2017). The data is collected from the watch data that is later incorporated in CV-SHARP. The Navy Training Information Management System "calculates the values that are presented in the training pillar of DRRS-N" (Olanowski et al. 2017).

Equation 4 displays how the Training FOM is calculated. The input metrics that make up the experience and performance factors are calculated and stored in Navy Training Information Management System (NTIMS). The DRRS-N output "is a training readiness factor for each NMET that is calculated by multiplying the P and E factors for NEMT" (Matthews 2012). The "Total Force Integrated Readiness Model (TFIRM) Training Readiness Calculation Engine (TTRCE) will provide the three indicators" (Matthews 2012). The "variable TR represents the product of the performance and experience factors divided by 100 and it will be expressed as an integer 0 < X < 100 PF represents the percentage proficiency of a given unit in a given NMET and shall be expressed as an integer 0 < X < 100" (Matthews 2012). The variable "EF represents the percentage exposure of a given unit in a given NMET and shall be expressed as an integer 0 < X < 100" (Matthews 2012).

$$Tr = PfEf \tag{4}$$

The variable "Tr will demonstrate three DRRS-N colors in association with each of the training readiness NMET indicators" (Matthews 2012). The colors that will be used are going to be green, yellow, and red. The green color will mean that it is the highest state of training readiness, the yellow color will mean that it is right below green, while the red color means the lowest training readiness state. Any value that is between 80 and 100 will indicate green, any value that is between 60 and 79 will indicate yellow, and any value that is 59 or less would be indicated red.

5. Ordnance Existing Capability

Within the Ordnance (O) Pillar "it reflects the standardized distribution load allowances available for performing each assigned NMET and capability" (Olanowski et al. 2017). The Ordnance Figure of Merit (OFOM) calculates "the delta between the standardized CVN distribution load allowance and the ordnance held onboard by capability" (Olanowski et al. 2017). It also allows ordnance items to be assigned to specific tasks and capabilities of RESPORG (Olanowski et al. 2017). In the ordnance information system-wholesale, all CVN standardized distribution are displayed and accessible through DRRS-N.

The OFOM "maps ordnance to capabilities that will require ordnance resources. Mapping is done by RESPORG and it also considers major end items and sub-assemblies" (Olanowski et al. 2017). The OFOM also "assigns thresholds for ordnance resources and its tables use the data interface with OIS-W to calculate ordnance item percentages" (Olanowski et al. 2017). Equation 5 displays how the OFOM is calculated. The following variables are broken up into Current On (*Co*), Hand Quantity *(Hq)*, and Authorization NAVSEA Allowance (*ANA*).

$$OFOM = \frac{Co-Hq}{ANA} \tag{5}$$

The percentages are quotients of Current on-hand quantities divided by Authorized NAVSEA allowance, which are not to exceed 100%. Just like the equipment pillar, ordnance is mapped to tasks that will require ordnance resources. The OFOM assigns ordnance to mission-essential tasking, assigns ordnance-related METs to capabilities, builds all up-round weapons, sets threshold readiness values, and authorized NAVSEA Allowance.

6. Network Existing Capability

The Network (N) pillar reflects the standardized distribution of communication effectiveness. To get a measure effectiveness for the network pillar, there will be a measure in operation availability (when demanded), Reliability (complete events), and Accessibly. Some inputs that could go through the network pillar are trouble tickets, RMF assessments, and CS integration. The PSP functions within the N pillar are cybersecurity, data sustainment, data infrastructure, CM software license management, and automated identification.

7. Infrastructure Existing Capability

The Infrastructure (I) pillar reflects the facilities needed to support capability. The infrastructure pillar includes the facilities needed to support missions. Some inputs going through the infrastructure pillar are capacity, facilities required documents, suitability, and security/vulnerabilities.

The PSP functions within the infrastructure pillar are real property sustainment, assets management, integration management, and modernization management. The internet Navy Facility Assets Data Store (iNFADS) is considered the authoritative data source for facilities information. The measures include condition, capacity, configuration, and safety. Equation 6 displays how the Infrastructure Figure of Merit (IFOM) is calculated.

$$IFOM = \min(condition, configuration, capability) \tag{6}$$

B. CONCEPT OF OPERATIONS

Prior to undertaking any project of appreciable size or scope, it is imperative that the capability need is well defined and understood. An easily overlooked, but equally important, part of any project that must be as well defined and understood is how the end-item will be used to satisfy that capability need. To ensure the design team and the stakeholders agree in terms of end-item expectations, a Concept of Operations is drafted and agreed upon by all parties.

A Concept of Operations explores what, if any, current capabilities are already 3available in the trade space and then examines the proposed solution that provides the requisite capabilities needed to satisfy the problem statement. Often, scenarios are drafted representative of how the proposed solution will be used from the point of view of the end-user to better paint a picture of what problem will be solved, and how. These scenarios are hypothetical in nature and aim to provide the answer to the standard who, what, why, where, when, and how questions that frequently accompany any emerging technology or solution.

The end goal of the proposed readiness model is to increase the FFG(X)'s readiness. To accomplish this mission, the readiness model intends to present the end-user with a resource allocation tool that will objectively aid in determining the risks and rewards of different resource allocation methodologies. The following scenario has been developed with two potential outcomes, one where the readiness tool is used and one where it is not.

1. Scenario

The year is 2021, the United States has been involved in one or more international conflicts for close to two decades. The nation is tired of seemingly endless conflict and the perceived bloated defense budgets. The previous election saw control of both chambers of Congress and the executive branch controlled by politicians who aim to reduce the national deficit by any means necessary. The largest slash to the defense budget in recent memory is passed with little resistance, and the Department of Defense (DOD) is left with a fraction of the money it was planning on having.

The budget cuts are so severe that not only were future programs canceled, but current programs are forced to find ways to project power with less capital. Unfortunately, the timing cannot be worse. With the changeover in administration, foreign state actors are poised to test the waters both figuratively and literally. USN program managers have been tasked with one objective: Maintain the highest level of fleet readiness possible with the resources allocated.

a. Current Capability Outcome

The program manager calls a meeting comprised of his closest advisors and subordinates to discuss the best way to allocate the given resources across the PESTONI pillars. The assembled team consists of seven individuals who each represent interests from one of the seven pillars of PESTONI. Years of experience in the current budget construct has made each pillar representative an expert in the art of presenting their areas of responsibility as the linchpin to the entire enterprise. Whether consciously or not, the pillar representatives each provide subjective justifications for desired resource allocation. While these representatives are acting in what they perceive as the best interest of the fleet, the reality is that decisions made on subjective information rarely yields the best results. In the end, the program manager very well may achieve an acceptable level of fleet readiness, but it is highly unlikely the fleet was able to reach its maximum potential.

b. Future Capability

The program manager calls a meeting comprised of the same seven PESTONI pillar representatives, only this time he is equipped with the proposed PESTONI readiness model. The program manager listens intently to each representative make their case for why their area of responsibility should receive the largest share of the funding. The program manager then opens the PESTONI readiness model. Given that the readiness model is based on objective equations and refined with the latest fleet data, the program manager can balance the risks and rewards of adjusting each pillar's funding in a completely unbiased environment. The readiness model contains the previous year's budget allocation as a baseline to start from. As funding for one pillar is adjusted, the readiness model not only updates the projected fleet readiness but highlights where other pillars are affected. The changes in the individual pillar's FOM present the program manager with an objective assessment of risk to the fleet's readiness.

In addition to the quantitative readiness assessment, the readiness model also contains flow charts providing a visual representation of how a change in funding on one pillar will propagate throughout the readiness model and ultimately impact other pillars. The flow chart's primary purpose is to provide the user with a visual reference to better understand how a change in funding for one PESTONI pillar will have a ripple effect throughout the readiness model and ultimately affect other pillars. An ancillary purpose of including the flow charts is to act to provide validation to the model for those in the crowd who are skeptical of the inner workings of the readiness model. The outcome of the meeting is a purely objective allocation of resources that results in the best possible fleet readiness given the budgetary limitations.

2. Scenario Breakdown

In the presented scenario, the funding is cut, and the fleet must find the best way to allocate the remaining resources to achieve the highest level of fleet readiness. Regardless of whether the project funding is increased, decreased, or remains the same, the goal of the proposed readiness model remains the same; to provide an unbiased decision-making tool to better allocate resources to achieve the highest fleet readiness possible. The end results of the scenario presented are identical to a contrasting scenario in which the funding is increased. The major players and their specific positions and organizations in the scenario were purposely left vague to remove the notion that this readiness model can only be applied to one specific system. The tool itself, however, is dependent on accurate fleet data with its capabilities having the ability to be easily expanded upon given precise correlations. As with any data-driven tool, the accuracy and fidelity of the data used is directly proportional to the accuracy of the tool itself. While the inner workings of the readiness model will be explained in a later section, the presented scenario highlights the shortcomings of the current resource allocation system and the potential for improvement

C. DATA COLLECTION

The goal of this project was to create a readiness model that uses fleet data to populate the individual PESTONI pillars and relate the pillars to one another in a way that predicts fleet readiness. One of the largest challenges the team faced was constructing a data-driven tool with little to no actual data. The team solved the problem by using dummy data to create each pillar and then used the qualitative flow charts to interconnect the pillars themselves. Prior to the first use of the readiness model, the data must be replaced with actual fleet data. The bulk of the data used within the readiness model requires no manipulation, other than inserting it into the model. The second major hurdle the team faced was how to relate a change in funding (dollars) to a change in readiness (Operational Availability).

The team chose to use a system of coefficients in each pillar that related funding shifts with FOM shifts. While the coefficients will be covered in detail later in this report, they must be brought up now to discuss how they are adjusted using fleet data. After the fleet data is inserted into the readiness model, the coefficients must be updated as well.

Updating the coefficients requires the user to look back at funding and FOM shifts to find correlations. These correlations will be used to populate the coefficients and ultimately fine-tune the readiness model.

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IV. CURRENT PILLAR DECOMPOSITION

This chapter provides insight into how the team explored how each of the PESTONI pillars interacted with each other. By having a better understanding of the PESTONI pillars the team was able to come up with a FOM for each of the PESTONI pillars. The following sections go over how each pillar was broken down in order to come up with an FFG(X) readiness model.

