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REVISING THE VALUE MODELS FOR THE MARINE FORCES RESERVE SUPPLY AND MAINTENANCE (SMAT) INSPECTION PROGRAM

by

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September 2020

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The Marine Forces Reserve (MARFORRES) comprises mainly "citizen-soldiers" who are required to operate across a broad spectrum of military operations at extended distances to support the Marine Corps missions. In recent years, the accountability and readiness scores for MARFORRES units have been declining. There have been previous studies endorsed by MARFORRES G-4 to develop a value model for the Supply and Maintenance Team (SMAT) inspection program through the analysis of a stakeholder-derived objectives hierarchy. This thesis expands upon previous work by focusing on the following: 1) review of the existing value models to ensure they reflect the true value of the SMAT inspection program, 2) validation of the value models to articulate the contributions that the SMAT inspection program provides to MARFORRES mission, and 3) demonstration of the utility of value models for resourcing decisions in a budget-austere environment. MARFORRES can use the value models to revise its inspection policies to focus on value-driven inspection rather than mission-driven inspection. This will help to maximize the total value of SMAT inspection to the MARFORRES mission.

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REVISING THE VALUE MODELS FOR THE MARINE FORCES RESERVE SUPPLY AND MAINTENANCE (SMAT) INSPECTION PROGRAM

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ABSTRACT

The Marine Forces Reserve (MARFORRES) comprises mainly “citizen-soldiers” who are required to operate across a broad spectrum of military operations at extended distances to support the Marine Corps missions. In recent years, the accountability and readiness scores for MARFORRES units have been declining. There have been previous studies endorsed by MARFORRES G-4 to develop a value model for the Supply and Maintenance Team (SMAT) inspection program through the analysis of a stakeholder-derived objectives hierarchy. This thesis expands upon previous work by focusing on the following: 1) review of the existing value models to ensure they reflect the true value of the SMAT inspection program, 2) validation of the value models to articulate the contributions that the SMAT inspection program provides to MARFORRES mission, and 3) demonstration of the utility of value models for resourcing decisions in a budget-austere environment. MARFORRES can use the value models to revise its inspection policies to focus on value-driven inspection rather than mission-driven inspection. This will help to maximize the total value of SMAT inspection to the MARFORRES mission.

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LIST OF ACRONYMS AND ABBREVIATIONS

COMMARFORRES	Commander, Marine Forces Reserve
COVID-19	2019 Novel Coronavirus
DASF	Due and Status File
DOD	United States Department of Defense
FTE	Full Time Equivalent
FY	Fiscal Year
GAMS	General Algebraic Modeling System
GAO	Government Accountability Office
GCSS	Global Combat Support System
INCOSE	International Council on Systems Engineering
MARFORRES	Marine Forces Reserve
MMT	Maintenance Management Tool
MOE	Measure of Effectiveness
MPR	Maintenance Process Request
MR	Maintenance Readiness
MSC	Major Subordinate Commands
NPS	Naval Postgraduate School
PMCS	Preventive Maintenance, Checks and Services
RTS	Return to scale
RVS	Raw Value Scores
SDP	Systems Design Process
SMAT	Supply and Maintenance Assistance Team
SR	Supply Readiness
TAMCN	Table of Authorized Material Control Numbers
WVS	Weighted Value Scores

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EXECUTIVE SUMMARY

Over the past decade, United States Department of Defense (DOD) has recognized that the operational tempo of numerous overseas deployments has impacted the operational readiness of the United States Armed Forces. This impact was reflected in the decline of accountability and readiness scores in the Marine Forces Reserve (MARFORRES) units in recent years. The concept of a Supply and Maintenance Assistance Team (SMAT) inspection program was introduced in 2013 to evaluate the overall logistical readiness and accountability of MARFORRES units. The MARFORRES G-4 (Logistics Directorate) has requested the Naval Postgraduate School (NPS) to develop a method to understand the contributions that the SMAT inspection program provides to the MARFORRES mission. The approach NPS took was to develop value models related to readiness and accountability metrics, validate the models, then apply the value models to support value-based decision making concerning SMAT inspection scheduling.

This thesis uses the Systems Decision Process (SDP) framework to examine the SMAT inspection program. An initial review of the existing value models from a previous study of SMAT operations (Yee 2019) revealed that the existing value models contained inconsistencies and ambiguities that could fail confuse interpretations of inspection data, thus possibly failing to accurately reflect the value of the SMAT inspection program. This thesis modified the existing value models and validated the updated value models with the MARFORRES G-4 to more accurately capture the contributions of the SMAT inspection program. Lastly, this thesis described how the application of value scores to a scheduling optimization model which resulted in more efficient resource usage in a budget-constraint environment.

The development of value metrics began with creating a comprehensive objectives hierarchy that accounted for all key objectives that are important to the stakeholders. The top-level fundamental objective was identified through stakeholder analysis, and was verified with the MARFORRES G-4. The top-level objective is focused on ensuring that the MARFORRES units have the right types and numbers of properly maintained equipment. The second level of the hierarchy decomposes the top-level objective into two sub-objectives: 1) Improve equipment readiness; and 2) Improve equipment accountability. A third original sub-objective "Improve impact on unit processes" was removed from the hierarchy based on changes made to the SMAT inspection program concept of operations that focus on virtual inspections and no longer requires the units to submit corrective action plans.

Key attributes and associated metrics were developed from the sub-objectives that would allow the SMAT to evaluate MARFORRES unit equipment readiness and accountability. The quality, utility, or relevance of some metrics made them unsuitable for creating useful value models; perpetual inventory status, maintenance process request (MPR) status, and the preventive, maintenance, checks and services (PMCS) status were removed from the original objectives hierarchy. Figure 1 illustrates the resulting objectives hierarchy of the SMAT inspection program. The overarching objective is in the white box, sub-objectives in blue boxes, attributes in red boxes, and metrics in yellow boxes.

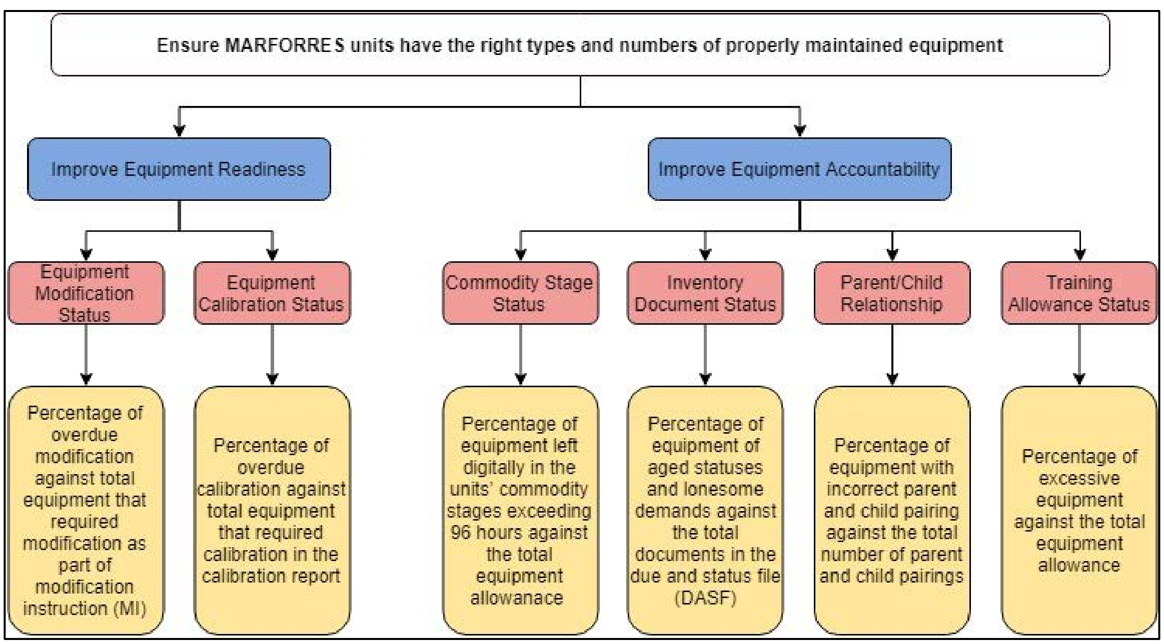

Figure 1. Objective Hierarchy of SMAT inspection program

The SMAT program's revised concept of operations focuses on virtual inspection, making supply readiness (SR) and maintenance readiness (MR) from Yee's (2019) study inapplicable as variables. The existing variables of SR and MR ratings are replaced by the percentage of PMCS discrepancies as the surrogate variable; approximately 70% of the PMCS discrepancies and value scores pairs are compatible. Due to the limited duration and the difficult in collecting new data midway through this study, the findings are accepted. The PMCS discrepancies provide an indication of the overall maintenance health of the organization and guides the development of the value curves.

This thesis represents the value derived from of each attribute through quantitative value modeling. The surrogate variable, percentage of PMCS discrepancies, is plotted against each metric to develop the value curves. There are three main shapes that are hypothesized in this thesis: 1) Linear return to scale (RTS), 2) Decreasing RTS (concave curves), and 3) Increasing RTS (convex curves). The thesis verified the relevance of the value curves through theoretical, empirical, and operational justifications. The value curves are then used to convert each unit's metrics captured in the inspection into raw value scores (RVS). The RVS are subsequently transformed into weighted value scores (WVS) using measure weights that reflect the importance of the metric to the stakeholder. The sum of the WVS can then be computed for the total value score of each unit, which represents the value that the unit would gain from the inspection and thereby the value that MARFORRES would gain from the unit being inspected. The total value score informs the SMAT program decisions on where scarce inspection resources should be invested to return the most value.

This thesis also demonstrated the application of the value models in scheduling SMAT inspections of MARFORRES units for a six-month period. A greedy heuristic model and Lugo's (2020) optimization model are used to develop inspection schedules with the objective of maximizing the total value, and then the results compared between the two models. The greedy heuristic model focuses on selecting locally optimal solutions (units with the highest value score) in each month. In general, the greedy heuristic is how the SMAT is implementing value scores. The greedy heuristic was able to schedule eight units for inspection in the six-month period and attained a total value score of 47.3. In this schedule, utilization of SMAT resources was approximately 60%. Lugo's (2020) optimization model was able to schedule 16 units for inspection in the six-month period and attained a total value score of 84.9. In this schedule, utilization of SMAT resources was 100%. Compared to the greedy heuristic model, Lugo's optimization model is able to attain approximately double the total value score. By implementing the value scores in conjunction with an optimization program, the G-4 can more efficiently use its resources to obtain the set of inspections that present the greatest contribution to the MARFORRES mission.

Although the value models are observed to generally follow a logical pattern, there are some exceptions. Due to the limited duration of this study, the exact explanation for these anomalies was not discerned. The SMAT program's revised concept of operations means that there may be certain unforeseen confounding factors such as misinterpretation and verification of data that are initially difficult to discern. A major recommendation of this thesis is to continue collection and analysis of data to improve the consistency and robustness of the value models. Lastly, should future developments allow, reinstate the sub-objective "Improve impact on unit processes" sub-objective to physically assess the degree to which the SMAT inspections improved the units' processes. This sub-objective encompasses another aspect of the SMAT inspection program that focuses on the developmental impact. Various metrics such as the percentage of corrective actions implemented can be further evaluated to examine the extent to which the efficiency of the unit processes has improved.

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I. INTRODUCTION

A. BACKGROUND

Logistics is the foundation on which successful military operations are built (Wissler 2019). However, past experiences and analysis have shown that the importance of logistics is often under-appreciated in most militaries around the world. The 1990s Gulf War underscored this attitude about logistics. Although the United States Armed Forces demonstrated its ability to transport large amounts of logistics to a theater and sustain its logistics readiness, it also faced several initial logistical shortcomings (Conahan 1991). The Government Accountability Office (GAO) highlighted that the Marine Corps had issues with the management and visibility of prepositioned supplies in the initial phase of the operations. The logistical shortcomings meant that the Marine Corps had to depend on their organic logistical supplies to maintain an acceptable level of logistical readiness for the initial phase of their operations (Conahan 1991).

The Gulf War also showcased the value of the total force. The Marine Forces Reserve (MARFORRES), which was established via the Naval Appropriations Act in 1916, had its largest mobilization since the Korean War in its effort to support the Marine Corps missions (United States Marine Corps Forces Reserve 2016). The MARFORRES, which comprised mainly of "citizen-soldiers," is an integral part of the Total Force. Given the requirements of the Marine Corps to operate across a broad spectrum of military operations at extended distances with little forewarning, it is crucial for MARFORRES to maintain high logistical readiness to sustain its force for mission success.

In recent years, the accountability and readiness scores for MARFORRES units have been declining (Yee 2019). This result has become especially evident in the complex operational environments in which the MARFORRES has been most deeply involved. The concept of a Supply and Maintenance Assistance Team (SMAT) inspection program was introduced in 2013 to gauge the overall readiness and compliance of MARFORRES units. The MARFORRES G-4 (Logistics Directorate) requested the Naval Postgraduate School

(NPS) to develop a set of value models for the SMAT inspection to understand the contributions that the SMAT inspection program provides to the MARFORRES mission.

B. OBJECTIVES

This thesis examines the inspection system that the MARFORRES G-4 has developed to support the MARFORRES mission with three primary objectives in mind. First, this thesis aims to review the existing value models to ensure that they reflect the true value of the SMAT inspection program. Secondly, this thesis validates the value models to articulate the contributions that the SMAT inspection program provides to MARFORRES mission. Lastly, this thesis describes the utility of value models for resourcing decisions in a budget-austere environment.

