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THESIS

DEVELOPING MEASURES OF EFFECTIVENESS FOR ASSESSING AND PREDICTING TECHNOLOGY INTEGRATION

by

Xinhong Lin

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13. ABSTRACT (maximum 200 words)

This thesis studies the development of measures of effectiveness (MOE) to determine the level of technology integration for Navy Environmental Sustainability Development to Integration (NESDI) projects, with a focus on identifying significant technology characteristics that can be used to predict the likelihood of integration for future projects. The definition of technology integration in this study comprises the three incremental phases of transition, adoption, and diffusion. Through case study analysis of completed NESDI projects, two approaches were employed to identify significant technology characteristics that seemed to impact the level of technology integration–correlation approach and graphical approach. Multiple linear regression was used to demonstrate how predictive models could be generated for the correlation approach, whereas the graphical approach presented significant characteristics as a success profile in the form of a Venn diagram. The predictive models and success profile aim to assist decision-making on whether resources should be invested in a future project, by predicting the likelihood of technology integration for that project. While the results were limited by time constraints and the availability of suitable case studies for analysis, this study demonstrated the methodology on how technology integration could be measured and predicted using the developed MOEs and significant technology characteristics.

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DEVELOPING MEASURES OF EFFECTIVENESS FOR ASSESSING AND PREDICTING TECHNOLOGY INTEGRATION

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LIST OF ACRONYMS AND ABBREVIATIONS

IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers
ISO	International Organization for Standardization
MOE	measures of effectiveness
NAVFAC EXWC	Naval Facilities Engineering and Expeditionary Warfare Center
NESDI	Navy Environmental Sustainability Development to Integration
PI	principal investigators
ROI	return-on-investment
SOP	standard operating procedures

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EXECUTIVE SUMMARY

The mission of the Navy Environmental Sustainability Development to Integration (NESDI) program is to develop, demonstrate, validate, and integrate technologies to minimize operational environmental risks to the fleet (U.S. Navy 2010). While a key objective of the program is to maximize the number of developed technologies that are successfully integrated (U.S. Navy 2010), the Naval Facilities Engineering Command and Expeditionary Warfare Center (NAVFAC EXWC) has found it a consistent challenge to determine the level of integration of a developed technology, as well as identify the underlying factors that resulted in varying levels of success across developed technologies. Hence, this thesis aims to 1) construct measures of effectiveness (MOEs) that can be used to quantitatively determine the level of technology integration, 2) identify significant technology characteristics that impact integration, and 3) demonstrate how predictive models can developed using identified significant characteristics to predict the likelihood of integration for future technologies.

The thesis first defined technology integration as comprising three phases of technology transition, adoption, and diffusion. As the focus of the study was on developed technologies that had been transitioned to the end users, only the stages of technology adoption and diffusion were analyzed. The thesis was structured according to a systems engineering approach comprising five steps of: problem definition, stakeholder analysis, system requirements, value systems design, and test and evaluation. Based on stakeholder analysis and literature review, four areas of usage, training, return-on-investment (ROI), and extent of diffusion were identified for measuring technology integration, and MOEs were developed for each respective area. Likewise, through stakeholder analysis, literature review, and a qualitative approach of case study analysis on four NAVFAC EXWC projects, eight technology characteristics that potentially affect technology integration were identified. The identified characteristics were: complexity, compatibility, relative advantage, cost, command emphasis, trialability, observability, and degree of need. Each case study was then assigned a score for each MOE and characteristic based on their performance in the respective areas.

While there had been no prior measures established to determine the level of integration of the four given projects, the stakeholders managed to agree on the integration levels (adopted, diffused, or both) based on this study's definition of technology integration. The constructed MOEs were then weighted based on stakeholder inputs and used to measure the respective adoption and diffusion scores of the four case studies. The MOEs were then validated by matching the resultant scores to the stakeholders' initial assessment of the respective projects.