A. PERSONNEL PILLAR

When looking at the PESTONI pillars the team was able to generate system architecture alternatives for the Personnel pillar. Within this pillar, there were different sub-factors that could go into this pillar that would affect the readiness model. For the first scenario, the first top-level functions that were investigated for the Personnel pillar were schedule, availability, performance, quality, morale, skills, experience, and health. After doing some research the team was able to narrow it down to four top-level functions in scenario two, which were experience, skills, morale, and performance. It was decided to go with scenario two because the team was able to generate scenarios on how personnel would be affected during their maintenance activities within each of these sub-factors without actually having real live data. The following sections will go over how the team defined each top-level function.

1. Personnel Figure of Merit

To measure personnel effectiveness and achieve the figure of merit the team decided to explore each of the top-level functions. Before choosing what top-level function to use, the team had to investigate what functions could be measured. The top-level functions that the team looked at before making a final selection were staffing allocation, experience, skills, moral, health, manpower/personnel analysis, and human factors engineering. After doing some research, the team realized that using staffing allocation, health, manpower/personnel, and human factors engineering were hard to measure without actual data to use. There were too many assumptions for each of these top-level functions, which made it hard for the team to incorporate them into the figure of merit that the team decided to go with. The top-level functions that the team decided to use were moral, experience, skills, and performance. Each of these top-level functions helped with measuring personnel effectiveness.

Before addressing each of these top-level functions the team decided to use coefficients to address current or future funding models. Each top-level function had a coefficient added to their section to address how allocating more funding to each top-level function would affect the effectiveness of personnel. Once that was taken into consideration the next step was to create a section on how to represent how many tasks personnel had to complete. Then the team was able to address each of the top-level functions to see how current and future funding affected personnel effectiveness. After this was taken into consideration for each top-level function the user would be able to weigh each of these top-level functions to have a final measurement for current and future personnel effectiveness. The distribution of weighing each of the top-level functions was from 0% - 100%. The team was able to come up with two figures of merit equations that represent current and future. The Current Personnel Figure of Merit (*PFOMc*) that the team came up with is *PFOMc* = morale current + experience current + skills current + performance current and the Future Personnel Figure of Merit (*PFOMf*) that the team came up with is *PFOMf* = morale future + experience future + skills future + performance future. With these two equations, the team was able to come up with a current and future figure of merit.

2. Personnel Pillar Construction

The following sections are going to describe how the team addresses each top-level function to come up with a current and future figure of merit for personnel effectiveness. Section 2.1 addresses personnel tasks, Section 2.2 addresses morale, Section 2.3 addresses experience, Section 2.4 addresses skills, Section 2.5 addresses performance, and Section 2.6 addresses current and future figure of merit.

3. Section 2.1 Personnel Tasks

Before the team could address the top-level functions, the team decided to add a section which would include how many tasks personnel would have to complete for maintenance.

By adding how many tasks were assigned to personnel the team was able to use that as a measurement to later address the top-level functions for morale, experience, skills, and performance. The following table shows how the personnel's tasks section looks.

Table 7. Maintenance Tasks

Work	**Tasks**
Maintenance	**Value**

a. Section 2.2 Morale

For the following section, the team decided to measure how morale affected personnel effectiveness. The team decided to use coefficients to address current or future funding models. This coefficient would address how allocating future funding to morale would affect the effectiveness of personnel. The team then researched how to measure the morale of personnel. After doing some research, the team found that if personnel worked on a task for 40 or fewer hours per week, they would have a morale score of 100%. The team also found out that once personnel hit 55 hours per week, their morale would be terrible. With these two measurements that the team was able to obtain through research, some assumptions were made to measure morale. The difference between 1% - 100% morale for personnel is 15 hours. To get a measurement for each hour worked above 40 hours, the team decided to calculate this by having 100 divided by the 15 (hours) to give a percentage to subtract for every hour worked past 40 hours per week. The following measurements were used to measure the morale of personnel.

In the morale section, the user will also be able to give this top-level function a weight. This weight will be different from the top-level functions for experience, skills, and performance. Once the user assigns the weight for morale, it will provide a final measurement for morale (Current) and morale (Future). The following table shows how the morale sections look like.

Table 8. Morale Section

Morale	Coefficient	Hrs. Per WK	Hrs. Per Week Weighted	Morale Level (Current)	Morale Level Weighted (Future)	Weighting Each Level	Morale Final (Current)	Morale Final (Future)
Commitment	Value	Value	Value	Value	Value	Value	Value	Value

b. Section 2.3 Experience

In this section, the team decided to measure how experience affects personnel effectiveness. It was decided to use a scale from 1–10. This would measure how many years of experience that personnel would have on working maintenance tasks. To get a percentage, the team divided the number of years by 10. This would give a percentage for the personnel experience. The following measurements were used to measure the experience of the personnel.

In the experience section, there is also a coefficient to address current or future funding models. The user using this model would also be able to give this top-level function a weight. This weight will be different from the top-level functions for morale, skills, and performance. Once the user assigns the weight for experience, it will provide a final measurement for experience (Current) and experience (Future). The following table shows how the experience section looks.

Table 9. Experience Section

Experience	Coefficient	Experience Obtained	Experience Obtained Weighted	Experience Level (Current)	Experience Level (Future)	Weighting Each Level	Experience Final (Current)	Experience Final (Future)
Retention	Value	Value	Value	Value	Value	Value	Value	Value

c. Section 2.4 Skills

For this section, the team decided to measure how skills affected personnel effectiveness. Just like experience, it was decided to use a scale from 1–10 to measure how many skills were obtained when performing the maintenance tasks. To get a percentage, the team divided the number of skills by 10. This would give a percentage for the personnel skills. The following measurements were used to measure the experience of the personnel.

In the skills section, there is also a coefficient to address current or future funding models. The user using the model would also be able to give this top-level function a weight. This weight will be different from the top-level functions for morale, experience, and performance. Once the user assigns the weight for skills, it would provide a final measurement for skills (Current) and skills (Future). The following table shows how the skills sections look.

Table 10. Skills Section

Skills	**Coefficient**	**Skills Obtained**	**Skills Obtained Weighted**	**Skills Level (Current)**	**Skills Level (Future)**	**Weighting Each Level**	**Skills Final (Current)**	**Skills Final (Future)**
Retention	Value	Value	Value	Value	Value	Value	Value	Value

d. Section 2.5 Performance

For the final top-level function, the team decided to measure how performance affected personnel effectiveness. The way the team decided to measure performance was by taking account of the measurement of how many skills and years of experience that personnel had. The team added the experience and skill level percentages to get an average. With this percentage average, the team multiplied it with the original number of tasks that were given in Section 2.1 to give an amount of how many tasks that personnel can complete/perform.

Once the team had the number of tasks that the personnel could complete, we then divided that by the original number of tasks assigned in Section 2.1 to give you an overall performance level for that personnel. In the performance section, there was also a coefficient to address current or future funding models. The user using the model would also be able to give this top-level function a weight. This weight was different from the top-level functions for morale, experience, and skills. Once the user assigns the weight for performance it would provide a final measurement for performance (Current) and performance (Future). The following table shows how the performance sections look.

Table 11. Performance Section

Performance	**Coefficient**	**Completed Tasks**	**Completed Tasks Weighted**	**Performance Level (Current)**	**Performance Level (Future)**	**Weighting Each Level**	**Performance Final (Current)**	**Performance Final (Future)**
Retention	Value	Value	Value	Value	Value	Value	Value	Value

e. Section 2.6 Current and Future Figure of Merit

For the final section of the personnel effectiveness model, it adds up the final weighted measurements for each top-level function. This would give you your single figure of merit (current) and single figure of merit (Future). The following table shows how the current and future figure merit sections look.

Table 12. Current and Future Figure of Merit

Single Figure of Merit (Current)	Value
Single Figure of Merit (Future)	Value

The following table demonstrates an example of all sections combined to come up with a single figure of merit (Current) and Single Figure of Merit (Future).

Table 13. Personnel Pillar Example Compiled

Personnel								
Work	**Tasks**							
Maintenance	500							
Morale	**Coefficient**	**Hrs. Per Week**	**Hrs. Per Week Weighted**	**Morale Level (Current)**	**Morale Level Weighted (Future)**	**Weighting Each Level**	**Morale Final (Current)**	**Morale Final (Future)**
Commitment	0.8	49	39.2	46%	100%	10%	5%	10%
Experience	**Coefficient**	**Experience obtained**	**Experience obtained Weighted**	**Experience Level (Current)**	**Experience Level (Future)**	**Weighting Each Level**	**Experience Final (Current)**	**Experience Final (Future)**
Retention	0.8	9	7.2	90%	72%	40%	36%	29%
Skills	Coefficient	Skills obtained	Skills obtained Weighted	Skills Level (Current)	Skills Level (Future)	Skills Each Level	Skills Final (Current)	Skills Final (Future)
Retention	0.8	8	6.4	80%	64%	40%	32%	26%
Performance	Coefficient	Completed Tasks	Completed Tasks Weighted	Performance Level (Current)	Performance Level (Future)	Weighting Each Level	Performance Final (Current)	Performance Final (Future)
Maintenance	0.8	425	340	85%	68%	10%	9%	7%
Single Figure of Merit (Current)	**81%**							
Single Figure of Merit (Future)	**71%**							

B. EQUIPMENT PILLAR

The equipment pillar encompasses all of the FFG(X)'s material. Time constraints only allowed for the top-level systems to be modeled, but future iterations can easily expand upon the model to add lower-level systems if desired. The methods used to model the items within the equipment pillar have been extensively studied over the years and typically fall under the Reliability, Availability, and Maintainability (RAM) construct. Using proven methods to model the equipment pillar allowed for fast verification of the results.

1. Equipment Figure of Merit

The FOM used to gauge pillar performance was operational availability. A_o was the clear choice for the pillar's FOM since it is most closely related to readiness and is typically a leading FOM when conducting a classical RAM analysis. The use of A_o as the equipment pillar's FOM also allows for a direct relationship to the overall FFG(X)'s readiness calculation.