C. RESEARCH QUESTIONS

In order to meet the thesis objectives, this thesis will answer three critical questions:

1. How can the SMAT inspection program be revised to evaluate MARFORRES's equipment readiness and accountability?

2. How can we validate and optimize the value model to articulate the value that the SMAT inspection program provides?

3. How can value models be used to support resourcing decisions?

D. BENEFITS OF THESIS

1. The reexamination of the contributions brought by the SMAT inspection program will enable MARFORRES stakeholders to adjust their inspection policy to focus on value-driven inspection of units that are anticipated to have the greatest improvement after inspections. This contrasts with the traditional priority-based inspection that focuses on operational and logistical commitments, which may be a challenge for SMAT's limited number of available inspectors. The derived value model will allow MARFORRES to improve SMAT's use of its resources to conduct inspection.

2. The methodology used to develop and validate the value model and its associated metrics can be adapted to other logistical inspection programs within the United States Armed Forces to reflect the true intent of these inspections. This is because while most services have several inspection programs that evaluate the state of units' readiness, there may be an unclear delineation among the various inspection programs. Having well-developed value models will aid in effectively using inspection and assistance resources to provide a comprehensive analysis of the units' logistical status and readiness to support their mission.

E. ASSUMPTIONS AND LIMITATIONS

The scope of this thesis is bounded by the following assumptions and limitations:

1. The metrics formulated can be used to quantitively assess the performance in achieving the objective.
2. The value functions for each metrics reflect the stakeholders' perception of the contribution that the inspection provides to the MARFORRES mission.
3. The value is defined as the anticipated improvement of the unit post-inspection.
4. The mode of data collection is homogenous across the units inspected virtually.
5. All units will strive to prepare well for the inspection.

F. ORGANIZATION OF STUDY

Chapter II focuses on a literature review that informs this work and reflects the current concept of the value model design based on stakeholder's analysis and objectives hierarchy. The key findings of the existing value model will be highlighted. Lastly, the value of inspection programs in industry and its metrics will be explored. Chapter III focuses on the validation process and the method used to revise the existing value model design. Chapter IV analyzes the data and validates the revised value model. Chapter V concludes the thesis by articulating the revision made to the existing value model design and highlights the value that the SMAT inspection program provides to MARFORRES. Recommendations for incorporating the value models for resource decisions are a natural extension of this work and are provided. Additionally, areas for further study are identified that will continue to enhance the value models and their usefulness to MARFORRES.

II. LITERATURE REVIEW

This chapter examines archived information that helps to form the methodology and analysis of this thesis. It begins with an overview of the organization of the MARFORRES and the SMAT inspection program. This chapter then examines the concept of readiness and accountability, followed by a discussion of the characteristics of good measures of effectiveness (MOEs). This chapter explains the formation of the objectives hierarchy and value model. Lastly, this chapter describes the study approach which includes value-driven decision making and optimization.

A. ORGANIZATION OF MARFORRES

The organization of MARFORRES provides a basic understanding of its missions and structure which helps to identify stakeholders with vested interests in the SMAT inspection program. The MARFORRES mission is to "…augment and reinforce active Marine forces in time of war, national emergency or contingency operations, provide personnel and operational tempo relief for the active forces in peacetime, and provide service to the community" (United States Marine Corps Forces Reserve 2020).

MARFORRES's organizational structure is similar to the Marine Expeditionary Force (Feickert 2014). The Commander MARFORRES (COMMARFORRES) exercises command and control of the Major Subordinate Commands (MSCs) through the General/Special Staff to fulfill their mission profiles. The General/Special Staff organization reflects the functions as the staff sections perform; G-1 Administrative and Personnel Section, G-2 Intelligence, G-3/5 Operations and Plans, G-4 Installations and Logistics Section, G-6 Communications, Command Inspector General, and the G-8 Requirements Section. The section of interest to this thesis is the G-4 Installations and Logistics Section, where the SMAT program resources reside that inspect the MSCs.

B. ORGANIZATION OF SMAT

The organization of SMAT provides a basic understanding of its mission and concept of operations. The concept of operations offers an insight into how the inspections are conducted and the types of data collected. The SMAT mission is to "…conduct analysis on MSCs to ensure Marine Corps orders, policies, and directives are adhered to in order to support accountability, readiness, and readiness reporting to the force" (United States Marine Corps 2016).

SMAT is made up of subject matter experts with knowledge and expertise in logistics readiness and accountability. The SMAT uses two modes of analysis, namely: 1) formal inspections, and 2) site-assist visits. When a unit is selected for formal inspection, the SMAT first conducts a virtual inspection using the Maintenance Management Tool (MMT). The MMT is used to retrieve inputs from Marine Corps Global Combat Support System (GCSS) records to determine the unit's current condition. After completing the virtual inspection, the formal on-site inspection will then be conducted on the unit's Supply and Maintenance sections. During the on-site inspection, the unit's supply and maintenance processes, procedures, accountability, and record keeping are examined for compliance with applicable regulations and directives.

Prior to the on-site inspection, a pre-determined sample of records and items are selected for inspection. After the on-site inspection, a formal report is produced within approximately 30 days for any deficiencies found, and corrective recommendations are made to the unit. The unit is then required to provide a corrective action plan to G-4 based on the equipment discrepancies identified in the inspection performance report (United States Marine Corps 2016). Depending on the severity of the deficiency, SMAT will re-inspect the unit to ensure corrections have been made. For the site-assist visits, SMAT conducts an informal inspection meant to train and guide requesting units that need assistance in ensuring compliance with MARFORRES orders. However, formal reports for site-assist visits are not produced unless requested by the MSC.

The SMAT inspection program has reviewed its concept of operations as of Fiscal Year (FY) 2020, focusing solely on virtual inspections using MMT for its analyzes. This is also influenced by the outbreak of 2019 Novel Coronavirus (COVID-19), in which the Marine Corps had to review its mission essential functions to restrict the movement of its personnel in accordance with the Marine Corps Disease Containment Preparedness

Planning Guidance (United States Marine Corps 2020). This unforeseen circumstance further promotes the implementation of virtual inspections. Additionally, the new guidelines no longer require the units to submit corrective action plans.

C. READINESS AND ACCOUNTABILITY

Readiness and accountability form the cornerstones of the SMAT's mission statement and articulate the purpose of the SMAT's operations. The mission statement provides the direction on where the organization is striving towards and assists in making informed decisions that will be beneficial to the organization. It is therefore crucial to understand the specifics of these two aspects of readiness and accountability in order to gain clarity on the focus of the SMAT inspection program.

The United States Department of Defense (DOD) defines operational readiness as "the capability of a unit/formation, ship, weapon system, or equipment to perform the missions or functions for which it is organized or designed" (Office of the Chairman of the Joint Chiefs of Staff 2020). Operational readiness is decomposed into three parts: 1) manning, 2) equipment, and 3) training. Equipment readiness can be defined as the influence of maintenance and parts availability on the equipment's operating status (Rumbaugh 2017). This aspect is crucial as the MSCs need to have the right type of properly maintained equipment to be operational ready.

Accountability is defined by DOD (2020) as "the obligation imposed by law or lawful order or regulation on an officer or other person for keeping an accurate record of property, documents, or funds." In the realm of logistics, it can be elaborated as the tracking and maintaining of proper records for the equipment assigned to the MSCs. This emphasizes on the importance of documentation, which allows MARFORRES to have an oversight on its equipment status to support decision-making.

Understanding the two objectives of the mission statement will therefore allow us to understand the focus of the SMAT inspection program. This will facilitate the conduct of the preliminary requirement assessment of the SMAT inspection program in conjunction with the stakeholder analysis to develop the value models that reflect the true value of the SMAT inspection program to support the MARFORRES mission.

D. MEASURE OF EFFECTIVENESS

MOEs are an essential part of systems engineering that help establish how well a system achieves a set of specific mission requirements. Despite the importance of MOEs, there is no one universally accepted definition for the term. The International Council on Systems Engineering (INCOSE) (2015) added that MOEs should be evaluated “in the intended operational environment under a specified set of conditions.” DOD (2020) emphasized that the metrics must be used to measure a current system state and “with change indicated by comparing multiple observations over time.”

In order to establish the contribution of the SMAT in its support to the MARFORRES mission, the proposed model must have well-defined metrics that realistically represent the status of the units’ equipment readiness and accountability. Sproles (2000) suggested that the development of these metrics should be focused on the stakeholder needs and requirements with the standards established by the stakeholders. INCOSE (2010) describes characteristics of a good metric as such: 1) Relevance, 2) Completeness, 3) Timeliness, 4) Simplicity, 5) Cost-Effectiveness, 6) Repeatability, and 7) Accuracy. The following three characteristics are adapted for the development of the metrics in this thesis.

1. Relevance

The developed set of metrics must be relevant to the mission with clear descriptions of their functions (Miller et al. 2010). Sproles (2000) added that the development of the metrics should be focused on the stakeholder needs and requirements. Sproles (2002) further explained that metrics must tackle the operational issues, which are the “emergent properties that the system must have in order to perform its function.” This will ensure that the identified metrics are pertinent to the objectives of the thesis and agreed upon by the stakeholders.

This thesis identifies the key value proposition through stakeholder analysis and develops the fundamental objective to promulgate the metrics for the value models. The SMAT inspection program can then use these metrics to collect relevant information during the inspections. The information collected will allow MARFORRES to understand how the SMAT inspection program contributes to make informed decisions on its use of the SMAT resources.

2. Completeness

The developed set of metrics must be comprehensive and account for all the key objectives of importance to the stakeholders (Miller et al. 2010). The relative importance of each metrics is be based on the stakeholder analysis and applied through swing weights. In this study, the completeness of the metric specifications ensures their reliability and the total quality of the SMAT value models. This will provide assurance that the model covers all angles and perspective of the stakeholders.

Kirkwood (1997) established that the metrics on the same tier within the hierarchy should not overlap in order to prevent redundancy. In a study conducted to model the selection of automobiles, research has shown that it is crucial that the metrics used in the model are not confounded by unintended correlated measures (Cook and Wissmann 2007). These correlated measures may unintentionally have an impact on the true value of the SMAT value models. Therefore, it is vital to identify a comprehensive set of metrics for the value models which conform to the relevant objectives.

3. Accuracy

The developed set of metrics must be specific and measurable. The accuracy of the metrics can be defined as the extent to which their numeric values truly represent the entity being measured (Miller et al. 2010). Keeney (1992) added that a good metrics should be able to provide a defendable method in collecting and assessing its performance. Furthermore, a measurable metric will help prevent ambiguity of interpretation or loss of information which will have an impact on the accuracy of the information collected.

Given that the SMAT inspection program has transitioned to virtual inspection in FY 2020, the SMAT inspectors no longer conduct formal on-site inspections. The readiness levels of the units are assessed virtually based on the individual units' GCSS records accessed through the MMT. Therefore, the specific and measurable metrics are even more crucial for the collection and dissemination of information between the various entities involve in the evaluation process. Having specific and measurable metrics helps prevent any ambiguity of interpretation and loss of information between the various entities.

E. OBJECTIVES HIERARCHY

Keeney (1992) explained that value-driven thinking placed emphasis on the proper structuring of decisions via a fundamental objective. It is therefore essential to identify the fundamental objective important to the stakeholders for decision making. This fundamental objective can then be translated into value objectives that can meaningfully established an objectives hierarchy. This forms the basis of the system's requirement that can be broken down into sub-objectives and their respective metrics for evaluation of the system.

As an example, an objectives hierarchy for the development of a rocket system is shown in Figure 1. Based on the illustration, the fundamental objective is "to develop a rocket that delivers payloads rapidly and accurately to the intended destination" (Parnell, Driscoll and Henderson 2010). The fundamental objective is decomposed into its functions and relevant objectives based on the values articulated by the stakeholders, which in this case is to "maximize mobility of the launch platform" and "minimize logistics footprint" (Parnell, Driscoll and Henderson 2010). The formulated metrics provide a quantitative means to analyze the extent to which the rocket system achieves the objectives, such as the speed of the launch platform and the percentage of platform that can traverse to deduce the mobility of the launch platform as part of its objectives.