Next, through cross-case synthesis, two different approaches were used to identify the significant characteristics of successfully adopted and diffused technologies. Predictive models were then developed for each approach. The first approach identified characteristics as significant if they were assessed to strongly correlate (correlation coefficient > 0.75) with the MOEs. Despite being limited by the small sample size of case studies available for analysis, this study demonstrated how the identified significant characteristics could be used to develop separate predictive models for the MOEs of "usage," "training," "ROI," and "extent of diffusion" respectively through multiple linear regression. With sufficient data, future work could continue to develop and refine the models.

The second approach presented the characteristic scores of the four case studies in the form of bar charts, and characteristics that score a minimum of 3 across all cases analyzed were assessed to be significant. "Relative advantage" and "degree of need" were identified as significant characteristics that impact technology integration (both adoption and diffusion). These characteristics were then presented in the form of a Venn diagram to illustrate a success profile for future projects' reference in order to improve their likelihood of integration. The case study technique of pattern matching was used to validate the model, where one of the case studies was used as a test case to evaluate if the predicted results match the results measured using the MOEs. In this case, the results did not match. While the test case met the success profile, it had been assessed as "not diffused" based on the developed MOEs. This was not unexpected, as the predictive models were meant to serve as a reference to improve the likelihood of technology integration and not guarantee the actual integration of the predicted case. In other words, predicting that a technology is likely to be integrated does not equate to the technology being in fact integrated.

While this study provided the methodology and approach on how technology integration could be measured and predicted through the use of predictive models and success profile, the results were limited by time constraints as well as the availability suitable case studies which could be used for analysis. In view of this, future work should look into refining and revalidating the predictive models and success profile through the analysis of more case studies.

References

U.S. Navy. 2010. "Standard Operating Procedures: Navy Environmental Sustainability Development to Integration (NESDI) Program." Accessed 12 April, 2018. http://navysustainability.dodlive.mil/environment/nesdi/.

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I. INTRODUCTION

A. PURPOSE

The definition of whether a technology has been successfully integrated is subjective, and there is no set of consistent, quantifiable measures of effectiveness (MOE) that can be studied to help predict the successful integration of future technologies. This research aims to identify the characteristics of successful technology integration, and translate these characteristics into a set of quantifiable MOEs to measure technology integration, and provide indicators to predict the successful integration of future projects.

B. BACKGROUND

The mission of the Navy Environmental Sustainability Development to Integration (NESDI) program is to "provide solutions by demonstrating, validating and integrating innovative technologies, processes, materials, and filling knowledge gaps to minimize operational environmental risks, constraints and costs while ensuring Fleet readiness" (U.S. Navy 2010, 1). One of the key objectives of the NESDI program is to increase the number of developed technologies that are "successfully integrated into the Fleet," and "verify that the solutions provided the anticipated benefits" (U.S. Navy 2010, 2). However, under the NESDI program, the Naval Facilities Engineering Command (NAVFAC) and Expeditionary Warfare Center (EXWC) have found it a consistent challenge to integrate facilities-related technology into the client organization, or end user. In fact, as much as 90% of these developed technologies have not been successfully integrated (Ken Kaempffe, email to author, 21 April 2018). While principal investigators (PI) generally agree that some developed technologies seem to be better integrated compared to others, they found it difficult to identify what caused the difference in "success" levels.[1] This can be traced to two key challenges.

[1] PIs are project managers responsible to develop the required technology based on the end-user's submitted needs, and deliver the developed technology to the end-user.

1. Inconsistent Use of the Term "Integration"

In systems engineering, systems integration is defined as the process of combining system elements to form whole or partial system configurations to meet the system requirements (ISO/IEEE 2008). Although the NESDI program's standard operating procedures (SOP) (U.S. Navy 2010) lists the conditions that a developed technology should fulfill in order to be considered as "integrated," NESDI's perspective on "integration" refers more to the transition of the developed technology to the client, and is incongruent with the systems engineering definition of integration. Further discussion with NAVFAC EXWC stakeholders confirmed that the term "integration" for the purpose of this study refers more to the degree of technology adoption within the client organization, and diffusion beyond the client organization.