2. Equipment Pillar Construction

The equipment pillar was modeled using the top-level mission capabilities and their systems that work together to form the SoS that is the FFG(X). For this project, it was determined that each top-level system was deemed mission-critical, meaning that if at any time a single system was offline, the FFG(X) would be unable to complete its mission. For modeling purposes, the mission-critical capabilities and their associated systems would be modeled in series as shown in Figure 4. The mission-critical capabilities are:

- MOB: Mobility
- ASW: Anti-Submarine Warfare
- SuW: Surface Warfare
- AAW: Anti-Aircraft Warfare
- CCC: Command, Control, and Communications
- EW: Electronic Warfare

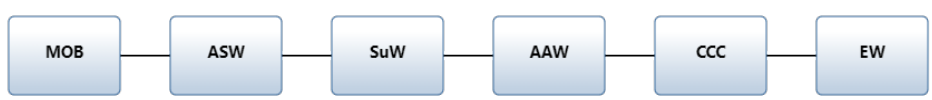

Figure 4. Mission-Critical Capabilities Block Diagram

To account for potential mission-critical system redundancies, the equipment pillar was provisioned for the possibility of up to three redundancies for each mission-critical system. Each optional redundant system capability would then be modeled in parallel within the mission-critical capability and its associated system itself, as shown in Figure 5.

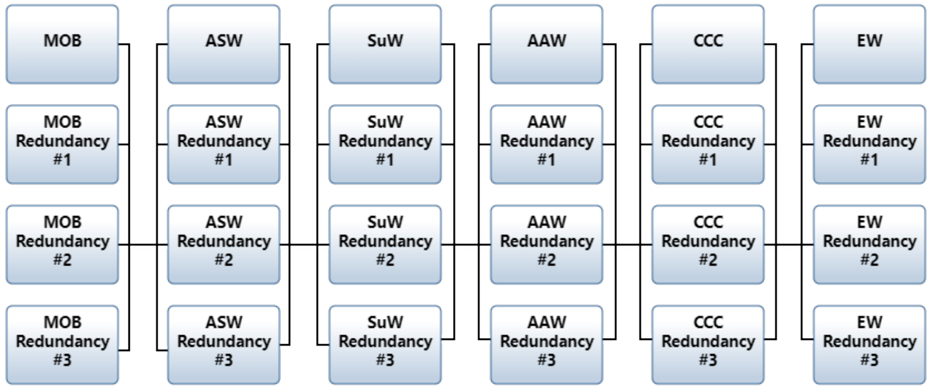

Figure 5. Mission-Critical Redundant Capabilities Block Diagram

The modeled equipment pillar was then duplicated to allow one model to present the current funding allocation and the other to represent the future funding allocation. Having both the current and future funding allocation models side-by-side allows for real-time monitoring of A_o changes as the funding is modified. Both the current and future A_o is then sent to the readiness model dashboard for use as the equipment pillar's FOM and to be used in the overall FFG(X)'s readiness calculation. Equation 8 displays how operational availability is calculated.

$$Ao = \frac{MTBM}{MTBM+MDT} \tag{8}$$

where *MTBM* is the Mean Time Between Maintenance and *MDT* is the Maintenance Down Time. *MDT* is the FOM of the supply pillar and is calculated within the supply pillar itself. *MDT* is then linked to the equipment pillar for use within the A_o calculation. To account for changes in funding, a coefficient for *MTBM* is used. The *MTBM* coefficient is intended to be directly proportional to the change in funding, which allows for the future A_o to be calculated. The coefficient is user updated to maintain the highest level of accuracy and is derived from past fleet data supported correlations.

The use of variable coefficients is advantageous for two reasons. First, it allowed for the model to be created without the need to execute extensive data analysis on insufficient or nonexistent data. Second, it allows for easy updates should the proportion between funding and *MTBM* change in the future. Both *MTBM* and *MDT* can be calculated elsewhere within the model or input directly should the user choose to.

C. SUPPLY PILLAR

The supply pillar is a supporting pillar in the readiness model, in that it does not produce a FOM that is used to directly calculate the overall FFG(X)'s readiness. The calculations done within the pillar are primarily used within the calculations of the equipment pillar. The supply pillar accounts for the time a system is down due to administrative, logistics, and corrective and preventative maintenance cycles.

1. Supply Figure of Merit

The FOM decided upon to represent the supply pillar was Maintenance Downtime (*MDT*). *MDT* comprises the total time a system is not operational due to the repair process. Equation 9 displays how *MDT* is calculated.

$$MDT = M + LDT + ADT \tag{9}$$

where $\bar{M}$ is the mean active maintenance time, *LDT* is the logistics delay time, and *ADT* is the administrative delay time. $\bar{M}$ is the total time elapsed to conduct a preventative or corrective maintenance action. *LDT* comprises the total downtime due to logistics reasons, such as part delivery time, waiting for test equipment to become available, and so on. *ADT* refers to total downtime due to administrative reasons such as a backlog due to organizational constraints or personnel turnover.

2. Supply Pillar Construction

Since the primary output of the supply pillar, *MDT*, was used as an input for the equipment pillar, the structuring of the supply pillar closely resembled that of the equipment pillar. The supply pillar modeled the eight mission-critical systems, each with up to three redundant systems. Each redundant system of the mission-critical systems calculates *MDT* using user input $\bar{M}$, *LDT*, and *ADT*.

The resulting *MDT* is then linked to the equipment pillar to be in calculating A_o. For each mission-critical system, the minimum *MDT* calculated between the main and redundant systems is used as the FOM for the mission-critical system. To produce a singular FFG(X) wide FOM for the supply pillar, the average *MDT* for all eight mission-critical systems is calculated and then linked to the readiness model dashboard. While the FOM on the readiness dashboard is not used to calculate the FFG(X)'s overall readiness, it is a valuable metric to have readily available when exploring the repercussions of a funding shift.

Again, to be able to compare current and future funding allocations, the entire set of calculations are duplicated. Much the same as the equipment pillar, coefficients are inserted into the equations to account for the changes that accompany any funding shift. $\bar{M}$, *LDT*, and *ADT* all are assigned a separate coefficient that is easily modified as data is collected, and correlations are made. Unlike the coefficients assigned to modify A_o, where a larger A_o is more desirable, the coefficients attached to the components of *MDT* are inversely proportional so that as funding is increased, *MDT* will decrease.

D. TRAINING PILLAR

To measure training effectiveness, the team was able to explore the same top-level functions that were used in the personnel pillar to come up with a figure of merit. Those top-level functions were moral, performance, skills, and results. Each of these top-level functions has a crucial role in developing a figure of merit for the training pillar.

1. Training Figure of Merit

The decided upon figure of merit for the training pillar is a composite score that is based on the weighted KirkPatrick levels. The Training pillar has almost the same structure as the personnel pillar but is different because the top-level functions that are being measured are being referenced to the KirkPatrick model. The weighting is input by the user and used to place one level in higher regard than another. The four levels of the KirkPatrick model are Reaction, Learning, Behavior, and Results. To use the KirkPatrick model the team had to reference each level of the KirkPatrick model to a top-level function to get measurable data values.

The pillar is broken up into four stages of training, A school, C school, on the job training, and continuous learning and education. Each stage is modeled the same but is customizable in which part leaders place the higher importance. Leaders can weigh the different levels within a stage based on mission needs. In other words, in some scenarios, the skillset of a sailor may be more important to the mission than that sailor's morale. In all levels, there are coefficients inserted to represent the impact a funding shift will have on specific aspects of the pillar. The purpose and use of coefficients will be explained later in the report.

2. Training Pillar Construction

The first few sections to measure training effectiveness were similar to the personnel pillar. Those sections dealt with the sailor's tasks and the four top-level functions which were morale, experience, skills, and performance. To have a better understanding of how each of those sections were expanded upon, refer to Chapter IV Section A. After exploring each of the top-level functions the team proceeded on with measuring training effectiveness in the following Section 2.1.

a. Section 2.1 Final Segment

The final section of the training effectiveness model takes account of all the four stages of training, which are A School, C School, on the job training, and continuing learning and education. Each of these stages are modeled the same with the three top-level functions. The following tables show the four stages with the three top-level functions.

Table 14. A School Stage 1

A School								
Training Task	**Activities**							
Maintenance	500							
Reaction (Morale)	**Coefficient**	**Hrs. Per Week**	**Hrs. Per Week Weighted**	**Morale Level (Current)**	**Morale Level Weighted (Future)**	**Weighting Each Level**	**Morale Final (Current)**	**Morale Final (Future)**
Commitment	0.5	49	24.5	46%	100%	50%	23%	50%
Behavior (Performance) Level 2	**Coefficient**	**Completed Tasks**	**Completed Tasks Weighted**	**Performance Level (Current)**	**Performance Level (Future)**	**Weighting Each Level**	**Performance Final (Current)**	**Performance Final (Future)**
Maintenance	0.5	400	200	80%	40%	40%	32%	16%
Learning (Skills) Level 3	Coefficient	Skills obtained	Skills obtained Weighted	Skills Level (Current)	Skills Level (Future)	Skills Each Level	Skills Final (Current)	Skills Final (Future)
Retention	0.5	4	2	40%	20%	10%	4%	2%
Single Figure of Merit (Current)	**59%**							
Single Figure of Merit (Future)	**68%**							

Table 15. C School Stage 2

C School								
Training Task	**Activities**							
Maintenance	500							
Reaction (Morale)	**Coefficient**	**Hrs. Per Week**	**Hrs. Per Week Weighted**	**Morale Level (Current)**	**Morale Level Weighted (Future)**	**Weighting Each Level**	**Morale Final (Current)**	**Morale Final (Future)**
Commitment	0.5	49	24.5	46%	100%	50%	23%	50%
Behavior (Performance) Level 2	**Coefficient**	**Completed Tasks**	**Completed Tasks Weighted**	**Performance Level (Current)**	**Performance Level (Future)**	**Weighting Each Level**	**Performance Final (Current)**	**Performance Final (Future)**
Maintenance	0.5	400	200	80%	40%	40%	32%	16%
Learning (Skills) Level 3	Coefficient	Skills obtained	Skills obtained Weighted	Skills Level (Current)	Skills Level (Future)	Skills Each Level	Skills Final (Current)	Skills Final (Future)
Retention	0.5	9	4.5	90%	45%	10%	9%	5%
Single Figure of Merit (Current)	**64%**							
Single Figure of Merit (Future)	**71%**							