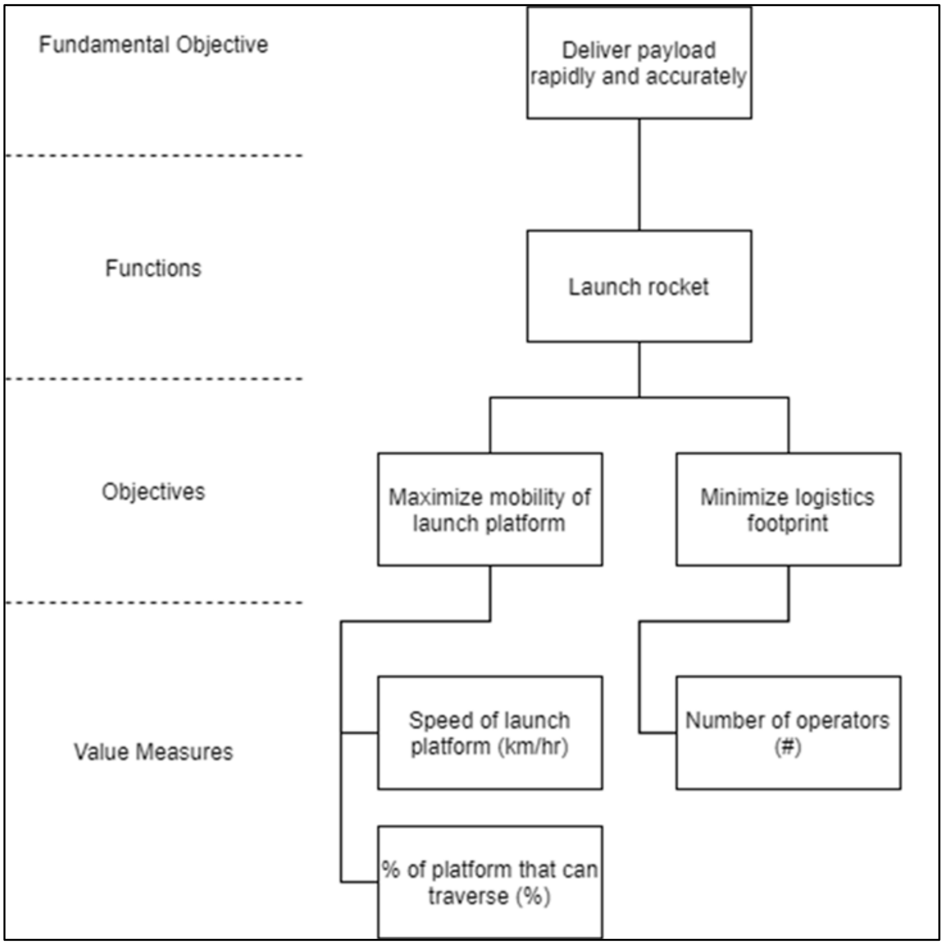

Figure 1. Objectives hierarchy of a rocket system. Adapted from Parnell, Driscoll, and Henderson (2010).

F. VALUE MODEL

Quantitative value modeling enables the assessment of the effectiveness of the various solutions based on the stakeholders' values. This is done by constructing the value curves and applying the swing weights for each of the identified objectives. The value curves can be constructed through the relationship between the metrics with a discrete or continuous scale as reflected in the y-axis. Moreover, Parnell (2010) emphasized that the y-axis must be strictly consistent for all the metrics.

The shapes of the value curve established by the metrics can then be classified under four general forms: 1) Linear return to scale (RTS), 2) Decreasing RTS (concave curves), 3) Increasing RTS (convex curves), and 4) S-curve as shown in Figure 2 (Parnell, Driscoll and Henderson 2010).

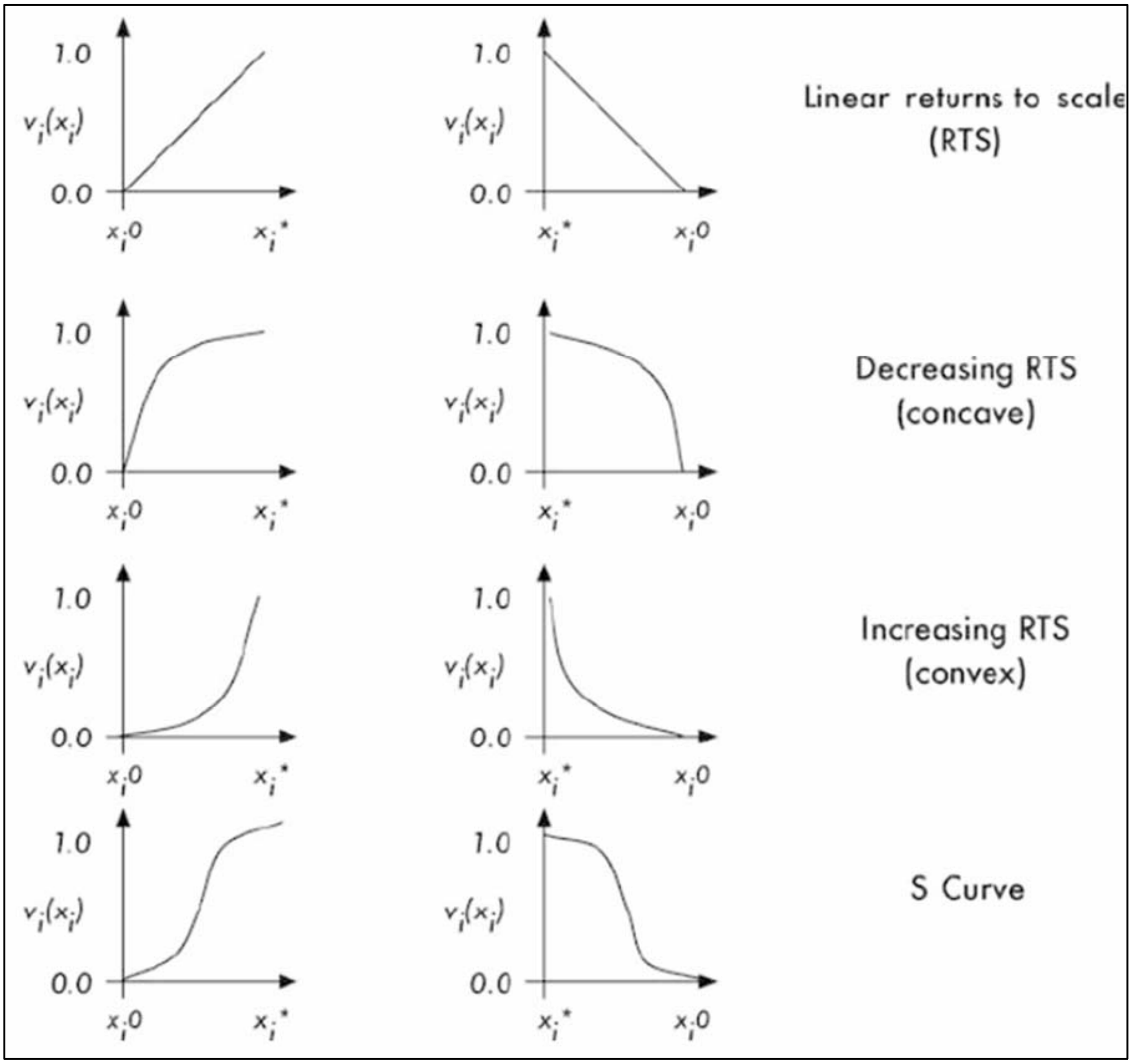

Figure 2. Shape of value curves. Source: Parnell, Driscoll, and Henderson (2010).

1. Linear RTS

A linear RTS indicates a proportional return of value between the variables within the range of interest. In order to assess if the variables of the value curve have a linear relationships between them, Pearson's correlation coefficient is used to measure the strength of their linear relationship (Hinkle, Wiersma and Jurs 2003). The absolute value of the correlation coefficient has a range 0 to 1, where a value of 0 denotes no linear correlation while a value of 1 denotes a perfect correlation. The interpretation of the strength of the Pearson's correlation coefficient is shown in Table 1.

In this thesis, an absolute correlation coefficient value of 0.5 and above, which minimally denotes a moderate relationship, would be sufficient to conclude that there is a linear correlation between the identified variables. Given that the value has been defined as the anticipated improvement of the unit post-inspection, the shape of the value model should exhibit a positive correlation with respective to the number of discrepancies that the SMAT can uncover during the inspection.

Table 1. The strength of Pearson's correlation coefficient. Source: Hinkle, Wiersma, and Jurs (2003).

Absolute Value of r	**Strength of Relationship**
$r \leq 0.3$	Negligible
$0.3 < r < 0.5$	Low
$0.5 < r < 0.7$	Moderate
$0.7 < r < 0.9$	High
$r \geq 0.9$	Very High

2. Decreasing RTS (Concave Curve)

The decreasing RTS is associated with the law of diminishing returns, in which the output increase at a decreasing rate (Buede 2009). This means that the proportionate increase in the inputs does not lead to an equivalent increase in output. As an example, a study from the Department of Mechanical Engineering, Polytechnic University of Milan, examined the relationship between the probability of failure and the length of inspection interval of various types of cracks found on railways components (Carboni and Cantini 2016). The proposed ultrasonic inspection procedure aimed to quantify the result as part of its dedicated inspection plan to optimize the inspection intervals and ensure the safety service of safety critical mechanical components.

The relationship is shown in Figure 3, where the graph adopts a concave curve in which probability of failure increases gradually to a certain threshold value as the length of the inspection interval gets wider. This quantitative assessment provides insights into the formulation of the shape of the SMAT value model. It is essential for SMAT to be aware that for a decreasing RTS, there is a maximum to which the stakeholder can extract from the inspection, beyond which any additional resources such as time and manpower will yield little or no additional value.

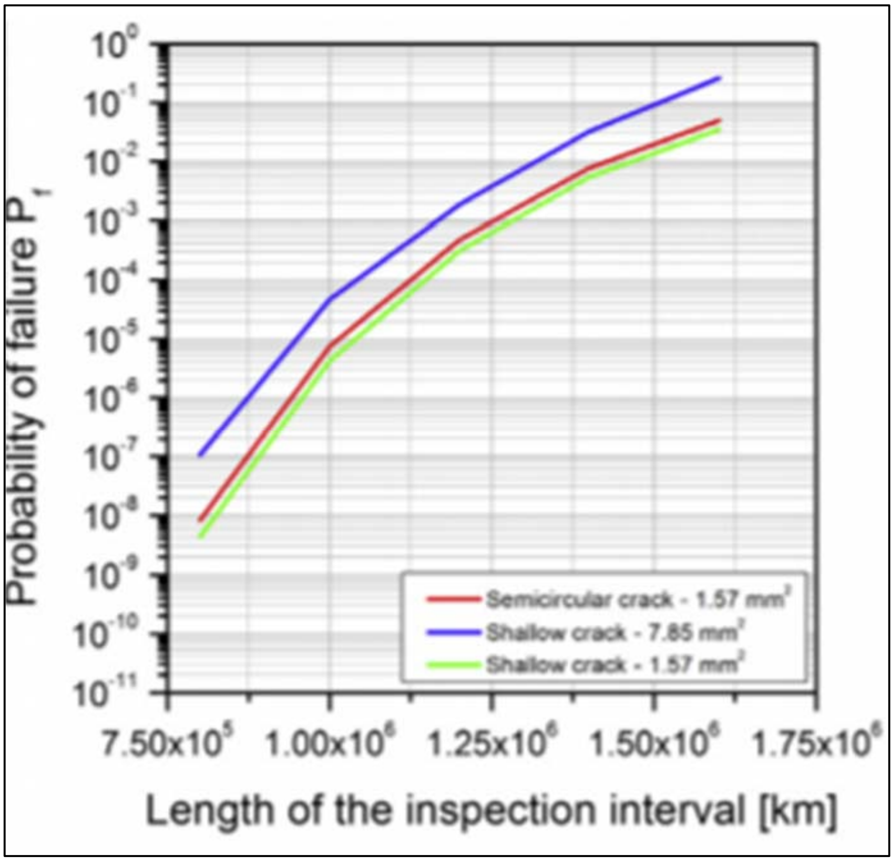

Figure 3. Probability of failure and inspection interval of railways components. Source: Carboni and Cantini (2016).

3. Increasing RTS (Convex Curve)

The increasing RTS is associated with economies of scale, which focuses on production where the output increases by a larger proportion as the input increases and reflects the marginal productivity with which resources are deployed (Suranovic 2010). An example of such a relationship is shown in a study conducted by the Department of Mechanical Engineering, Polytechnic University of Milan, which analyzed the fatigue crack growth lifetime estimations (Carboni and Cantini 2016). The relationship between crack dimensions and the normalized life of the railways components is shown in Figure 4. The graph adopts a convex curve relationship where the propagation of crack increases by a larger proportion as its normalized lifetime increases.

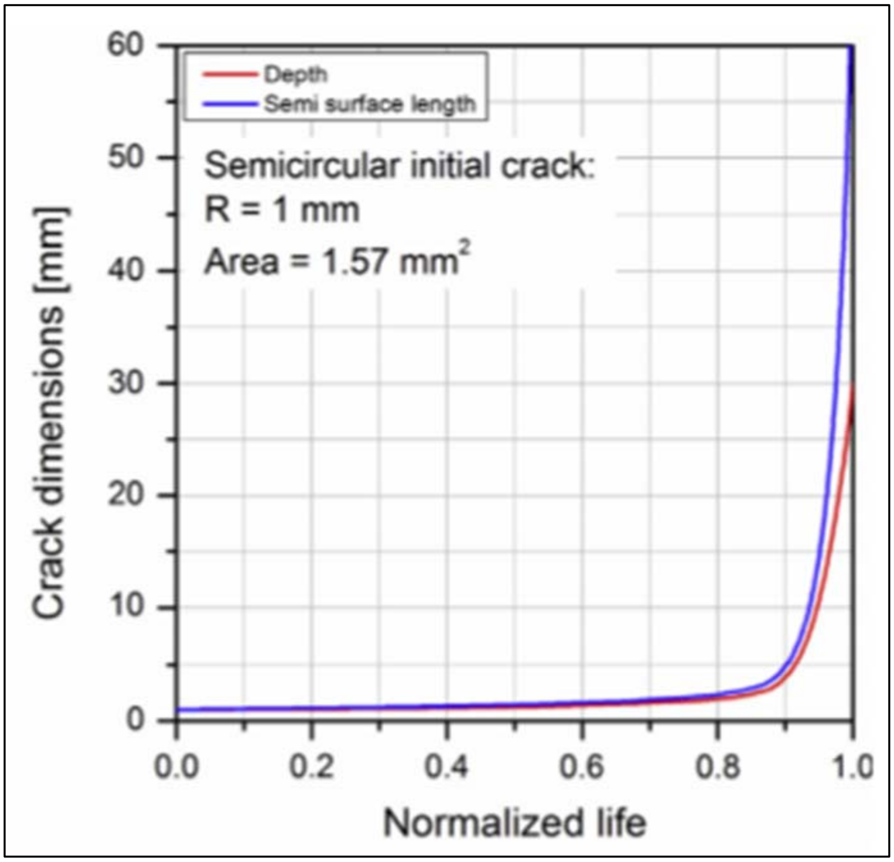

Figure 4. Fatigue crack growth lifetime estimations of railways components.
Source: Carboni and Cantini (2016).