2. Definition of "Success" Is Subjective

The NESDI program's SOP also lists the potential benefits and performance metrics that may be applied to individual projects to determine their level of success (U.S. Navy 2010). However, these metrics (e.g., savings on manpower requirements) remain vague and subjective. Without a consistent, quantifiable set of measures, different stakeholders can have differing descriptions of success or failure for any given developed technology or project. Hence, there is a need for a set of quantifiable measures which can be applied to all projects to guide stakeholders, and to align their assessment and determination of success or failure. In addition, a set of quantifiable measures can also serve as indicators to help predict success for future projects.

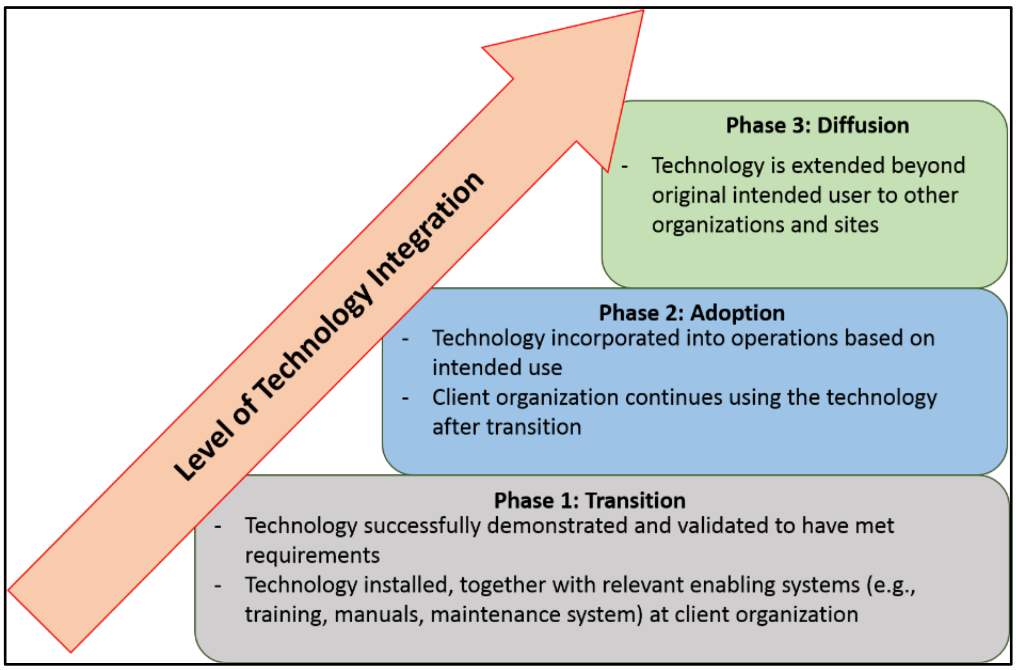
C. PROBLEM STATEMENT

The system of interest (SOI) for this study is NESDI's technology integration process, and the problem statement comprises two parts. First, NESDI does not have a consistent set of measures to understand the level of integration achieved for its developed technologies. Second, NESDI does not have a means to predict the expected level of integration for proposed technology developments. Hence, this thesis aims to define and develop relevant MOEs to quantify the level of integration of NESDI's developed technologies, and predict the likelihood of integration of future technologies.

D. TECHNOLOGY INTEGRATION

In this study, the definition of technology integration comprised three distinct phases—transition, adoption, and diffusion. These definitions were agreed upon by NAVFAC EXWC stakeholders (Lin 2018). Figure 1 summarizes the three phases and their definitions.