Table 16. On-The-Job Training Stage 3

On-The-Job Training								
Training Task	**Activities**							
Maintenance	500							
Reaction (Morale)	**Coefficient**	**Hrs. Per Week**	**Hrs. Per Week Weighted**	**Morale Level (Current)**	**Morale Level Weighted (Future)**	**Weighting Each Level**	**Morale Final (Current)**	**Morale Final (Future)**
Commitment	0.5	49	24.5	46%	100%	50%	23%	50%
Behavior (Performance) Level 2	**Coefficient**	**Completed Tasks**	**Completed Tasks Weighted**	**Performance Level (Current)**	**Performance Level (Future)**	**Weighting Each Level**	**Performance Final (Current)**	**Performance Final (Future)**
Maintenance	0.5	300	150	60%	30%	40%	24%	12%
Learning (Skills) Level 3	Coefficient	Skills obtained	Skills obtained Weighted	Skills Level (Current)	Skills Level (Future)	Skills Each Level	Skills Final (Current)	Skills Final (Future)
Retention	0.5	7	3.5	70%	35%	10%	7%	4%
Single Figure of Merit (Current)	**54%**							
Single Figure of Merit (Future)	**66%**							

Table 17. Continue and Learning Education Stage 4

Continue and Learning Education								
Training Task	**Activities**							
Maintenance	500							
Reaction (Morale)	**Coefficient**	**Hrs. Per Week**	**Hrs. Per Week Weighted**	**Morale Level (Current)**	**Morale Level Weighted (Future)**	**Weighting Each Level**	**Morale Final (Current)**	**Morale Final (Future)**
Commitment	0.5	49	24.5	46%	100%	50%	23%	50%
Behavior (Performance) Level 2	**Coefficient**	**Completed Tasks**	**Completed Tasks Weighted**	**Performance Level (Current)**	**Performance Level (Future)**	**Weighting Each Level**	**Performance Final (Current)**	**Performance Final (Future)**
Maintenance	0.5	350	175	70%	35%	40%	28%	14%
Learning (Skills) Level 3	Coefficient	Skills obtained	Skills obtained Weighted	Skills Level (Current)	Skills Level (Future)	Skills Each Level	Skills Final (Current)	Skills Final (Future)
Retention	0.5	5	2.5	50%	25%	10%	5%	3%
Single Figure of Merit (Current)	**56%**							
Single Figure of Merit (Future)	**67%**							

The final segment of the training pillar compiled the weighted results of the four stages of training and applies another set of weights that results in one set of composite scores that make up the figures of merit for the training pillar. This second set of weights, allows the user to place a higher emphasis on different stages of training. This is required, since typically on the job training will play a larger role in the overall skillset of a sailor than what can be taught in the sailor's A school. The following table shows the four stages being weighted to form a current and future combined figure of merit.

Table 18. Stages Current and Future Combined Figure of Merit

Training Activities					
A School	**Current**	**Future**	**Weighting Each Activity**	**A School Final (Current) Weight**	**A School Final (Future) Weight**
Single Figure of Merit	55%	68%	30%	17%	20%
C School	**Current**	**Future**	**Weighting Each Activity**	**C School Final (Current) Weight**	**C School Final (Future) Weight**
Single Figure of Merit	64%	71%	30%	19%	21%
On the Job Training	**Current**	**Future**	**Weighting Each Activity**	**On the Job Training Final (Current) Weight**	**On the Job Training Final (Future) Weight**
Single of Figure of Merit	54%	66%	20%	35%	13%
Continue and Learning Education	**Current**	**Future**	**Weighting Each Activity**	**Continue and Learning Education Final (Current) Weight**	**Continue and Learning Education Final (Future) Weight**
Single Figure of Merit	56%	67%	20%	11%	13%
Results					
Combined Figure of Merit (Current)	**82%**				
Combined Figure of Merit (Future)	**68%**				

E. ORDNANCE PILLAR

The ordnance pillar of the FFG(X) readiness model is designed to quantify the overall readiness of the frigate by means of operational availability of onboard ordnance systems. The reliability and maintainability metrics of the primary ordnance systems aboard the frigate contribute to the operational availability of the ordnance pillar. To measure ordnance operational availability, the FFG(X) readiness model was configured to accept reliability and maintainability data. The top-level functions analyzed were reliability, availability, maintainability, and funding allocation.

1. Ordnance Figure of Merit

The figure of merit used to quantify the ordnance pillar within the FFG(X) readiness model was A_o. A_o was chosen by the team because it was determined to be an accurate measure of readiness, in addition to integrating well with the other PESTONI pillars. Overall ordnance operational availability was calculated by multiplying the operational availability of individual ordnance systems aboard the frigate.

To account for any changes in funding, a coefficient for *MTBM* is used. The *MTBM* coefficient is directly proportional to the change in funding, which allows for the future A_o to be calculated. The coefficient is user updated to maintain the highest level of accuracy and is derived from past fleet data supported correlations. The use of variable coefficients is advantageous for two reasons. First, it allowed for the model to be created without the need to execute extensive data analysis on insufficient or nonexistent data. Second, it allows for easy updates should the proportion between funding and *MTBM* change in the future. Both *MTBM* and *MDT* can be calculated elsewhere within the model or input directly should the user choose to.

2. Ordnance Pillar Construction

The ordnance pillar was constructed to calculate the overall availability of the ordnance systems within the frigate. For this project, it was determined that each top-level capability was deemed mission-critical, meaning that if at any time a single system was offline, the FFG(X) would be unable to complete its mission. The following mission-critical capabilities would be modeled in series:

- AAW: Anti-Aircraft Warfare
- ASW: Anti-Submarine Warfare
- SuW: Surface Warfare
- OS: Ordnance Stores

The ordnance pillar was modeled to incorporate three system redundancies for each mission-critical system. Each system redundancy would then be calculated in parallel to increase the reliability of the system.

The ordnance pillar model was then duplicated to present the current funding allocation and the future funding allocation side-by-side. This enables real-time monitoring of A_o changes as the funding amount is modified. The readiness model dashboard pulls both the current and future A_o from the ordnance pillar to use as the ordnance pillar's FOM and to be used in the overall FFG(X)'s readiness calculation.

F. NETWORK PILLAR

The network pillar of the FFG(X) readiness model is designed to quantify the overall readiness of the frigate by means of operational availability of onboard network systems. The reliability and maintainability metrics of the primary network systems aboard the frigate contribute to the operational availability of the network pillar. To measure network operational availability, the FFG(X) readiness model was configured to accept reliability and maintainability data from individual systems. The top-level functions analyzed were reliability, availability, maintainability, and funding allocation.

1. Network Figure of Merit

The figure of merit used to quantify the network pillar within the FFG(X) readiness model was operational availability. Operational availability was chosen by the team because it was determined to be an accurate measure of readiness, in addition to integrating well with the other PESTONI pillars. Overall network operational availability was calculated by multiplying the operational availability of individual network systems aboard the frigate.

To account for any changes in funding, a coefficient for *MTBM* is used. The *MTBM* coefficient is directly proportional to the change in funding, which allows for the future A_o to be calculated. The coefficient is user updated to maintain the highest level of accuracy and is derived from past fleet data supported correlations. The use of variable coefficients is advantageous for two reasons.

First, it allowed for the model to be created without the need to execute extensive data analysis on insufficient or nonexistent data. Second, it allows for easy updates should the proportion between funding and *MTBM* change in the future. Both *MTBM* and *MDT* can be calculated elsewhere within the model or input directly should the user choose.

2. Network Pillar Construction

The network pillar was constructed to calculate the overall availability of the network systems aboard the frigate. For this project, it was determined that each top-level system was deemed mission-critical, meaning that if at any time a single system was offline, the FFG(X) would be unable to complete its mission. The mission-critical systems Radio Comms, GPS, and NMCI Networks, would be modeled in series.

The network pillar was modeled to incorporate three system redundancies for each mission-critical system. Each system redundancy would then be calculated in parallel to increase the reliability of the system. The network pillar model was then duplicated to present the current funding allocation and the future funding allocation side-by-side. This enables real-time monitoring of A_o changes as the funding amount is modified. The readiness model dashboard pulls both the current and future A_o from the network pillar to use as the network pillar's FOM and to be used in the overall FFG(X)'s readiness calculation.

G. INFRASTRUCTURE PILLAR

Infrastructure is "the basic physical and organizational structures and facilities (e.g., buildings, roads, power supplies) needed for the operation of a society or enterprise." In the PESTONI model, the capstone team is taking a slightly different approach to analyzing infrastructure based on the available data and guidance from the stakeholders. The stakeholders advised researching and modeling infrastructure at a higher level using Mean Down Time (*MDT*) as the appropriate figure of merit (FOM). *MDT* was chosen and recommended by the project sponsors and stakeholders based on the currently available data involving repair analysis, scheduling, and maintenance tasks for the FFG(X).

1. Infrastructure Figure of Merit

Mean down time is the average time that a system is non-operational (Blanchard 2011). This includes all "downtime associated with the repair, corrective and preventative maintenance, self-imposed downtime, and any logistics or administrative delays" (Smith 2011). The best ways to help reduce *MDT* are in the systems design, repairability, and support systems. Determining how each pillar of PESTONI affects the FFG(X) is a major goal of this capstone project. The more reliable a system is the less downtime it will experience. The level of repair the FFG(X) must go through will greatly affect the infrastructure needed for that repair as well as the *MDT* for the ship.