This type of quantitative assessment also provides insights into the formulation of the shape of the SMAT value models. Increasing RTS in economics is an indicator that a firm can produce its output efficiently and thereby has the capability to undertake future growth (Suranovic 2010). In the context of SMAT inspection, this would mean that increase in the number of discrepancies that the SMAT uncovers during an inspection would provide a greater proportion of value in terms of the anticipated improvement of the unit post-inspection.

4. S-Curve

The S-curve reflects a combination of increasing and decreasing RTS, where the maximum and minimum performance preference is within the range of interest (Buede 2009). The S-curve indicates an initial exponential growth rate and subsequently adopts a linear profile before reaching saturation as per the law of diminishing returns. The S-curve can be formulated using the logistic function which considers the maximum capacity of growth the model can achieve.

In the context of SMAT inspections, the logistic function means that limited value can be extracted unless significant changes and resources are committed. The SMAT has optimize the usage of its resources to conduct inspections to assess the units' logistics readiness. Due to the limited number of available inspectors, there is a maximum to the value which the stakeholder can extract from the inspection, beyond which any additional resources such as time and personnel staffing will yield little or no additional value.

G. OPTIMIZATION OF SMAT INSPECTION

Given the limited resources coupled with competing interests from various inspection requirements, the SMAT inspection program is aware that it needs to improve its usage of resources to conduct inspections that will be the most beneficial to the MARFORRES mission. There are many different methods to optimize a schedule, such as a greedy heuristic model or using a mathematical integer model. The greedy heuristic model is a simple and intuitive method that works on the principle of selecting locally optimal solutions at each decision point of the optimization program (Brilliant 2020). The mathematical integer model focuses on objective functions and constraints to optimize a schedule. Furthermore, this model is highly useful for practical applications that involves multiple variables and constraints.

As part of an optimization study for inspection scheduling, Lugo (2020) developed a multi-period mixed-integer linear program using the General Algebraic Modeling System (GAMS) to maximize the total number of higher priority units within a 36-month period, while satisfying various resource and budget restrictions. Based on Lugo's model, the units are quantified using various variables such as the inspection prioritization criteria. The prioritization criteria depend on the MARFORRES's operational and logistical commitments, where units scheduled for deployment or assigned mobilization to support active duty force are assigned a higher score. The priority score ranges from one to five, with priority one denoting the highest priority units and priority five denoting the lowest priority units. Both the greedy heuristic and Lugo's optimization model provide the foundation to use the results derived from the value models to develop a schedule that maximizes the total value of SMAT inspection program.

H. APPROACH TO VALUE MODELING

DOD recognizes that numerous overseas deployments over the past decade has reduced the operational readiness of the United States Armed Forces. The GAO has attributed the low readiness level to "emerging and continued demands on their forces, reduced force structure, and increased frequency and length of deployments" (Pendleton 2016). The Marine Corps specifically identified the shortfalls in training resources, such as the availability of aircraft as one of the challenges they faced in rebuilding readiness. DOD has therefore prioritized improving the readiness level of its forces as part of its mission to deter war and to protect the security of the country.

DOD has undertaken efforts to transform its Global Force Management from combatant-demand to a resource-informed process to address the decline in readiness. As part of its analysis of the readiness rebuilding effort, the GAO (2016) recommended the services to establish goals and associated metrics to evaluate and validate their readiness efforts to meet the mission requirements. This shows the emphasis placed on value-driven decision-making.

Yee (2019) formulated an objectives hierarchy based on MARFORRES stakeholders as part of his research into the development of a value proposition for the SMAT inspection program. He formed a hypothesis that the value of an inspection is related to the inspected unit's response to the SMAT findings and will therefore improve supply readiness (SR) and maintenance readiness (MR) ratings after 90 to 120 days of the inspections. The shapes of the value curve for each metrics are subsequently constructed using the SR and MR ratings as a guide for the shape of the value model. MR ratings are used to evaluate metrics that fall under the sub-objective to "improve equipment readiness," and the SR ratings are used to evaluate the metrics that fall under the sub-objective to "improve equipment accountability."

Yee (2019) concluded that some of the empirical analysis proves to be difficult, and as such, theoretical and operational justifications were used to approximate the shapes of metrics with weak correlations. He recommended that the existing value model should be examined and revised to provide a better evaluation of MARFORRES's supply and maintenance readiness. A potential method may be to identify a surrogate variable that can be used to capture the value of the metrics. However, a critical issue is identifying the best way to assess the feasibility of the surrogate variables against the currently available metrics to improve the quality assessment of the value model.

III. METHODOLOGY

This thesis adopts the Systems Decision Process (SDP) framework of Parnell, Driscoll, and Henderson (2010) which provides a collaborative, dynamic, and value-driven decision process. Throughout the SDP framework, there is a strong emphasis on continuous engagement with the stakeholders to identify their concerns, in order to formulate a coherent value model. The SDP framework consists of stakeholder analysis, objectives hierarchy and formulation of the value model as shown by an IDEF2 model in Figure 5. Verification and validation are be conducted to ensure that the value models fulfill their intended purpose. Lastly, the impetus for optimization of the SMAT inspection schedule is discussed to maximize the total value of SMAT inspection to the MARFORRES mission.

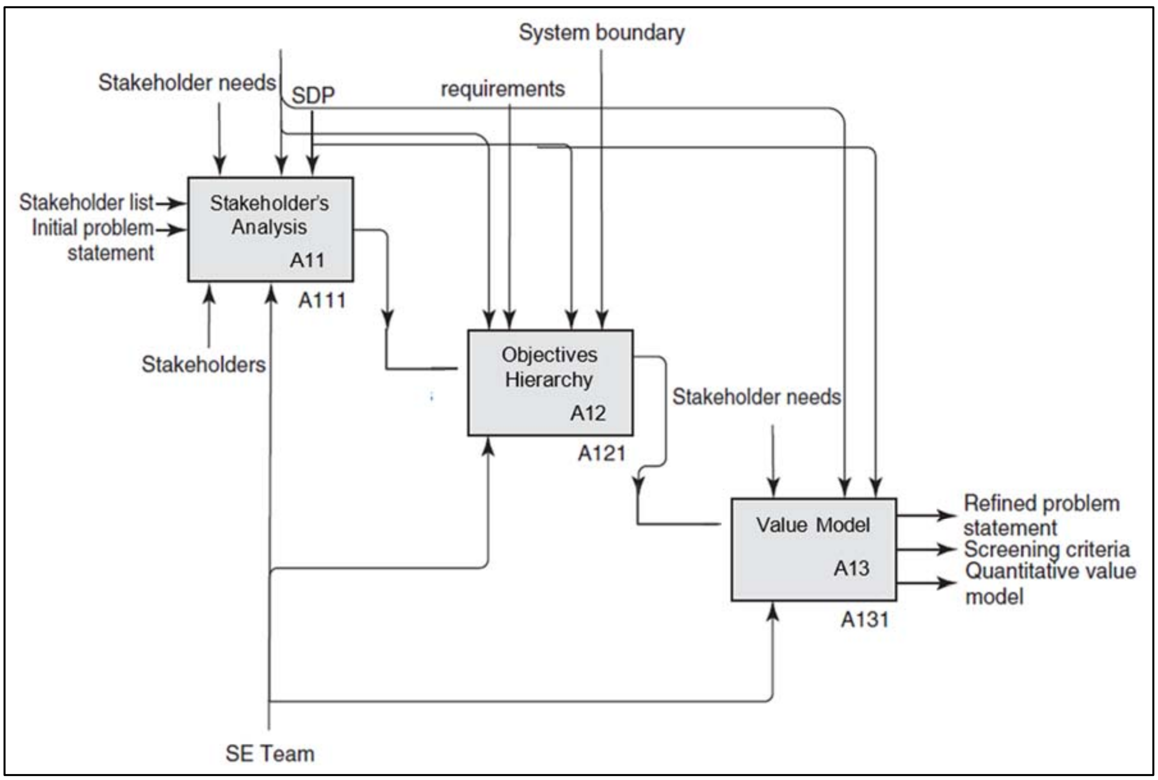

Figure 5. IDEF2 representation of the problem definition phase of the SDP. Adapted from Parnell, Driscoll, and Henderson (2010).

A. STAKEHOLDER ANALYSIS

The stakeholder analysis forms the basis of deriving the fundamental objective, functions, and constraints of the system. It is crucial to identify key interests and concerns of the stakeholders since they may have different perspectives on the overall system (Buede 2009). Given that managing stakeholder expectations is intrinsic to the success of the system, attributes have been established to prioritize stakeholder's concerns based on the stakeholder's power to influence the system, and the stakeholder's interest in the system (Mayers 2005).

The result of the previous stakeholder analysis conducted is revisited through teleconference and email correspondence to understand any changes in their perspective, functions or concept of operation. This reexamination identifies the key value proposition which captures the concerns of the different groups of stakeholders based on the established stakeholders' prioritization attributes.

B. OBJECTIVES HIERARCHY

The objectives hierarchy is a qualitative model of the stakeholder's valuation of the system's behavior or performance. This hierarchical model is critical for assessing and evaluating the value of the inspection program to the MARFORRES mission. Chapter II notes that the objectives hierarchy of a system contains a pictorial representation of the objectives and the relevant metrics that are important to the system's stakeholders for decision-making (Buede 2009). Through the stakeholder analysis, the top-level fundamental objective can be defined with the identification of the stakeholders' key value proposition.

The fundamental objective can be subsequently decomposed into its sub-objectives and their metrics as shown by illustration of the rocket development program in Chapter II. This thesis uses the characteristics of relevance, completeness, and accuracy to support the metrics that reflect the objectives hierarchy. There must be well-defined metrics that realistically represent the status of the unit's equipment readiness and accountability. This gives the assurance that the model reflects the true interest of the stakeholders towards the value models. The objectives hierarchy also serves as a qualitative value model that will be used to build the quantitative value model to evaluate to what extend the metrics meet the fundamental objective.

C. VALUE MODEL

Quantitative value modeling focuses on constructing the value curves and applying the swing weights to each of the identified objectives. Chapter II discusses how the value curves can be constructed through the relationship between the metrics. Yee's (2019) previous study has highlighted that using supply and maintenance readiness ratings may not be an ideal choice due to the inconsistency in evaluating the value model and the ambiguity in interpreting the function of supply and maintenance readiness. This thesis extends Yee's (2019) work by identifying a surrogate variable that can be used to guide the development of the value curves.

Multivariate analysis was conducted on the nine existing metrics based on the inspection findings of 23 units. Based on the analysis, the author has identified the percentage of Preventive Maintenance, Checks and Services (PMCS) discrepancies as the best candidate for the surrogate variable. The variable can be computed based on the percentage of overdue PMCS against total equipment that required PMCS in the MARFORRES PMCS report. The last step in value modeling is to apply swing to develop the value functions. The swing weights depend on the relative importance of each metrics to the stakeholders and their variation within the range of the metrics (Parnell, Driscoll, and Henderson (2010). The value modeling process provides the framework to evaluate the total value of the SMAT inspection program to the MARFORRES mission.

D. VERIFICATION AND VALIDATION

INCOSE (2017) defines verification as a set of activities that "compares a system or system element against the required characteristics." It is further added that verification may consist of "specified requirements, design description, and the system itself." Verification addresses whether the system was built right. INCOSE (2017) defines validation as the set of activities that ensures the system can "accomplish its intended use, goals, and objectives in the intended operational environment." Validation addresses whether the right system has been built in accordance with the stakeholders. For this thesis, the system refers to the value models formulated to address the contribution of SMAT inspection while the requirements refer to the objectives developed.

Verification and validation are inherently incremental processes that occur throughout the various phases of SDP. Michael's (2017) continuous validation and verification process is applied in this thesis as illustrated in Figure 6. Due to the incremental nature of the validation and verification process, the focus is initially on the objectives, followed by the design of the sub-objectives and MOEs, and subsequently the formulation of the value curves.