Figure 1. Three Phases of Technology Integration



The first phase of technology transition is the phase in which the developed technology has been verified and validated to meet the stakeholders' system specification requirements. In this phase, the developed technology is installed, together with relevant enabling systems including the operating system, support system, training system, as per the requirements (ISO/IEEE 2008).

The second phase, technology adoption, is the phase in which a technology continues to be used by the client organization (Carr 1999). This means that the client organization has accepted the developed technology and has incorporated the technology into its operations based on the technology's intended use.

The third phase, technology diffusion, is defined as the phase in which the developed technology is extended beyond its original intended user to general use and application (Carr 1999). For this study, a developed technology will be considered to be in the diffusion phase when it has been extended to at least one other user which is not in the original client organization.

Based on these definitions, a technology will only be considered as fully integrated when it achieves all three phases of transition, adoption, and of diffusion. A key part of this study, as confirmed with NAVFAC EXWC stakeholders, will focus on measuring the level of technology integration. In order to have a precise evaluation of the level of integration achieved, a set of relevant and quantifiable MOEs must be developed for coherent comparison between projects.

E. MEASURES OF EFFECTIVENESS

A MOE is defined as the measure of how well a system achieves a set of specific mission requirements. Stevens (1986) expanded the definition to state that "a MOE is any set of criteria established to determine the resolution of a critical issue." In systems engineering, an appropriately structured value hierarchy and credible value functions form the basis of developing quantifiable MOEs. These developed MOEs can then be used to provide an evaluation whether or not a technology has been adequately integrated, as well as compare the level of integration across different technologies. Similarly, MOEs can also be used as indicators in the design and development of future NAVFAC EXWC projects to increase the likelihood of their successful integration.

F. OBJECTIVES OF STUDY

This study sought to answer the following research questions:

1. How may we measure whether a technology has been successfully integrated into a client organization?

2. What are the identifiable characteristics of a technology system that signals its successful integration?

3. Which technology characteristics correlate with the developed MOEs, and how can they be used to predict the successful integration of future technologies?

G. BENEFITS OF STUDY

There are three potential benefits to this study.

1. Consistent Measure of "Successful Technology Integration"

The creation of a set of consistent MOEs could provide a precise evaluation of the degree by which a developed technology has been integrated into the client organization, hence determining the level of success without ambiguity. These MOEs could become a major target in the subsequent development of technologies' design and development phases to ensure a higher likelihood of successful integration.

2. Indicators to Predict Success of Future Projects

Based on the developed MOEs, technology characteristics that significantly correlate with the MOEs can be identified to act as indicators for future projects to work towards so as to increase their likelihood of subsequent integration.

3. Extension of Usage beyond NAVFAC EXWC and the NESDI Program

While the development of the MOEs was based on the case study analyses of NAVFAC EXWC's completed shore-based projects, the developed MOEs could be developed as sufficiently robust to ensure applicability to different technologies beyond shore-based technologies. The MOEs could also be extended to other organizations, including those in the commercial sectors, which have similar needs to measure the success of technology integration.

H. ASSUMPTIONS

The scope of this study was bounded by two key assumptions:

1. Although we defined technology integration as comprising three phrases of transition, adoption and diffusion, the primary concern of NAVFAC EXWC stakeholders was to measure and improve technology adoption and diffusion. The projects involved in this study had already been completed and delivered. Hence, the phase of transition was assumed to have been achieved for all NAVFAC EXWC projects, and the focus of this study was on adoption and diffusion.

2. Several research studied both technology characteristics and user characteristics (e.g., socioeconomic characteristics, personality, communication behavior) as factors that affect the rate of technology adoption and diffusion. For example, Rogers (2003) categorized adopters into innovators, early adopters, early majority, late majority, and laggards, and discussed how adopter characteristics such as socioeconomic status and personality affected the likelihood of an individual to adopt an innovation or technology. The focus of this study, however, was only on the characteristics of the technology, and did not cover the analysis of the characteristics of the users.