There are three levels of repair for a system that the FFG(X) will go through. The first level is Organizational Maintenance (O-level). If a system is more repairable and can be repaired by the user or at an O-level of repair will significantly help the FFG(X). All repairs done at O-level maintenance are typically normal day-to-day repairs. The repairs may consist of inspections, servicing, handling, removal, and replacement of defective parts and components (Aviation n.d.). These repairs are typically done on the ship and will have little effect on the overall infrastructure of the FFG(X). The second level is Intermediate Maintenance (I-level) which includes the repair and test of components and the items requiring shop facilities and/or skills or equipment not available in O-level repairs (Aviation n.d.). These repairs would require the ship to be docked or at a certain port to undergo the maintenance needed. They will typically take longer than O-level repairs. The third level is Depot maintenance (D-level) which is the classification of tasks performed at the industrial-type activities such as a depot or port. These are used for major rework on the FFG(X), engines, and components on a scheduled basis as directed by NAVSEA (Aviation n.d.). They could even require the ship to be brought out of the water during the repair. They also perform a customer service program for non-scheduled overhaul or repair on components to satisfy non-mission capable supply requirements (NMCS) during these repairs (Aviation n.d.). D-level repairs could be lengthy in time and require very specific types of infrastructure to complete the needed maintenance.

By understanding the urgency and type of work that needs to be repaired on the ship will further allow the stakeholders to know what type of facilities will be needed to repair the system. Having the schedule and maintenance tasks will allow the stakeholders to be able to estimate the *MDT* that each ship will go through before returning to the fleet. Depending on the tasks at hand and the level of repair required will ultimately depend on what type of infrastructure is required to satisfy the FFG(X) needs.

2. Infrastructure Pillar Construction

Decomposing infrastructure was done by breaking down the complexity of the FFG(X) and understanding the system. The following table shows the breakdown of infrastructure and gives the equation, source of the equation, Source of inputs, and potential pillar interactions that it can have on the other PESTONI pillars. This analysis was used to help create the PESTONI model and determine what contributing factors, equations, and potential pillar interactions that infrastructure would have throughout this project.

Table 19. Infrastructure Decomposition

Infrastructure				
Contributing Factor	**Equation**	**Source of Equation**	**Source of Inputs**	**Potential Pillar Interactions**
O-Level	$MDT = \overline{M} + LDT + ADT$	RAM B&F	Repair Analysis and Work History	Personnel, Training, Supply, Equipment, Networks
I-Level				
D-Level				

When further analyzing infrastructure in more detail, the following Reliability Block Diagram (RBD) was formed to help give some further detail about what variables can affect the FFG(X)'s infrastructure.

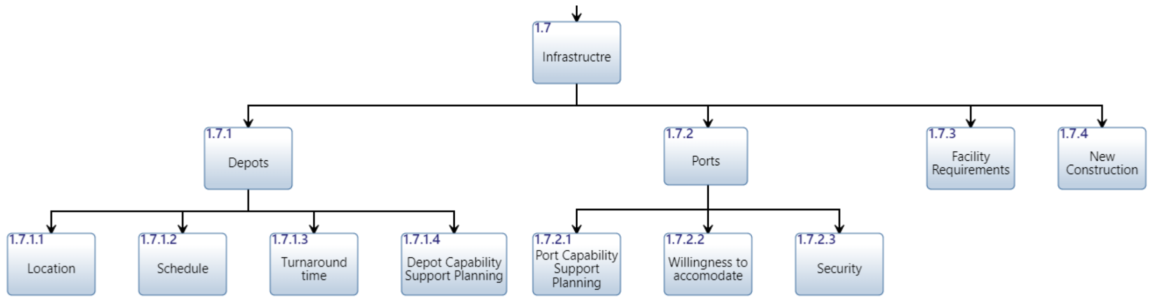

Figure 6. Infrastructure RBD

This RBD is important to the capstone team because it shows a breakdown of the complexity that infrastructure can have to real-world items. It differs between the table's contributing factors because the table gives a view of the repair analysis. The RBD is more detailed and specific to the ship itself. The level of repair will help determine the other key factors that were examined to further the accuracy of the model.

H. FAILURE PROPAGATION

To build an effective readiness model, an understanding of how each pillar affected one or more of the other pillars had to be achieved. There was no previous work that specifically outlined the relationship between the pillars, let alone which pillar affected another pillar. The team had to develop a method to map how adjusting funding in one pillar rippled out to the other pillars.

Drawing on past experience populating fault trees, the team decided to develop a failure propagation, or cause-and-effect, model for each pillar. These models would start with a degradation of a component within that pillar and then the effects of that degradation would then be mapped out until they ultimately would affect another pillar. Each model would include as many high-level degradations as possible, to ensure the failure propagation models were as accurate as possible. An example of the equipment pillar's failure propagation model is shown in Figure 7, with the rest of the pillar's models located in *Appendix Failure Propagation Models*.

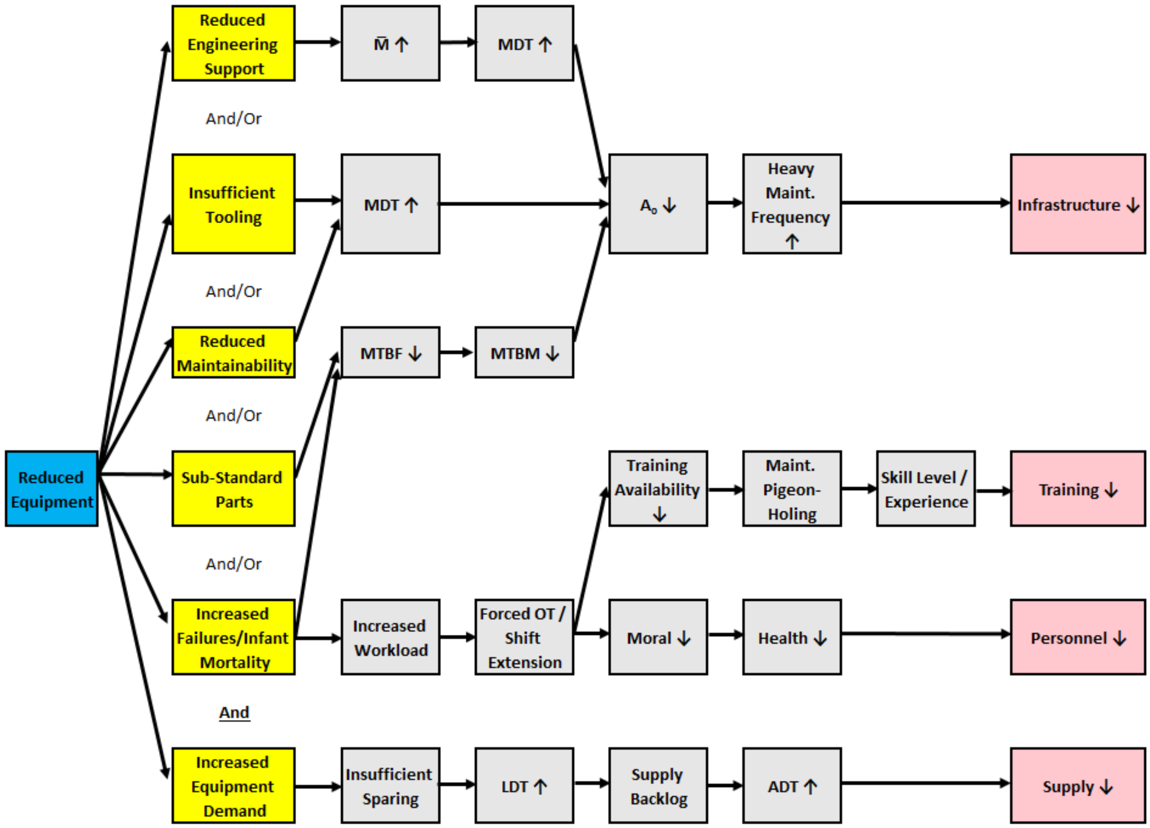

Figure 7. Equipment Failure Propagation Model

Constructing the failure propagation models served multiple purposes. First, they act as the qualitative solution to the PESTONI resource allocation problem. The models provide a visual representation to the decision makers of how funding across each pillar would affect other pillars. Secondly, the failure propagation models worked as sort of a blueprint in interconnecting the readiness model itself. Having thought out diagrams of how a degradation in one pillar ultimately affects the other pillars made making those same connections in the readiness model much easier to keep track of them. With the failure propagation models matching the design of the readiness model, they will also help users of the model in the future understand the framework of the readiness model itself.

While the failure propagation models were designed assuming a funding decrease in the starting pillar, simply reversing the effects will represent a funding increase. For consistency, all models are presented as if a funding decrease occurred.

I. PILLAR INTEGRATION

Building the individual pillars in a vacuum with respect to the rest of the pillars made sense from the point of validation and testing, but eventually, the pillars had to be interconnected with one another. Integrating the pillars, as suspected, proved to be one of the more complicated tasks associated with building the readiness model. Using the qualitative diagrams, or failure/funding propagation chains, as a guide to integrating the individual pillars proved to be extremely helpful. Having a well thought out roadmap of sorts detailing how a change in one pillar would ripple throughout the rest of the pillars, removed a lot of the guesswork, and ensured the qualitative solution paired well with the quantitative solution.

To enhance the usability of the readiness model, a dashboard was designed and inserted, shown in Figure 8. The dashboard allows the user to perform funding allocation optimization and see how the individual pillar's figure of merits change after a funding shift. In addition to displaying the current and future figures of merit for each pillar, the dashboard presents the user with the overall frigate's current and future operational availability based on the PESTONI pillars.

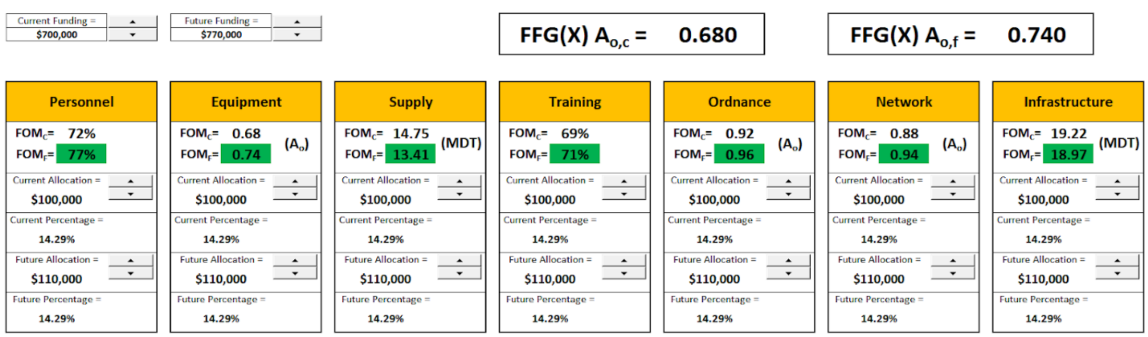

Figure 8. Readiness Model Dashboard

J. RESOURCE ALLOCATION

While the FFG(X) is using many of the same or similar mission-critical systems as other ships in the fleet, there is no FFG(X) currently fielded. Without an FFG(X) underway, the data needed to correlate resource allocation to overall fleet readiness is insufficient or non-existent. This proved to be a substantial obstacle to work around during this project.