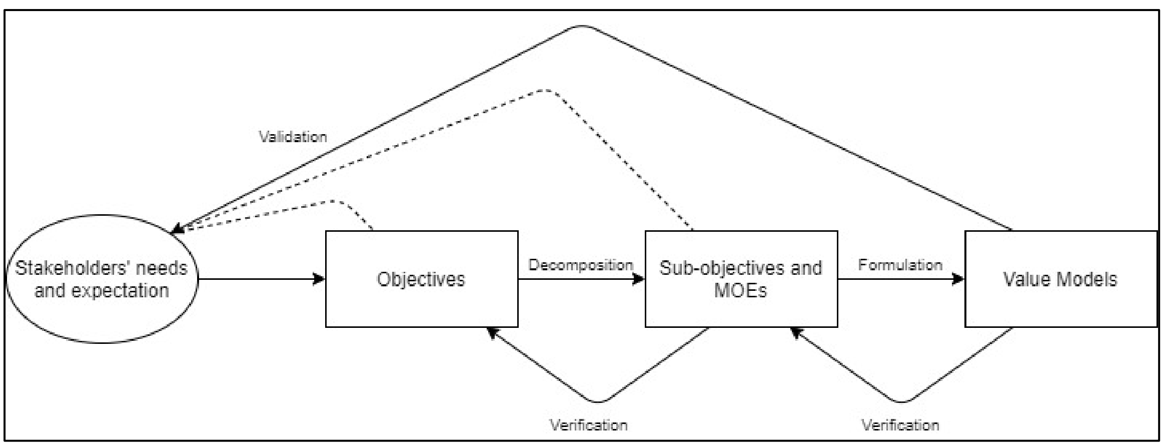

Figure 6. A continuous validation and verification process. Adapted from Ryan and Louis (2017).

First, the fundamental objective and its sub-objectives must be verified through the stakeholder analysis. Next, relevant MOEs developed must also be verified to be relevant, complete and accurate. This will ensure the completeness of the objectives hierarchy and ensure that the objectives of the thesis study are met. Third, the value curves formulated must be verified through theoretical and operational justifications. The data collected from the various units must conform to the specifications as defined by the MOEs. The shapes of the value curves between the MOEs must be theoretically justified as reflected in

Chapter II. Furthermore, the relationship between the surrogate metric and MOEs must be justified based on understanding of the operational procedure of the MARFORRES units.

Lastly, the post-inspection data of each inspection units' percentage of PMCS discrepancies is collected 30–90 days after their virtual inspection. These data should show improvement in the units' performance to verify that value models developed meet the objectives. In terms of validation, the system validation process adopts a iterative nature and provide continuous feedback on how well the requirement meets the stakeholders needs and expectations, and how well the value models serve their intended purpose in articulating the contributions that the SMAT inspection program provides to MARFORRES mission.

E. OPTIMIZATION OF SMAT INSPECTION

Chapter II notes the current emphasis on MARFORRES's traditional operational and logistical commitments as a basis to develop the SMAT inspection schedule. It also discusses the different methods such as greedy heuristic model and Lugo's (2020) optimization model which are simple and intuitive. This thesis seeks to demonstrate how value modeling can be applied to both the greedy heuristic and Lugo's optimization model to develop the SMAT inspection schedules for a six-month period. The aim is to maximize the total value that can be derived from the inspections in order to improve the SMAT program use of its resources.

Given that the SMAT requires two weeks to inspect each unit, the manpower resources required to inspect a unit and the SMAT manpower resources available to conduct the inspections are defined as the Full Time Equivalent (FTE) requirements and availability from Lugo's (2020) model. Both the greedy heuristic and the Lugo's optimization model would be computed based on the value score generated from the value model in this thesis. The greedy heuristic model prioritizes each unit based on the value score generated and chooses the unit with the highest value with regard to the SMAT resources available for that month. The greedy algorithm is a myopic view of the schedule, only considering the current month. The heuristic would decide from month to month, regardless of what resources are unused in the previous month and what resources may be required in the next month.

Lugo’s optimization model also prioritizes each unit based on the value score generated. However, it also focuses on maximizing the utility of the inspectors available by including units that may require less resources to inspect. Both model focus on value-drive inspection than mission-driven inspection and serve as a basis to maximize the total value of SMAT inspection to the MARFORRES mission.

IV. ANALYSIS OF RESULTS

This chapter examines the data collected and the resultant value models, and provides analyses of the value score for any given unit. The analysis follows the SDP framework introduced in Chapter III. This chapter begins with the review of the stakeholder's needs and concerns. Next, the objectives hierarchy is evaluated to provide a qualitative assessment of the value models. Lastly, the formation of the value functions and their application on inspection schedule are discussed to articulate the contribution to MARFORRES mission.

A. STAKEHOLDER ANALYSIS

In Chapter III, the importance of stakeholder's power and interest is emphasized to assist in the formulation of the value models. The stakeholder's power to influence is defined as the ability to "persuade others into making decisions" on the inspection program based on the hierarchy structure of the stakeholder's organization (Mayers 2005). The stakeholder's interest is defined as the "aspirations or concerns" of the outlook of the inspection program (Bryson, Patton, and Bowman 2011).

The stakeholder's power and influence are essential to balance their needs appropriately given their different competing interests and the limited number of inspectors. After revisiting the previous stakeholder analysis, the prospective stakeholders involved in the SMAT inspection program are identified as such: 1) COMMARFORRES, 2) MARFORRES G-4, 3) Inspectors, and 4) MSCs. The key value propositions which captured the influence and concerns of the different stakeholders are shown in Table 2.

Table 2. Stakeholder matrix. Adapted from Yee (2019).

Stakeholder	Power of Influence	Interest
COMMARFORRES	• High. Able to provide overall leadership and influence on all aspects of policy.	• Understand the resources need to achieve the MARFORRES mission. • Optimize the use of resources to achieve MARFORRES mission.
MARFORRES G-4	• High. Able to provide leadership and influence on guidelines.	• Justify the resources needed for the SMAT inspection program to support the MARFORRES mission. • Differentiate the SMAT inspection program from the FSMAO program.
Inspectors	• Medium. Able to influence on nature of support, implementation, and coordination.	• Find the areas for improvement and areas that are not performing well.
MSCs	• Medium. Responsible for the outcome of the inspection.	• Identify the value that the SMAT inspection program contributes to the performance of the unit.

A power interest matrix is also utilized as part of stakeholder mapping to provide a visual representation of the stakeholder analysis. As show in Figure 7, the two-by-two matrix has a vertical axis that represents the stakeholder's power to influence and a horizontal axis that represents the stakeholder's interest (Bryson, Patton, and Bowman 2011). Each of the four quadrants of the matrix provides an indication of the level of stakeholder prioritization required which will also influence the mode and style of communication.

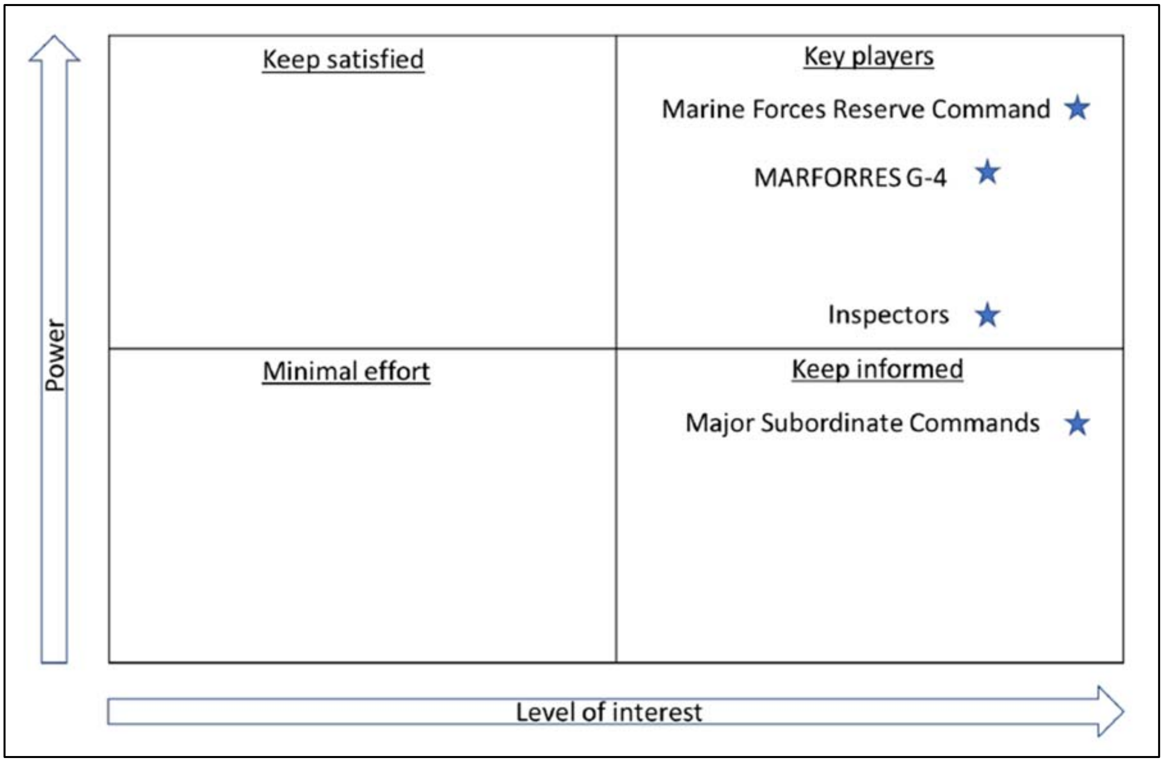

Figure 7. SMAT power interest matrix. Source: Yee (2019).

Based on Figure 7, the COMMARFORRES and MARFORRES G-4 are located at the top right-hand side of the power interest matrix, given that they have the highest power of influence on the policy and interest in the success of the inspection program. By contrast, the MSCs is located at the bottom right-hand side of the power interest matrix, which indicates that they do not have significant influence on the policy but continue to have a high interest in inspection program. This is rightfully so given that the MSCs have limited influence on the decision and are responsible for the outcome of the inspection. With the completion of the stakeholder analysis, the objective hierarchy can then be developed based on the matrix and materials discussed in Chapter II.

B. OBJECTIVES HIERARCHY

There is a need as part of the SDP framework for continuous engagement with the stakeholders to verify the relevance of the existing top-level fundamental objective, sub-objectives, and their respective metrics. This iterative approach is conducted through multiple teleconference and email exchanges with the stakeholders to solicit inputs to refine the existing objectives hierarchy. Through the stakeholder analysis, the top-level fundamental objective remains focused on ensuring that the MARFORRES units have the right types and numbers of properly maintained equipment.

The second level of the hierarchy continues to focus on MARFORRES G-4's interest. The sub-objectives are revised from the existing objectives hierarchy to the following: 1) Improve equipment readiness; and 2) Improve equipment accountability. The sub-objective "Improve impact on unit processes" was removed since the SMAT has changed its concept of operations to focus on virtual inspections and no longer requires the units to submit corrective action plans. The outbreak of COVID-19 also limits the SMAT program's ability to physically assess the degree to which the corrective action plans improve the units' processes. The sub-objectives are subsequently used to identify the key attributes and associated metrics that would allow the SMAT to evaluate the equipment readiness and accountability of the MARFORRES units.

The quality, utility, or relevance of some variables made them unsuitable for creating the value models. As a result, perpetual inventory status, maintenance process request (MPR) status, and PMCS status were omitted from the existing objectives hierarchy. The perpetual inventory status is the percentage of total errors in recording of the table of authorized material control numbers (TAMCN) serialized equipment against the total number of equipment in perpetual inventory. Based on the data analysis of the percentage of perpetual inventory discrepancies, the team observed limited variations across the 23 units that are inspected. Consequently, there would be little utility in using the perpetual inventory status to delineate that value of inspecting one unit in lieu of another.

The MPR status is the percentage of equipment incorrectly processed for maintenance against the total number of maintenance requests. Discussion with the SMAT verified that the attribute was not relevant to the stakeholder's needs. Lastly, the PMCS status is removed from the existing objective hierarchy since it will serve as the surrogate variable for indicating the overall maintenance health of the organization and guides the development of the value curves. The importance of this surrogate variable is elaborated in the next section. Figure 8 illustrates the resulting objectives hierarchy of the SMAT inspection program. The overarching objective is in the white box, sub-objectives in blue boxes, attributes in red boxes, and metrics in yellow boxes.