I. ORGANIZATION OF STUDY

This study is organized into five chapters. The remaining chapters are structured in the following manner: Chapter II contains the literature review on the NESDI program process, NESDI program's SOP, the characteristics of good MOEs, and the characteristics of successful technology adoption and diffusion; Chapter III details the research methodology of identifying characteristics of successful technology integration through qualitative case study analysis, and discusses how the identified characteristics can be translated into quantifiable measures to be used as indicators for future projects; Chapter IV analyzes and presents the results from the case studies; based on the findings, Chapter V concludes with recommendations and highlights areas for further research.

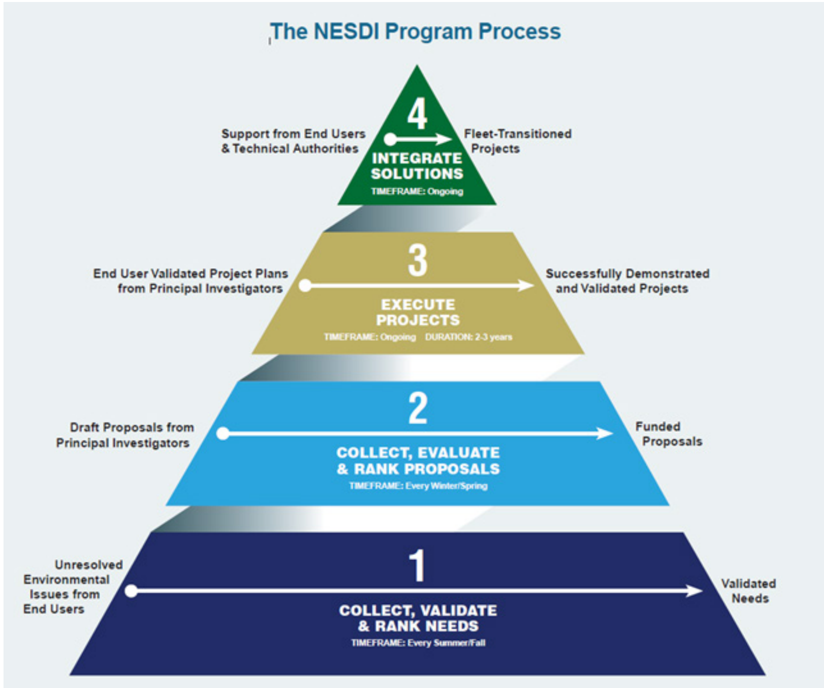
II. LITERATURE REVIEW

This chapter begins with an overview into the NESDI program's process and standard operating procedures (SOP) (U.S. Navy 2010). The SOP details how NESDI collects, validates and rank needs and proposals, execute the projects to develop the requisite technology, and eventually transfer the developed technology to the end users. Reviewing the SOP would identify potential gaps in NESDI's processes that could have resulted in the developed technologies not being successfully integrated. Likewise, the SOP provides insight into how technology integration is currently being defined and measured by the NESDI program. A review of the NESDI integration process highlights the need for a set of consistent MOE. Characteristics of good MOEs will be discussed to establish their importance in forming a good basis for eventual determination of technology integration levels. Lastly, technology characteristics that affect adoption and diffusion would be explored to gain insight into possible predictors of successful technology integration for future NESDI projects.

A. THE NESDI PROGRAM PROCESS

Based on the NESDI program's annual report, the program uses a four-phased process that covers needs collection, proposal evaluation, project execution and "integration" (U.S. Navy 2016). Figure 2 summarizes the NESDI program process.

Figure 2. The NESDI Program Process. Source: U.S. Navy (2016).