The team's solution to the data problem was to insert a series of coefficients within individual pillar calculations. Equation 8 and Equation 10 show an example of how the coefficients are inserted into an equation, changing the variables that will be reflective of how a finding shift would change them.

$$A_{o,wt} = \frac{C1 \cdot MTBM}{(C1 \cdot MTBM) \cdot (C2 \cdot MDT)} \tag{10}$$

The use of coefficients eliminated the need for large-scale data collection and analysis that would have proven difficult even for a larger capstone team. It also allows for simplified readiness model refinement when additional data becomes available or when system sensitivities change. Each pillar's coefficients are conveniently located at the top of each pillar's page to allow for quick viewing and updating as needed.

The funding allocations are located and changed on the dashboard itself. The dashboard will display the current and future allocation to highlight how the figures of merit change.

V. PESTONI MODEL TEST AND VERIFICATION

Testing and verification procedures were conducted once a functional iteration of the FFG(X) readiness model was created. The basis of the test and verification process was to implement use case examples were formulated that would represent specific scenarios in which the model could potentially be used. The use case examples were inputted into the FFG(X) readiness model to test its functionality. The resulting FGG(X) overall readiness was then verified by cross-referencing with the expected FFG(X) overall readiness.

A. SYSTEM ANALYSIS

To study the system functionality of the FFG(X) readiness model, a form of system analysis was conducted. Comparing the outputs from specific scenarios in the readiness model to their expected corresponding outputs allows the system's developers to examine and optimize the interaction of the systems within the model. Performing the required system analysis ensures that all of the components within the system work effectively and efficiently to satisfy the requirement.

1. Simulation Description

To better understand the potential outputs of the FFG(X) readiness model, simulated scenarios will be executed during the system analysis of the functional model. The three general scenarios represent a reduction in program funding, an increase in program funding, and an optimization of the current program funding allocation.

a. Funding Cut

In the event of a reduction in funding for the program, two simulations will be tested. The first will represent a program-wide funding cut, where all PESTONI pillars receive an equal funding reduction. The second would represent pillar-specific reductions, where each pillar experiences different degrees of reduction with some potentially not experiencing any reduction.

b. Funding Increase

Simulations representing an increase in program funding will mirror that of the funding reduction. Two testing simulations will be representative of a funding increase. The first will represent a program-wide funding increase, where all PESTONI pillars receive an equal funding modification. The second would represent pillar-specific increases, where each pillar experiences different degrees of increase with some potentially not experiencing any increase.

c. Funding Optimization

The third simulation category will involve optimizing the current funding allocation to the program, assuming no change in funding.

B. TEST CASES

Data tables of use-case scenarios were constructed to facilitate the model testing for system analysis. Each table represents the use-cases within the three top-level simulation scenarios. The first table represents use-cases within a program funding decrease scenario. Table 20 represents the option of the user to manipulate a funding decrease across all pillars simultaneously or assign reduction percentages to individual pillars. Either of the user's entries will output the resulting reduction in FFG(X) readiness as the percentage differing from the original value.

Table 20. Funding Decrease Scenario

Funding Distribution Type	Pillar	Allocation Modification (User Input)	FFG(X) Readiness Delta
Uniform	PESTONI	-15%	0.62%
Pillar Independent	Personnel	-2.62%	
	Equipment	-2.62%	
	Supply	-2.62%	
	Training	+12.38%	
	Ordnance	-2.62%	
	Networks	-2.62%	
	Infrastructure	+.71%	

Table 21 represents use-cases within a program funding increase scenario. The table represents the option of the user to manipulate a funding increase across all pillars simultaneously or assign increased percentages to individual pillars. Either of the user's entries will output the resulting increase in FFG(X) readiness as the percentage differing from the original value.

Table 21. Funding Increase Scenario

Funding Distribution Type	Pillar	Allocation Modification (User Input)	FFG(X) Readiness Delta
Uniform	PESTONI	15%	.993%
Pillar Independent	Personnel	-0.54%	
	Equipment	-1.79%	
	Supply	-1.79%	
	Training	5.71%	
	Ordnance	-0.54%	
	Networks	-0.54%	
	Infrastructure	-0.54%	

Table 22 represents use-cases in which program funding has remained the same. The table represents the option of the user to manipulate funding among different pillars. The user's entries will output the resulting FFG(X) readiness as the percentage differing from the original value.

Table 22. Funding Stays the Same Scenario

Funding Distribution Type	Pillar	Allocation Modification (User Input)	FFG(X) Readiness Delta
Uniform	PESTONI	14.29%	.614%
Pillar Independent	Personnel	0%	
	Equipment	0%	
	Supply	0%	
	Training	0%	
	Ordnance	0%	
	Networks	0%	
	Infrastructure	0%	

C. MODEL VERIFICATION

The team verified the model by conducting three use-case scenarios. The three scenarios that the team used to verify the model were funding increase, funding decrease, and equal disbursement with each of the PESTONI pillars.

1. Readiness Model Test Cases Verification

For the first scenario, the team decided to start the verification with equal disbursement. The current budget was going to start at $7,000,000. Those $7,000,000 were going to be equally disbursed between each of the pillars. For the second scenario, the team decided to increase the budget by $1,000,000. The $1,000,000 was going to be added within the model to get a better FFG(X) A_o. For the third scenario, the team decided to decrease the budget by $1,000,000. The $1,000,000 was going to be subtracted within the

PESTONI pillars, but the goal was to have a better FFG(X) A_o than the equal disbursement scenario.

a. Funding Equal Disbursement

For this scenario, the $7,000,000 was distributed equally with the PESTONI pillars. The FFG(X) Operation Availability Current ($A_{o,c}$) equaled 0.873, while the FFG(X) Operation Availability Future ($A_{o,f}$) equaled 0.614.

Table 23. Funding Equal Disbursement Use-Case Scenario

	Funding Equal Distribution						
	Personnel (Comp.)	Equipment (A_o)	Supply (MDT)	Training (Comp.)	Ordnance (A_o)	Network (A_o)	Infrastructure (MDT)
FOMc	56%	.966	12.67	61%	0.942	0.96	13.76
FOMf	56%	.966	12.67	61%	0.942	0.96	13.67
Current Allocation	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000
Current Percentage	14.29%	14.29%	14.29%	14.29%	14.29%	14.29%	14.29%
Future Allocation	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000
Future Percentage	14.29	14.29	14.29	14.29	14.29	14.29	14.29
FFG(X)Ao,c	0.873						
FFG(X)Ao,f	0.614						

b. Funding Increase Scenario

For this scenario, the team decided to increase the budget by $1,000,000 to be distributed within the PESTONI pillars. When increasing the budget within the PESTONI pillars it was noticed that the training pillar had the greatest effect on the other pillars. By increasing the budget on the training pillar, it made sure that the sailors are well trained which has a better effect on the other pillars. It was noticed that the FFG(X) $A_{o,c}$ equaled 0.873, while the FFG(X) $A_{o,f}$ equaled 0.993.

Table 24. Funding Increase Use-Case Scenario

	Funding Increase						
	Personnel (Comp.)	Equipment (A_o)	Supply (MDT)	Training (Comp.)	Ordnance (A_o)	Network (A_o)	Infrastructure (MDT)
FOMc	56%	.966	12.67	61%	0.942	0.96	13.76
FOMf	93%	.967	7.96	85%	0.998	0.998	6.87
Current Allocation	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000
Current Percentage	14.29%	14.29%	14.29%	14.29%	14.29%	14.29%	14.29%
Future Allocation	$1,100,00	$1,000,00	$1,000,000	$1,600,000	$1,100,000	$1,100,000	$1,100,000
Future Percentage	13.75%	12.50%	12.50%	20.00%	13.75%	13.75%	13.75%
FFG(X)$A_{o,c}$	0.873						
FFG(X)$A_{o,f}$	0.993						

c. Funding Decrease Disbursement

For this scenario, the team decided to decrease the budget by $1,000,000 within the PESTONI pillars. When decreasing the budget, it was noticed that FFG(X) future figure of merit was decreasing drastically. That was expected since there was a cut in funding, but in order to have a decent future FFG(X) figure of merit, it was decided to decrease less funding on the training pillar. It was noticed that having a well-trained group of sailors would give you a better result towards your future FFG(X) figure of merit. The FFG(X) $A_{o,c}$ equaled 0.873, while the FFG(X) $A_{o,f}$ equaled 0.626.

Table 25. Funding Decrease Use-Case Scenario

	Funding Decrease						
	Personnel (Comp.)	Equipment (A_o)	Supply (MDT)	Training (Comp.)	Ordnance (A_o)	Network (A_o)	Infrastructure (MDT)
FOMc	56%	.966	12.67	61%	0.942	0.96	13.76
FOMf	20%	.803	17.11	80%	0.839	0.928	25.75
Current Allocation	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000
Current Percentage	14.29%	14.29%	14.29%	14.29%	14.29%	14.29%	14.29%
Future Allocation	$700,00	$700,000	$700,00	$1,600,000	$700,00	$700,000	$900,000
Future Percentage	11.67	11.67%	11.67%	26.67%	11.67%	11.67%	15.00%
FFG(X)$A_{o,c}$	0.873						
FFG(X)$A_{o,f}$	0.626						

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VI. SUMMARY AND FUTURE WORK

A. SUMMARY OF WORK

In July 2017, the CNO gave direction for the top-level requirements that included adding the FFG(X) to the SSC family of ships for lethal multi-missions to support the National Defense Strategy for AW, ASW, SuW, and EW (OPNAV N96E 2019). The FFG(X) will provide more offensive capability, survivability, range, endurance, and self-sufficiency to the fleet. It will execute multiple types of missions from the beginning of use. In supporting the FFG(X) the capstone team created a readiness model that collected information from PESTONI pillars to estimate fleet readiness. The model clarified relationships between each pillar and possible scenarios that leadership may come across. The model can be used to help determine the options and outcomes of certain what-if scenarios about investment. The efforts of this project helped define and develop the FFG(X) SoS effectiveness model and metrics.