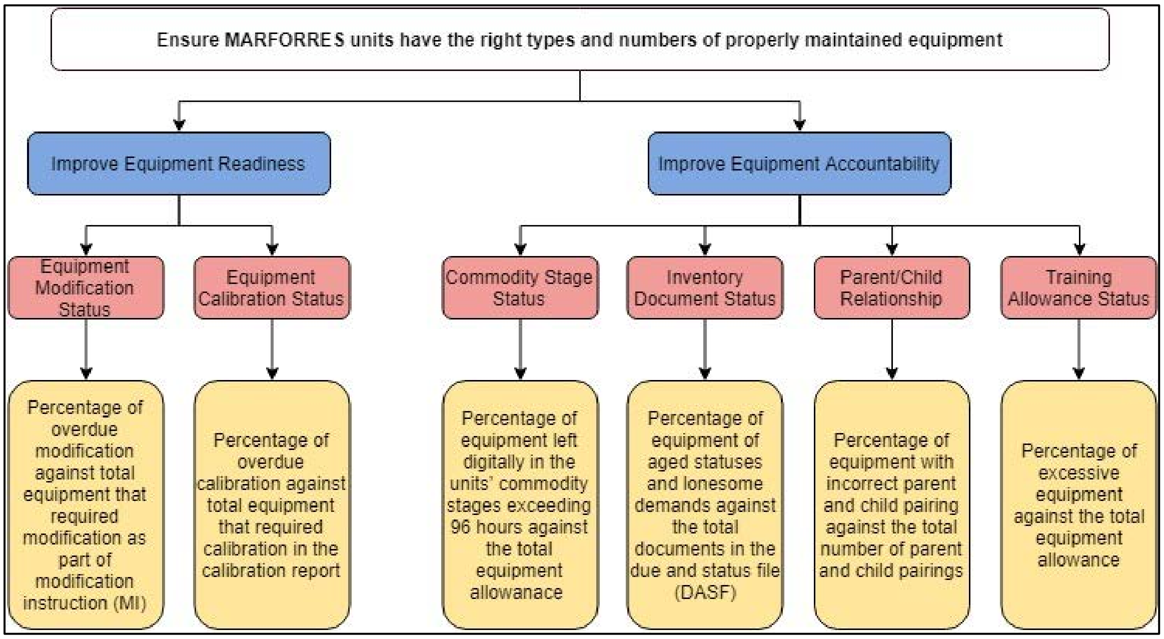

Figure 8. Objective Hierarchy of SMAT inspection program

C. VALUE MODEL

In Chapter III, the team identified the percentage of PMCS discrepancies as a surrogate variable to develop the shapes of the value curve. Theoretically, the strength of the relationship between the metrics and the surrogate variable would be measured with the correlation coefficient. When there are strong correlations, the metrics would follow a linear relationship with the surrogate variable. However, when there are negligible or low correlation, supporting theories and operational justifications are used to articulate the relationship between the metrics and the surrogate variable. The relationship then informs how the value scores should behave as the metric changes.

For linear RTS, the linear function “$y = a + bx$” has been adopted, where y and x are the dependent and independent variables respectively, a represents the constant term and b represents the rate of change of the dependent variable coefficient as the independent variable changes (Columbia 2020). For decreasing RTS, the concave curve function “$y = log(x\text{-}h) + k$” has been adopted, where y and x are the dependent and independent variables respectively, H and k represent the horizontal and vertical shift factors respectively (Lumen 2020). Lastly for increasing RTS, the convex curve function “$y = a\ b^x$” has been adopted, where y and x are the dependent and independent variables respectively, a represents the y intercept and b represents the growth factor (Lumen 2020).

1. Value Curve for Equipment Modification Status

The metric of equipment modification status focuses on capturing the percentage of equipment modification discrepancies found during the SMAT inspections. Operationally, the purpose of modification instruction enforces timely equipment modification requirements to correct safety and operational deficiencies of the equipment. This metric reflects the operational status of the units’ equipment which ultimately influences their equipment readiness.

The value curve assumes a concave shape based on the relationship between the metric and the surrogate variable, where the percentage of PMCS discrepancies increases at a decreasing rate with the metric scores. This is similar to the concept of decreasing RTS as discussed in Chapter II. Based on the empirical data, the metric shows little correlation relationship with the surrogate variable. Moreover, the data points of the units inspected are concentrated at below 11% of the metric score. This would mean that the added value from the findings beyond 11% diminishes rapidly. Based on the law of diminishing return, there is a maximum range of values from which stakeholder can extract from the inspection.

As more modification discrepancies are discovered during the inspection, up to a point there would be more value derived from the inspections to improve the unit equipment readiness. However, when more than 11% of equipment modification discrepancies are discovered, the SMAT should re-allocate its limited resources and analyze the poor inspection findings to discover possible causes such as administrative lapses or systemic issues. Figure 9 illustrates the value curve for the equipment modification status, in which the least value is where the metric score is zero and reaches a maximum value of 10 at a metric score of 11%.

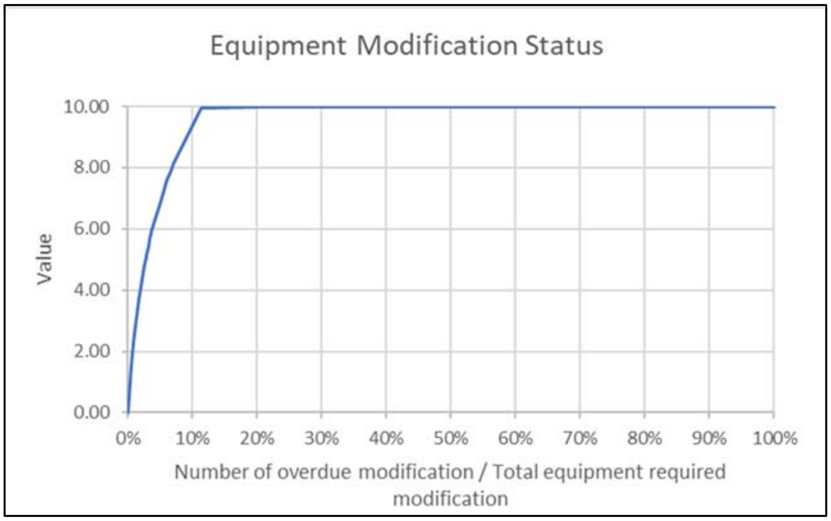

Figure 9. Value curve for equipment modification status

2. Value Curve for Equipment Calibration Status

The metric of equipment calibration status focuses on capturing the percentage of equipment calibration discrepancies during the SMAT inspections. This metric also reflects the operational status of the units' equipment and ultimately influences their equipment readiness. Operationally, equipment calibration is mission critical to ensure quality, safety and performance of military equipment. Given that the equipment is required to be tested at different intervals, any significant findings may point towards potential administrative lapses which could pose safety and operational vulnerabilities.

The value curve has a convex shape based on the relationship between the metric and the surrogate variable, where the percentage of PMCS discrepancies increases by a larger proportion with the metric scores. This is similar to the concept of increasing RTS which is associated with marginal productivity as discussed in Chapter II. Based on the empirical data, the metric shows little correlation relationship with the surrogate variable. Moreover, the data points of the units inspected are concentrated at above 57.7% of the metric score. This would mean that an increase in the number of discrepancies that the SMAT uncovers during an inspection would provide greater proportional of value in the anticipated improvement of the unit post-inspection. Therefore, the value curve can be seen to convex upwards at beyond 57.7% of the metric score as shown in Figure 10.

As more equipment calibration discrepancies are discovered during the inspection, there would be more value derived from the inspections to identify the administrative lapse which would ultimately improve the unit equipment readiness. Based on Figure 10, the value curve has the least value at the metric score of zero and reaches a maximum value of 10 at a metric score of 100%.

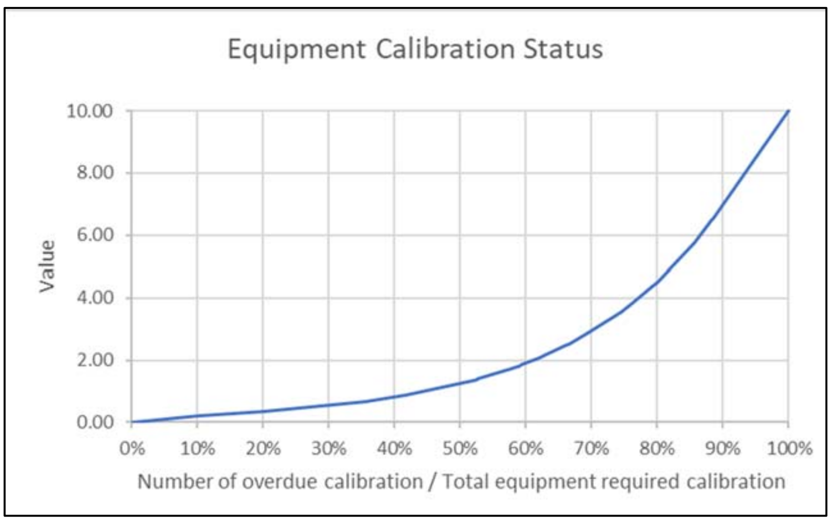

Figure 10. Value curve for equipment calibration status

3. Value Curve for Training Allowance Status

The metric of training allowance status focuses on capturing the percentage of absolute surplus or deficit in the total training equipment assigned to the units. Operationally, training allowances are critical to the units as they signify the minimum amount of training assets required for training.

The value curve assumes a linear shape based on the relationship between the metric and the surrogate variable, where there is a proportional increase in the value derived as the percentage of training allowance discrepancies increase. Based on the empirical data, the metric shows moderate correlation relationship, with a correlation coefficient of 0.5. Moreover, the data points of the units inspected are concentrated at below 37.7% of the metric score. This would mean that the added value from findings beyond 37.7% diminishes rapidly.

As more training allowance discrepancies are discovered during the inspection, there would be more value derived from the inspections to improve the unit equipment accountability. However, when more than 37.7% training allowance discrepancies are discovered, the SMAT should re-allocate its limited resources. Figure 11 illustrates the value curve for the training allowance stat, in which the least value is where the metric score is zero and reaches a maximum value of 10 at a metric score of 37.7%.

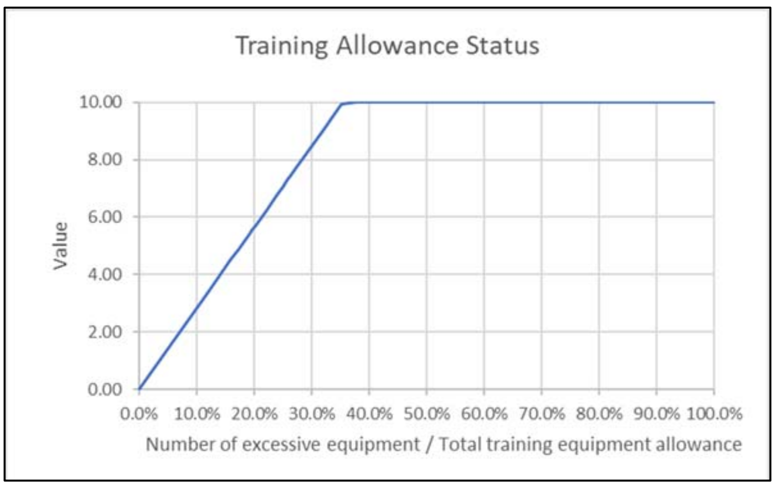

Figure 11. Value curve for training allowance status

4. Value Curve for Commodity Stage Status

The metric of commodity stage status focuses on capturing the percentage of equipment left in commodity stage for more than 96 hours during the SMAT inspections. Operationally, the purpose of the commodity stage is to act as a temporary digital storage account for equipment received by the units. The unit by regulation has 96 hours to move accountability for the equipment from the commodity stage to one of its other accounts. Units are advised not to hold equipment in the commodity stage for more than 96 hours as it would result in administrative lapse that would affect equipment accountability in the system.

The value curve assumes a concave shape based on the relationship between the metric and the surrogate variable, where the percentage of PMCS discrepancies increases at a decreasing rate with the metric scores. This is similar to the concept of decreasing RTS as discussed in Chapter 2. Based on the empirical data, the metric shows little correlation relationship with the surrogate variable. Moreover, the data points of the units inspected are concentrated at below 6.7% and above 95.1% of the metric score with a low percentage of PMCS discrepancies. This would mean that the added value from findings beyond 95.1% diminishes rapidly. Based on the law of diminishing return, there is a maximum range of value to which stakeholder can extract from the inspection.

As more commodity stage discrepancies are discovered during the inspection, there would be more value derived from the inspections to improve the unit equipment accountability. However, when more than 95.1% of commodity stage discrepancies are discovered, the SMAT should re-allocate its limited resources and analyze the poor inspection findings to discover possible causes such as administrative lapses. Figure 12 illustrates the value curve for the commodity stage status, in which the least value is where the metric score is zero and reaches a maximum value of 10 at a metric score of 95.1%.

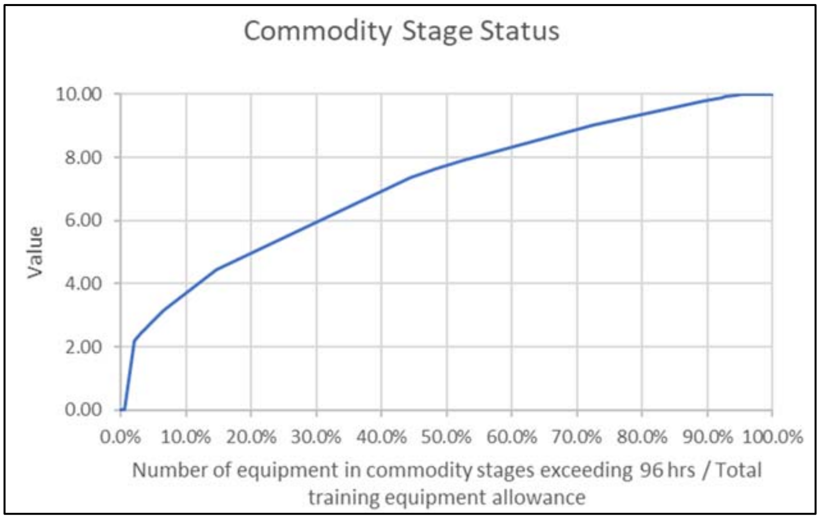

Figure 12. Value curve for commodity stage status

5. Value Curve for Inventory Document Status

The metric of inventory document status focuses on capturing the percentage of equipment with aged status and lonesome demands in the due and status file (DASF) during the SMAT inspections. Operationally, the DASF provides the order record of all equipment of each unit. All units are required to manage their records properly to have oversight on their equipment status. Document discrepancies may lead to accountability issues and are usually indicative of administrative lapses.