1. Phase 1: Collect Validate and Rank Needs

In this phase, a management team solicits needs from the end users. The needs are then validated and prioritized based on the priority investment areas of the program severity of the associated risk, and potential operational impact if left unaddressed. While this seems similar to a needs analysis phase in a systems engineering approach, a potential issue may be that the needs analysis is incomplete. This results in only the "perceived" need and not the "effective" need of the requestor submitting the need to be addressed, which does not help in solving the real issue (Blanchard and Fabrycky 2011). This subsequently leads to a technology that does not meet the effective needs of the requestor.

2. Phase 2: Collect, Evaluate and Rank Proposals

In this phase, the management team collects the proposals, evaluates them, and recommends short-listed projects to the program's sponsor[2] for approval. Again, a

[2] The NESDI program is funded by the Chief of Naval Operations (CNO) Environmental Readiness Division (N45).

potential pitfall in this phase is an incomplete stakeholder analysis. When evaluating the proposals, the management team needs to identify and engage all relevant stakeholders (e.g., end users, maintenance personnel, regulatory authorities, funding sponsors, other potential users). The management team may not have the capacity or the requisite expertise to perform this role, which may result in them recommending proposals that fail to address concerns of important stakeholders.

3. Phase 3: Execute Projects

This phase focuses on the actual project execution to address the approved needs. At this phase, an incomplete needs analysis and stakeholder analysis will likely result in the development of a technology that does not address the effective needs.

4. Phase 4: Integrate Solutions

This phase focuses on transferring the demonstrated and validated technology to the end-user and ensuing that "various solutions are successfully integrated into the Fleet" (U.S. Navy 2016, 8). The term "integrate" here, however, differs from our definition of integration discussed in the previous chapter. The focus of this phase in on the handing over, or transitioning, of the technology, and does not extend into the stage of ensuring technology adoption.

B. NESDI STANDARD OPERATING PROCEDURES

As Phase 4 in the program process focuses on the successful "integration" of the developed technology, the NESDI SOP accordingly lists a set of conditions that needs to be met before a technology is considered as successfully integrated. These conditions are listed in the NESDI SOP as follows:

- The user community has validated the technology.
- Funding has been planned for and is in place for transition.
- The stakeholders have accepted the technology.
- Customer satisfaction has been assessed and documented.

- A marketing strategy is in place.
- An implementation plan and schedule are in place.
- The support infrastructure (Integrated Logistics Support) is in place.
- A training plan has been developed and fleet personnel have been trained.
- The use of the technology has been implemented (regardless of pathway).
- An acquisition agent has been identified and funding secured.
- Commercialization is available (if no acquisition agent exists).
- The system commands and the fleet recognize a formal change in their business processes to accept the new technology.
- The former technology has been replaced or eliminated.
- Benefit metrics have been re-assessed and validated.
- The technology has been made available through the supply/procurement system (U.S. Navy 2010, 13).

In this case, we see that the conditions for "integration" actually refers to *adoption*, as per our definition in Chapter I. This in itself seems to differ from Phase 4 of the NESDI program process discussed earlier, which was focused on *transition*, and further highlights the inconsistency of NESDI's use of the term "integration."

While this list of conditions provides some basis for NESDI to evaluate whether a technology has been successfully adopted, many of the conditions are vague and cannot be directly measured, hence limiting their effectiveness. Nonetheless, these conditions listed in the SOP can serve as a guide in the development of quantifiable MOEs in the next chapter.

C. CHARACTERISTICS OF GOOD MEASURES OF EFFECTIVENESS

Defining measures of effectiveness (MOE) is fundamental to almost all systems engineering projects, and well-defined MOEs are crucial to evaluate whether a system meets the mission requirements. Hence, not surprisingly, several studies of systems engineering approaches have identified key characteristics of good MOEs. Of note, Stevens (1986) and Green (2001) both listed characteristics of good MOEs in their respective work. These are summarized in Table 1.

Table 1. Summary of Characteristics of Good MOE. Adapted from Stevens (1986) and Green (2001).