The project team used a system engineering method based on the Vee model. To help support the team's research with the Vee model they utilized the *Innoslate* tool to represent all system models to stakeholders. The stakeholders then gave the team their needs and requirements, including preparation for the definition process, the development of OpsCon, and MOE. All information regarding needs and requirements was conducted through multiple meetings and Q&A sessions with the stakeholders. The meetings and sessions help validate the team's research, work, and verify that the PESTONI model will be useful to the stakeholders in the future.

B. CONCLUSION

The outcome of PESTONI provided and reported readiness insight into underlying resource conditions at the task and capability level. Each pillar was analyzed, modeled, and linked to one another to determine the individual and overall effect they have on the FFG(X). Below are the results and conclusions gathered from each PESTONI pillar decomposition:

The personnel pillar consisted of calculating four top-level functions, which were morale, experience, skills, and performance. The personnel pillar top-level functions would evaluate the sailor's commitment, retention, and how maintenance was performed. Evaluating morale for the sailors was important because it would affect their productivity when doing tasks. If the sailor worked for too many hours without a break on a task it would affect their productivity and their mental health. This was crucial to calculate to see after how many hours it started to affect the sailor's morale. It was determined that after 40 hours per week the morale of the sailor would start to go down. Calculating experience and skills were important to measure because it would determine the different types of levels your crew would fall in. One would be able to measure how much experience and skill the crew obtained when performing tasks that were assigned to them.

The structure of the equipment pillar consisted of calculations using typical reliability, availability, and maintainability equations. The major mission systems of the FFG(X), such as ASW, SuW, and AAW are modeled in series with up to three redundant systems modeled in parallel. Modeling the equipment pillar in this fashion calculated the operational availability of each system and then used that to calculate the operational availability of the system of systems as a whole, which is the equipment pillar's FOM.

The supply pillar is structured in a near-identical fashion as the equipment pillar since they are highly interconnected. The FOM of the supply pillar is *MDT*. The *MDT* of each mission-critical system is calculated within the supply pillar and then sent to the equipment pillar for use in the operational availability calculation. Since *MDT* comprises of *ADT*, *LDT*, and $\bar{M}$, the supply pillar is one of the most affected pillars by changes in other pillar funding.

Similar to the personnel pillar, the training pillar also consisted of calculating morale, experience, skills, and performance as the top-level functions. For this pillar, these top-level functions were based on the KirkPatrick levels, which were reaction, learning, behavior, and results. For the team to reference the KirkPatrick model each of those levels had to tie into a top-level function to get measurable data. By incorporating the KirkPatrick model, it helped by determining which stages of training were more beneficial for the sailors when they conducted their training. Those stages were A School, C School, On the

Job Training, and Continuing Education. After evaluating each top-level function within each of the stages a final combined FOM could be calculated for current A_o and future A_o.

The ordnance pillar within the FFG(X) readiness model analyzes the readiness capability of the critical ordnance systems aboard the frigate. The ordnance systems can be categorized into AAW, SuW, and ASW. The readiness capability of the ordnance pillar affects that of the supply, equipment, and training pillars. Consequently, any change in ordnance readiness affects the overall readiness of the FFG(X). Operational availability is the designated figure of merit for the ordnance pillar. This FOM is used to quantify the readiness of the ordnance pillar and integrate it into the overall readiness of the FFG(X).

The network pillar within the FFG(X) readiness model analyzes the readiness capability of the critical network systems aboard the frigate. The network systems modeled are categorized into Radio Communications, Navigation, and NMCI. The readiness capability of the network pillar affects that of the personnel, equipment, supply, and ordnance pillars. Consequently, any change in network readiness affects the overall readiness of the FFG(X). Operational availability is the designated figure of merit for the network pillar. This FOM is used to quantify the readiness of the network pillar and integrate it into the overall readiness of the FFG(X).

Infrastructure reflects the facilities needed to support the capability of the FFG(X) using *MDT* as the FOM for the readiness model. The team decomposed repair into three levels. O-level repair is the minor day to day repairs. I-level repair is the repair and test of components that require a specific shop or facility. D-level repair is lengthy and requires specific conditions or facilities to complete. The schedule, maintenance tasks, and repair analysis allow the *MDT* of the FFG(X) to be determined and also where the work will need to take place to successfully complete it. The determination of work will ultimately result in the infrastructure needed to support the FFG(X) before returning to the fleet. This pillar can have direct impacts on the personnel, training, supply, equipment, and network pillars.

Overall, this project provided means to improve system engineering tools by utilizing each of the PESTONI pillars. In the model, they were first built independently, and then they were connected with one another. The team built the interconnection based on coefficients of each FOM and funding allocations to each pillar. This information was all on a dashboard that is very simple to use and allowed for quick changes for the user. It allowed the users to edit multiple variables for each pillar's specific FOM based on the continuously changing data the FFG(X) will create as future work and more data comes about. The user could then alter the amount of funding that each pillar received based on user preference or available information. That would allow the user to see the effect that it had on the overall FFG(X). The pillars were successfully interconnected using qualitative diagrams, failure/funding propagation chains, and having a well-developed roadmap.

C. FUTURE RESEARCH

As with most model projects of appreciable size, there is work that must be done in the future and work that should be done in order to keep the model up to date and relevant. The basic readiness model will require a significant data collection and analysis effort when the FFG(X) is fielded in order for the model to perform its primary goal of acting as a readiness tool. Iterating the data collection and analysis tasks will ensure the readiness model stays as accurate and up to date as possible in the future.

1. Data Collection

The foundation of any data-driven model is a sufficient amount of accurate data with the necessary amount of fidelity needed to produce quality results. Gathering the requisite data can often be more difficult and take longer than building the model itself. The PESTONI readiness model is not different. To make the readiness model shift from a qualitative to a quantitative model, a significant data collection effort must be undertaken.

Since at the time of this project, there have been no FFG(X) fielded, the task of collecting data may seem fruitless, but can still be beneficial. The FFG(X) is utilizing a number of systems that are common to already fielded ships. While the data collected from different ships with similar systems will not allow for a perfect model to be built, it will help the model provide a more accurate representation of the FFG(X) while the first few ships are fielded and data is collected.

The biggest hurdle of the data collection task is to ensure that the data collected has the appropriate amount of fidelity to be useful in populating the readiness model. Systems as complicated and dynamic as the FFG(X) will have a seemingly endless potential of items that can flood a data stream. Those undertaking the data collection task must be well trained in what the pertinent data is and how to use the data collected to derive other data needed. Even if the correct amount of the correct data is collected, it still must be analyzed.

2. Data Analysis

Once the appropriate data is collected, it must be analyzed to accurately populate the coefficients in the PESTONI readiness model. The coefficients in the readiness model are used to relate a shift in funding to a shift in FFG(X) readiness. These relationships are peppered throughout the readiness model and, just like any data-driven tool, cause the readiness model to become more accurate as the coefficients themselves become more accurate.

Determining the best coefficient to insert throughout the readiness model will also not be an easy task. The complexity of the FFG(X) makes filtering out the noise to draw accurate correlations a delicate and daunting task. As the correlations are made and the coefficients were proven by future state FFG(X) readiness model predictions, the data analysis will become easier during future iterations.

3. Iteration

Once the data is collected, analyzed, correlations are made, and the coefficients are input into the model, the next step is to repeat the process. Each iteration of the aforementioned process will lead to a more powerful and accurate PESTONI readiness model. No matter how many times the data collection and analysis process is completed, the iteration process will never be over and must continue throughout the entire life cycle of the FFG(X). Like any other military system, the FFG(X) will be modified over the years to incorporate new technologies and capabilities. Every time the FFG(X) is upgraded or changed, the coefficients within the readiness model will need to be updated as well to keep the model as accurate as possible. Non-FFG(X) changes will require data iterations as well. Changes in the human factors discipline or generational changes in personnel will also impact the efficacy of the readiness model. The bottom line is that the PESTONI readiness model will stay as relevant and as up to date as the data it uses to operate.

APPENDIX. FAILURE PROPAGATION MODELS

This appendix displays the failure propagations for each of the PESTONI pillars. Each of these models were used to see how each pillar affected the rest of the pillars. Once the models were created the team had a better understanding on how the pillars interacted with each other which aided in constructing the readiness model.