The shape of the value curve assumes a concave shape based on the relationship between the metric and the surrogate variable, where the percentage of PMCS discrepancies increases at a decreasing rate with the metric scores. This is similar to the concept of decreasing RTS as discussed in Chapter II. Based on the empirical data, the metric shows little correlation relationship with the surrogate variable. Moreover, the data points of the units inspected concentrates at below 34.5% of the metric score. This would mean that the added value from findings beyond 34.5% diminishes rapidly. Based on the law of diminishing return, there is a maximum range of value to which stakeholder can extract from the inspection.

As more document discrepancies are discovered during the inspection, there would be more value derived from the inspections to improve the unit accountability. However, when more than 34.5% of inventory document discrepancies are discovered, the SMAT should re-allocate its limited resources and analyze the poor inspection findings to discover possible causes such as administrative lapses. Figure 13 illustrates the value curve for the inventory document status, in which the least value is where the metric score is zero and reaches a maximum value of 10 at a metric score of 34.5%.

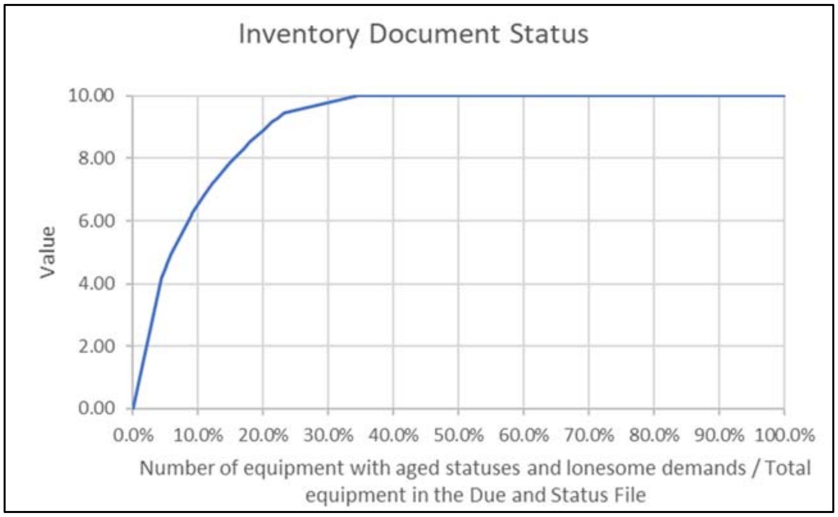

Figure 13. Value curve for inventory document status

6. Value Curve for Parent and Child Relationship Status

The metric of parent and child relationship status focuses on capturing the percentage of equipment with incorrect parent and child configuration. Operationally, it is important to serialize and manage equipment with parent-child configurations due to their intrinsic dependency which would influence their functionality. When the relationship is not established and managed properly, it has an impact on the timely conduct of PMCS actions.

The value curve assumes a convex shape based on the relationship between the metric and the surrogate variable, where the percentage of PMCS discrepancies increases by a larger proportion with the metric scores. This is similar to the concept of increasing

RTS which is associated with marginal productivity as discussed in Chapter II. Based on the empirical data, the metric shows little correlation relationship with the surrogate variable. Moreover, the data points of the units inspected concentrates at above 50.5% of the metric score. This would mean that an increase in the number of discrepancies that the SMAT uncovers during an inspection would provide greater proportional of value in terms of the anticipated improvement of the unit post-inspection. Therefore, the value curve can be seen to convex upwards significantly at beyond 50.5% of the metric score as shown in Figure 14.

As more parent and child relationship discrepancies are discovered during the inspection, there would be more value derived from the inspections to identify the administrative lapses which would ultimately improve the unit equipment accountability. Based on Figure 14, the value curve has the least value at the metric score of zero and reaches a maximum value of 10 at a metric score of 100%.

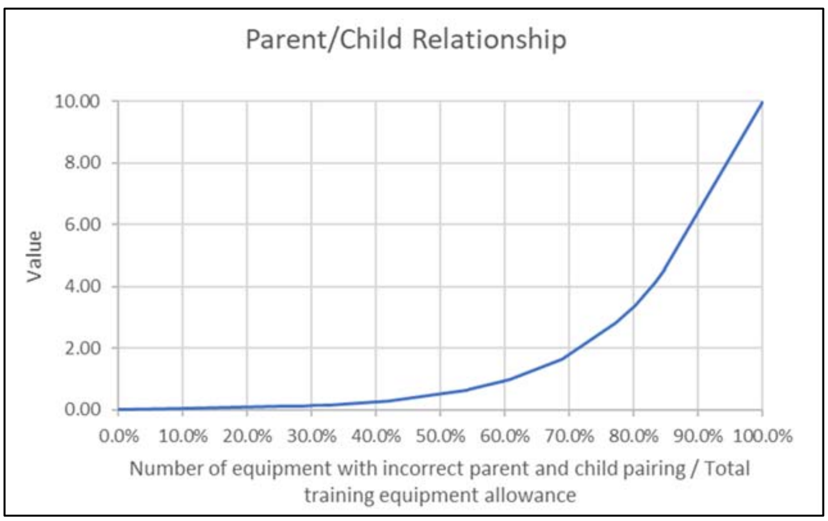

Figure 14. Value curve for parent and child relationship status

D. CONVERTING MEASURES INTO VALUE SCORES

After the development of the value curves, the inspection team can convert the relevant metrics into raw value scores (RVS) for each unit. For operational security considerations, the MARFORRES units are given code designations in this thesis. An example of the inspection findings is shown in Table 3 for the unit code-named "R."

Table 3. SMAT inspection findings for Unit R

	Equipment Readiness		Equipment Accountability			
Unit (Code Name)	**Percentage of Equipment Modification Discrepancies**	**Percentage of Equipment Calibration discrepancies**	**Percentage of Commodity Stage Discrepancies**	**Percentage of Inventory Document Discrepancies**	**Percentage of Parent/Child Relationship Discrepancies**	**Percentage of Training Allowance Discrepancies**
R	11.4%	58.6%	100.0%	23.2%	54.6%	32.7%

In this example, The SMAT inspection of Unit R has recorded an equipment modification discrepancies of 11.4%. Referring to the value model for this metric results in a corresponding RVS of 9.94. The RVS for the remaining metrics for Unit R can be derived in similar fashion as shown in Table 4. As described in the next section, swing weights are applied to these value scores to represent the importance of the metric to the stakeholder.

Table 4. Raw value scores for Unit R

	Equipment Readiness		Equipment Accountability			
Unit (Code Name)	**RVS (Equipment Modification Status)**	**RVS (Equipment Calibration Status)**	**RVS (Commodity Stage Status)**	**RVS (Inventory Document Status)**	**RVS (Parent/Child Relationship Status)**	**RVS (Training Allowance Status)**
R	9.94	0.81	10.00	9.46	0.68	10.00

E. ELICITING VALUE WEIGHTS

An additive value model is used to evaluate the total value that a unit gains from receiving a SMAT inspection. The value score for each metric is weighted and summed for each unit. Equation 1 is the expression of the additive value model for the application of swing weights (Parnell, Driscoll and Henderson 2010):

$$v(x) = \sum_{i=1}^{n} w_i \, v_i(x_i), \tag{1}$$

where $v(x)$ is the value that the unit x would gain from the inspection, based on the value scores for metrics $i = 1$ to n. w_i is the measure weight of the i^{th} metric, $v_i(x_i)$ is the value of the score of the ith value metric for unit x, and x_i is the score of the ith value metric for unit x. The weight assigned to the metrics reflect their importance to the stakeholders. The variation in the metrics' range is based on data from past inspections. Figure 15 shows the matrix of the swing weights allocations in accordance with G-4 stakeholder assessments of the metrics.

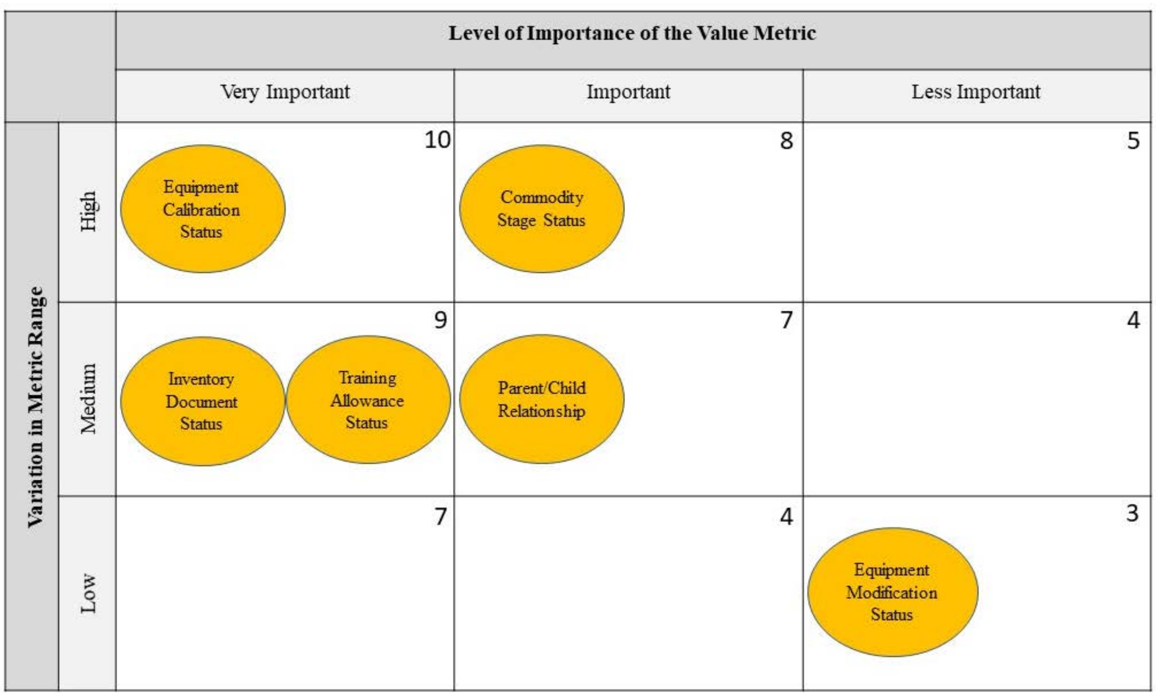

Figure 15. Swing weight matrix. Adapted from Yee (2019).

For example, Figure 15 shows that the stakeholders have determined that equipment calibration status (placed on the top left) as very important for evaluating a unit's maintenance health. Furthermore, this metric is also assessed to have a high variation in its measured range, which enables analysts to more easily delineate the relative goodness of a unit's score with other units. Therefore, equipment calibration status receives a score of 10. The metric for equipment modification status (placed on the bottom right) has been identified as a less important measure and has low variation across its measured range, thereby receives a score of 3.

Next, the swing weights of the metrics are normalized into weights on a scale of 0 to 1 using Equation 2 (Parnell, Driscoll and Henderson 2010):

$$w_i = \frac{f_i}{\sum_{i=1}^{n} f_i} \qquad (2)$$

where f_i is the original swing weight assigned to *i*th metric, $i = 1$ to n metrics, and w_i is the corresponding measure weight for the *i*th metric. Table 5 shows the computed measure weights for each metric.

Table 5. Computation of measure weights

Metric	Swing Weights	Measure Weights
Equipment Modification Status	3	**0.065**
Equipment Calibration Status	10	**0.217**
Commodity Stage Status	8	**0.174**
Inventory Document Status	9	**0.196**
Parent and Child Relationship Status	7	**0.152**
Training Allowance Status	9	**0.196**
Total:	46	1

The final step is to assign a meaning to the final value score derived from the SMAT inspection program. This value score represents the SMAT program's contribution to the MARFORRES mission. Yee (2019) adapted a performance matrix from the U.S. Army personnel readiness assessment shown in Table 6. The performance matrix has four levels, with Level 1 representing the greatest support to the MARFORRES mission while Level 4 represents negligible impact towards supporting the MARFORRES mission. The thesis has adopted the same performance matrix to provide a common platform for evaluating the SMAT program.

Table 6. Performance matrix of SMAT inspection program. Source: Yee (2019).

Value to Unit Mission	Value Score	Color Code	Definition
1	10 to >8 points		Has significant impact towards supporting the MARFORRES mission.
2	8 to >6 points		Has considerable impact towards supporting the MARFORRES mission.
3	6 to >5 points		Has limited impact towards supporting the MARFORRES mission.
4	5 points and below		Has negligible impact towards supporting the MARFORRES mission.

F. COMPUTING OVERALL VALUE SCORES

Applying Equation 1, results in Table 7, the overall value scores of the MARFORRES units. The corresponding performance measure is derived from Table 6.

Table 7. Overall value scores for MARFORRES units

Unit	Unit's PMCS Discrepancies	Overall Value Score	Value to Unit Mission
A	0.51	3.8	4
B	0.34	3.4	4
C	0.28	4.4	4
D	0.27	5.0	4
E	0.17	5.2	3
F	0.16	4.2	4
G	0.28	4.9	4
H	0.13	5.4	3
I	0.49	5.7	3
J	0.45	6.9	2
K	0.36	5.9	3
L	0.52	5.7	3
M	0.10	7.3	2
N	0.32	5.2	3
O	0.15	6.9	2
P	0.28	6.2	2
Q	0.44	6.4	2
R	0.81	6.5	2
S	0.49	7.4	2
T	0.05	4.5	4
U	0.07	6.8	2
V	0.00	4.9	4
W	0.36	7.4	2

The resulting value scores are checked with the designated surrogate variable (percent of PMCS discrepancies) to track the overall equipment readiness and accountability of the unit. It is logical to expect that the inspection program's value score would be higher for units with higher PMCS discrepancies, meaning that the unit should be inspected. As a result of the inspection, the unit would assumedly correct the identified discrepancies and thus improve its standing within a reasonably short amount of time. For example, Unit R had a high PMCS discrepancies value of 0.81. Therefore, it is expected to have a significant number of adverse findings across the various metrics, resulting in a relatively high value score. Based on the performance matrix in Table 4, Unit R has a value score of 6.5 which indicates that the inspection would have considerable impact towards supporting the MARFORRES mission.

Although the value scores are observed to generally follow a logical pattern, there are some exceptions. For example, Unit U has a low PMCS discrepancies value of 0.07. However, it has a relatively high overall value score of 6.8, which puts it in the same category as Unit R. Given the SMAT program's revised concept of operations focuses on virtual inspection, this has made the SR and MR from Yee's (2019) study inapplicable. The need to find a new overarching variable for the unit's maintenance and supply health has made it difficult to have a direct correlation. While adopting the PMCS discrepancies as a replacement for SR and MR, it is possible that there may be unforeseen confounding factors such as misinterpretation and verification of data that are initially difficult to discern. Since the change in SMAT CONOPS occurred midway through this study, there was no opportunity to other collect data to study the topic further. Overall, approximately 70% of the PMCS Discrepancies and Value Scores pairs are compliant. Due to the limited duration and the difficult in collecting new data midway through this study, the findings are accepted. A major recommendation for this study will be to re-assess the value models and determine their consistency and robustness data that represents the actual performance of the unit in terms of equipment readiness and accountability.

To verify the functionality of the value function, the post-inspection data of each units' percentage of PMCS discrepancies were collected from 30 to 90 days after their virtual inspection. The units generally show improvement in their percentage of PMCS discrepancies values. For example, the post-inspection percentage of PMCS discrepancies value of Unit R improves from 0.81 to 0.76 within 30 days after inspection. At the time of writing this report, post-inspection data for other units was not available. However, the improvement indicates the utility that the value scores can provide.

G. OPTIMIZATION OF SMAT INSPECTION

Chapter III discussed the procedure to develop the SMAT inspection schedule for a six-month period using a greedy heuristic to optimize the inspection schedule. However, the objective function was based on maximizing the total value score of inspection schedule. In general, the greedy heuristic is how the SMAT is implementing value scores. Considering these 23 units, the greedy heuristic scheduled eight units for inspection in the six-month period and attained a total value score of 47.3 as shown in Table 8. However, approximately 40 out of 100 available FTE were unused. These results highlight the principle of the greedy heuristic model; the model selects a locally optimal solution (unit with the highest value score) for the given month of the inspection schedule. The model will choose the unit with the highest value score that can be inspected with the available FTE in that given month only.

Table 8. Inspection schedule using greedy heuristic model

Units	Inspection Period	Value Score
B	Month 1	3.4
A	Month 2	3.8
R	Month 3	6.5
Q	Month 3	6.4
M	Month 4	7.3
U	Month 4	6.8
O	Month 5	6.9
P	Month 6	6.2
	Total Value Score:	**47.3**

An optimization model based on Lugo's optimization model and focusing on maximizing total value scores resulted in scheduling 16 units for inspection in the six-month period and attained a total value score of 84.9 (Table 9). In this schedule, all SMAT available resource were used to gain the most value from the inspections. Compared to the greedy heuristic model, Lugo's optimization model is able to attain approximately double the total value score.

Table 9. Inspection schedule using an optimization model based on Lugo's (2020) optimization model.

Units	Inspection Period	Value Score
U	Month 1	6.8
W	Month 1	7.4
M	Month 2	7.3
O	Month 2	6.9
B	Month 3	3.4
N	Month 3	5.2
S	Month 3	7.4
A	Month 4	3.8
I	Month 4	5.7
Q	Month 4	6.4
P	Month 5	6.2
R	Month 5	6.5
D	Month 6	5
J	Month 6	6.9
	Total Value Score:	**84.9**

The results of implementing the value scores in conjunction with an optimization program, provides evidence for how the G-4 can more efficiently use its resources. Through this process the G-4 SMAT can obtain the set of inspections that will provide the greatest contribution to the MARFORRES mission.

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V. CONCLUSION AND RECOMMENDATIONS

A. CONCLUSION

This thesis examined the SMAT inspection program that the MARFORRES G-4 has developed to support the organization’s mission. First, this thesis reviewed the value models from a previous study of SMAT operations. The existing value models contained some inconsistencies and ambiguities for interpretations that would fail to reflect the value of the SMAT inspection program. Next, this thesis sought to modify and validate the value models to more accurately capture the contributions of the SMAT inspection program to the MARFORRES mission. Lastly, this thesis described how the application of value scores in an optimization model may assist in resourcing decisions in a budget-austere environment.

Based on the SDP framework, this thesis reviewed the existing SMAT objectives hierarchy to verify the stakeholder’s needs, and to assess the value models. The objectives hierarchy leads to the attributes and the corresponding metrics, which must comprehensively account for all key objectives that are important to the stakeholders. Through the stakeholder analysis, the top-level fundamental objective was verified as being focused on ensuring that the MARFORRES units have the right types and numbers of properly maintained equipment. The second level of the hierarchy continues to focus on MARFORRES G-4’s interest. The sub-objectives were revised to the following: 1) Improve equipment readiness; and 2) Improve equipment accountability. The sub-objective “Improve impact on unit processes” was removed since the SMAT has changed its concept of operations to focus on virtual inspections and no longer requires the units to submit corrective action plans.

The sub-objectives are subsequently used to identify the key attributes and associated metrics that would allow the SMAT to evaluate the equipment readiness and accountability of the MARFORRES units. The quality, utility, or relevance of some variables made them unsuitable for creating the value models. As a result, perpetual inventory status, MPR status, and PMCS status were omitted from the existing objectives hierarchy.

Given the SMAT program's revised concept of operations focuses on virtual inspection, this has made the SR and MR from Yee's (2019) study inapplicable. The need to find a new overarching variable for the unit's maintenance and supply health made it difficult to have a direct correlation. The existing variables of SR and MR ratings are replaced by the PMCS discrepancies as the surrogate variable. This thesis finds that of the 23 observed units approximately 70% of the PMCS discrepancies and value scores pairs are compatible. Due to the limited duration and the difficult in collecting new data midway through this study, the findings are accepted. The PMCS discrepancies provides an indication of the overall maintenance health of the organization and guides the development of the value curves.

Next, the thesis attempted to represent the value derived from the performance of each attribute with a value curve through quantitative value modeling. The surrogate variable, the percentage of PMCS discrepancies. is plotted against each metrics to develop the value curves. There are three main shapes that are hypothesized in this thesis: (1) Linear RTS, (2) Decreasing RTS (concave curves), and (3) Increasing RTS (convex curves). The thesis verified the relevance of the value curves through theoretical, empirical, and operational justifications. Furthermore, the post-inspection data of each inspected units' PMCS discrepancies are also collected to verify that value models meet the objectives. The inspection findings of the metrics of each unit are then converted into RVS using the value curves developed. The RVS are subsequently transformed into WVS using the measure weights to represent the importance of the metric to the stakeholder. This WVS can then be computed for the total value score of each unit, which represents the value that the unit would gain from the inspection and thereby the value that MARFORRES would gain from the unit being inspected. The value score will serve as basis for SMAT to make better-informed decisions on whether resources should be invested to inspect the unit physically.

The thesis also demonstrated the application of the value model in scheduling SMAT inspection for a six-month period. A greedy heuristic model and Lugo's optimization model are used to develop the inspection schedule to maximize the total value that can be derived from the inspections. The principle of the greedy heuristic model focuses on selecting locally optimal solutions (units with the highest value score) in each month. The greedy heuristic was able to schedule eight units for inspection in the six-month period and attained a total value score of 47.3. In this schedule, approximately 40 out of 100 units of the SMAT resources were unused. Lugo's optimization model was able to schedule 16 units for inspection in the six-month period and attained a total value score of 84.9. In this schedule, all SMAT available resource were used to gain the most value from the inspections. Compared to the greedy heuristic model, Lugo's optimization model is able to attain approximately double the total value score. The results of implementing the value scores in conjunction with an optimization program, provided evidence for how the G-4 can more efficiently use its resources. Through this process the G-4 SMAT can obtain the set of inspections that will provide the greatest contribution to the MARFORRES mission.

B. LIMITATIONS AND RECOMMENDATIONS FOR FUTURE WORK

The SMAT program's revised concept of operations means that there may be certain unforeseen confounding factors such as misinterpretation and verification of data that are initially difficult to discern. The exact explanation for this abnormally is not available due to the limited duration of the study. A major recommendation is to allow the value models to be re-assessed and improved on for their consistency and robustness through a more representative measure for a unit's equipment readiness and accountability.

The sub-objective "Improve impact on unit processes" is removed in the revised objectives hierarchy based on the new SMAT guideline and due to the outbreak of COVID-19 that limits SMAT's ability to physically assess the degree to which the inspections improved the units' processes. This sub-objective can be re-assessed in future as it encompasses another aspect of inspection that focuses on the developmental impact. Various metrics such as the percentage of corrective actions implemented can be further evaluated to examine the extent to which the efficiency of the unit processes has improved.

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APPENDIX

Specifics of the Value Scores for MARFORRES units

Unit	Equipment Modification Status		Equipment Calibration Status		Commodity Stage Status		Inventory Document Status		Parent and Child Relationship Status		Training Allowance Status		Unit's PMCS Discrepancies	Overall Value Score	Value to Unit Mission
	RVS	VVS	RVS	VVS	RVS	VVS	RVS	VVS	RVS	VVS	RVS	VVS			
A	5.07	0.33	0.17	0.04	0.00	0.00	10.00	1.96	0.31	0.05	7.30	1.43	0.51	3.8	4
B	1.92	0.13	0.55	0.12	0.00	0.00	7.25	1.42	2.84	0.43	6.76	1.32	0.34	3.4	4
C	0.00	0.00	1.33	0.29	2.21	0.38	10.00	1.96	1.00	0.15	8.36	1.64	0.28	4.4	4
D	7.92	0.52	0.26	0.06	2.68	0.47	10.00	1.96	0.13	0.02	10.00	1.96	0.27	5.0	4
E	5.65	0.37	1.02	0.22	9.02	1.57	6.22	1.22	0.17	0.03	9.38	1.84	0.17	5.2	3
F	0.00	0.00	2.36	0.51	3.16	0.55	7.84	1.53	0.10	0.02	8.33	1.63	0.16	4.2	4
G	5.13	0.33	0.54	0.12	4.45	0.77	8.91	1.74	0.15	0.02	10.00	1.96	0.28	4.9	4
H	6.87	0.45	6.00	1.30	2.43	0.42	6.19	1.21	0.16	0.02	10.00	1.96	0.13	5.4	3
I	4.79	0.31	2.66	0.58	9.92	1.72	4.95	0.97	0.93	0.14	10.00	1.96	0.49	5.7	3
J	3.67	0.24	3.42	0.74	9.90	1.72	10.00	1.96	1.66	0.25	10.00	1.96	0.45	6.9	2
K	2.60	0.17	1.66	0.36	7.38	1.28	10.00	1.96	0.91	0.14	10.00	1.96	0.36	5.9	3
L	4.95	0.32	0.77	0.17	7.65	1.33	9.46	1.85	0.52	0.08	10.00	1.96	0.52	5.7	3
M	7.59	0.49	6.09	1.32	9.79	1.70	8.73	1.71	0.94	0.14	10.00	1.96	0.10	7.3	2
N	5.42	0.35	3.28	0.71	10.00	1.74	6.44	1.26	0.65	0.10	5.09	1.00	0.32	5.2	3
O	1.53	0.10	9.00	1.96	7.92	1.38	7.19	1.41	0.70	0.11	10.00	1.96	0.15	6.9	2
P	2.29	0.15	0.86	0.19	10.00	1.74	10.00	1.96	3.40	0.52	8.65	1.69	0.28	6.2	2
Q	0.00	0.00	0.83	0.18	10.00	1.74	9.16	1.79	4.54	0.69	10.00	1.96	0.44	6.4	2
R	9.94	0.65	0.81	0.18	10.00	1.74	9.46	1.85	0.68	0.10	10.00	1.96	0.81	6.5	2
S	5.96	0.39	5.02	1.09	10.00	1.74	8.36	1.64	4.16	0.63	10.00	1.96	0.49	7.4	2
T	0.00	0.00	1.09	0.24	0.00	0.00	4.19	0.82	10.00	1.52	10.00	1.96	0.05	4.5	4
U	0.00	0.00	1.40	0.30	10.00	1.74	9.30	1.82	10.00	1.52	7.07	1.38	0.07	6.8	2
V	0.00	0.00	1.40	0.30	10.00	1.74	6.86	1.34	10.00	1.52	0.00	0.00	0.00	4.9	4
W	8.10	0.53	8.00	1.74	9.97	1.73	8.52	1.67	0.95	0.14	8.20	1.60	0.36	7.4	2

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