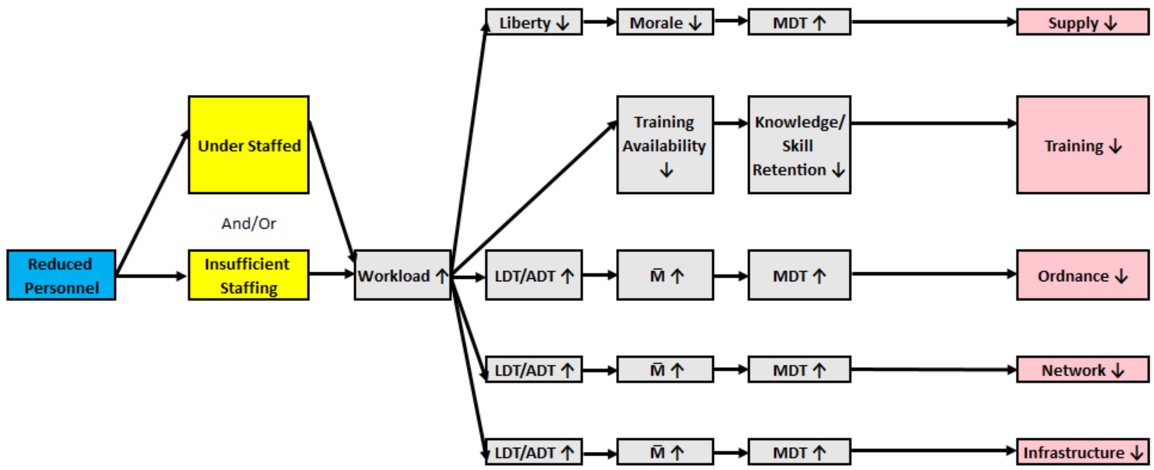

Figure 9. Personnel Failure Propagation Model

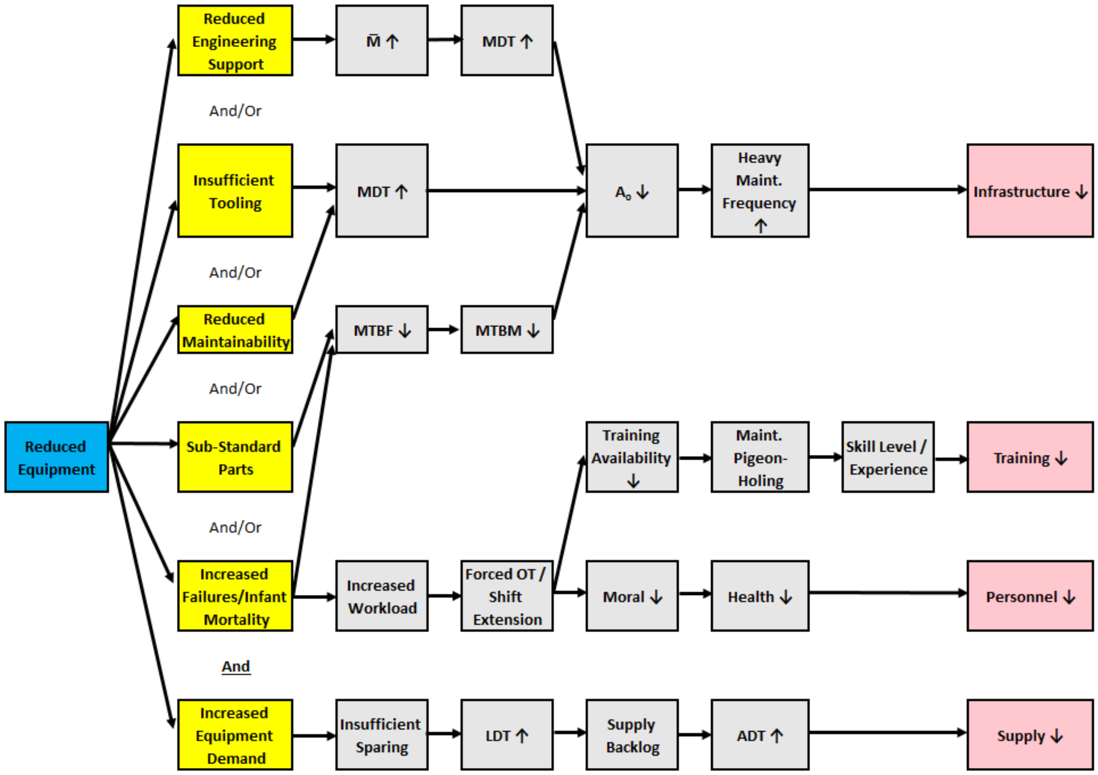

Figure 10. Equipment Failure Propagation Model

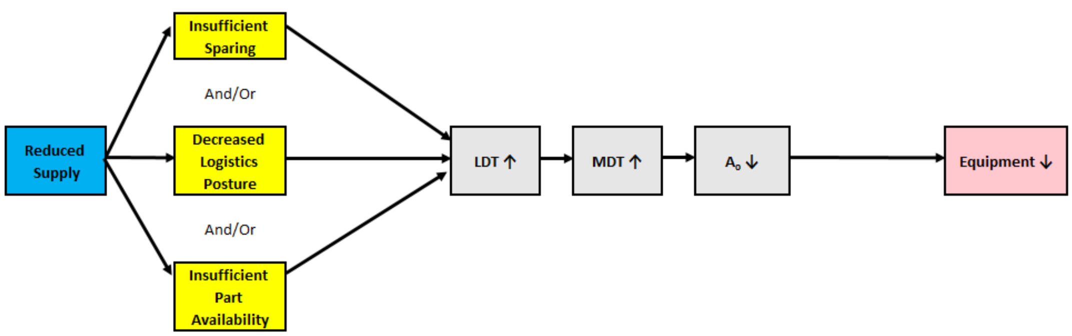

Figure 11. Supply Failure Propagation Model

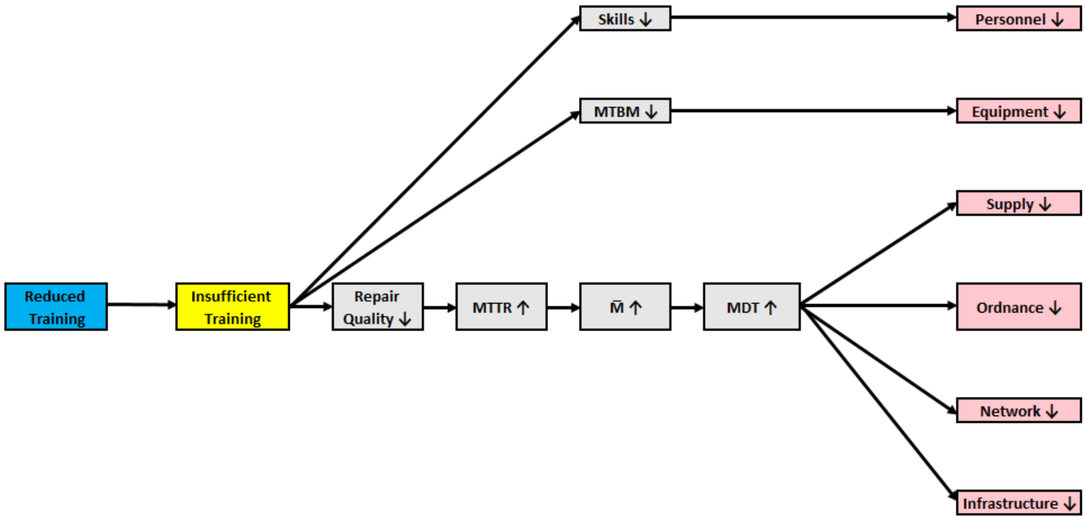

Figure 12. Training Failure Propagation Model

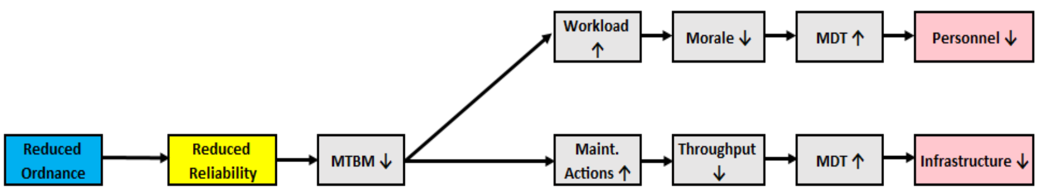

Figure 13. Ordnance Failure Propagation Model

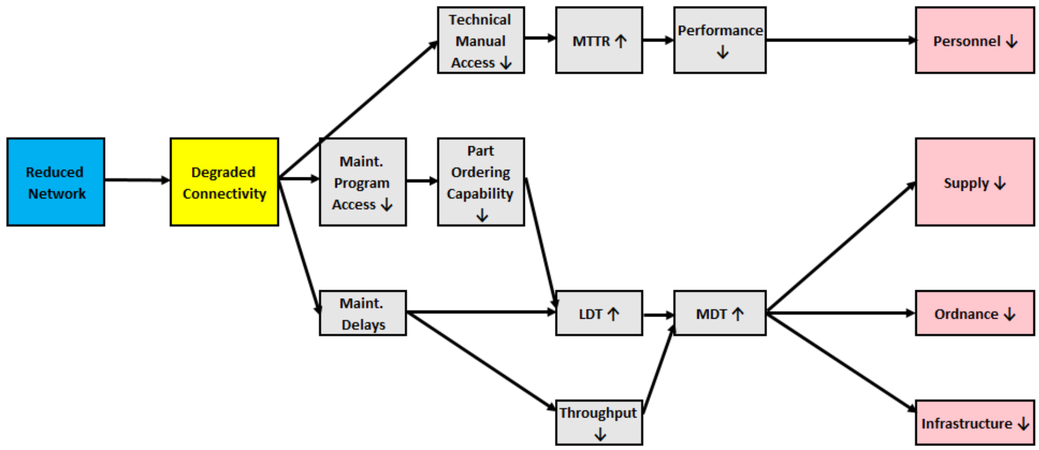

Figure 14. Network Failure Propagation Model

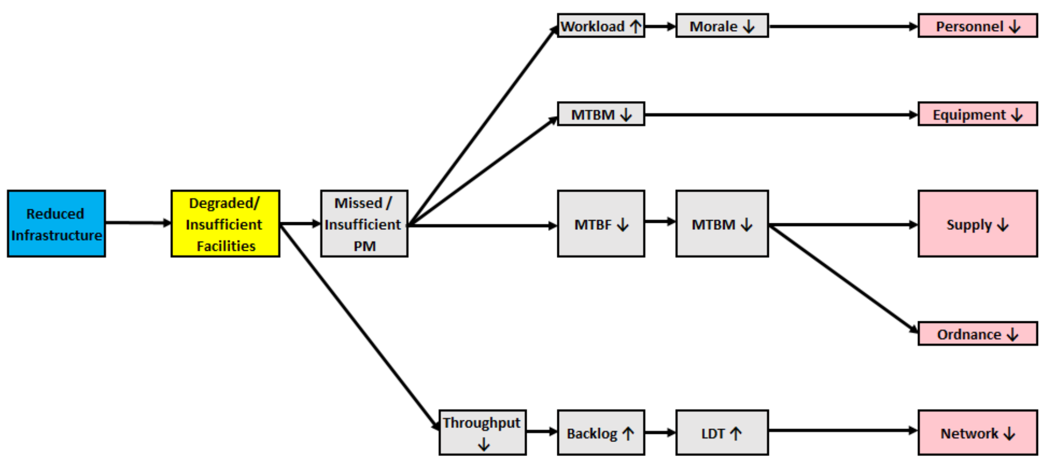

Figure 15. Infrastructure Failure Propagation Model

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