Stevens' list	Green's list (equivalent)	Definition
Relevant	Mission Oriented, Realistic, Inclusive, Appropriate	Relates to the mission of the system
Complete	Sensitive	All input parameters affecting system mission effectiveness should see a change in the MOEs
Mutually exclusive	Independent	No overlap between MOEs
Meaningful, Precise	Simple	Easy to understand, meaning of MOEs not in doubt
Measurable	Measurable, Quantitative	Can be assigned numbers or ranked
No equivalent measure	Objective	Independent of subjective opinion

Taking reference from Stevens (1986) and Green (2001), the following three characteristics will be used in the development of MOEs for this study:

1. Relevant

The developed MOEs must be relevant and directly related to the mission. For the purpose of this study, the mission was to evaluate the stage of integration of a technology. The MOEs should hence be able to clearly distinguish between the different stages of technology integration.

2. Measurable

The developed MOEs for this study must be quantifiable either as a number, a percentage, or a function of time. This helps to prevent ambiguity in the interpretation of parameters, and assists in clearly and accurately defining the stage of integration of a given technology.

3. Precise

The developed MOEs must be precise in its definition, and easy to understand. This characteristic promotes consistency in evaluation and interpretation of results even when the MOEs are used by different personnel within the NESDI program.

D. CHARACTERISTICS OF TECHNOLOGY AFFECTING ADOPTION AND DIFFUSION

Several studies have ventured into identifying key characteristics of technology adoption and diffusion. Leonard-Barton's (1988) research focused on technology characteristics linked with their implementation, while Moore and Benbasat (1991) sought to measure the eight specific information technology characteristics. Other research of note include Ramiller's (1994) analysis on the compatibility of technology, and Rogers' (2003) identification of five characteristics of an innovation, and how they influence whether someone adopts it. However, to our knowledge, none of the studies specifically looked into translating these characteristics into quantifiable measures which can be used to predict whether a new technology in development is likely to succeed in integration.

Rogers' work, to this day, continues to be widely cited by researchers on the topic of diffusion of innovations. Also, while Rogers' work focused on innovations, his research was the most relevant for the purpose of this study. The characteristics Rogers defined could be directly applied to technology adoption and diffusion. Generally, technologies with favorable characteristics are more attractive, and leads to more rapid adoption and diffusion compared to technologies with less favorable characteristics (Rogers 2003). The identified characteristics could hence be used to develop models to help predict the success of future NESDI projects in terms of technology integration. The five characteristics that this thesis uses are: relative advantage, compatibility, complexity, trialability, and observability. Quantifying these characteristics is a major part of this study.

1. Relative Advantage

Relative advantage was defined as the extent where a developed technology is deemed as an improvement compared to the idea or process that it replaced (Rogers 2003). This may come in the form of reduction in costs, manpower and time, as well as simplified processes. We expect the relative advantage of a technology to be positively related to its level of adoption.

2. Compatibility

Rogers (2003) defined compatibility as the extent of a technology's consistency with the existing experiences of end users. He further explained that a technology that is more compatible with previously introduced ideas (i.e., familiarity) tend to result in higher levels of adoption.

3. Complexity

Complexity is the perceived difficulty of understanding and using a technology. In general, we expect the perceived complexity of a technology to be negatively related to its rate of adoption (Rogers 2003).

4. Trialability

Trialability is the extent to which a technology can be trialed on a limited basis (Rogers 2003). While Rogers (2003) identified this characteristic with technology adoption, it was assessed that trialability leans more towards impacting technology diffusion—a technology that is trialable provides more certainty for other potential users before they commit for full-scale use, which is consistent with our definition of diffusion in Chapter I. In general, we expect a trialable technology to be more likely to succeed in being diffused.

5. Observability

Rogers (2003) defined observability as the extent of visibility of a developed technology. Again, this characteristic was assessed to affect diffusion rather than adoption in the context of this study. Certain technologies result in improvements that can be easily measured, observed, and communicated to other potential users. We generally expect a technology with higher observability to more likely to succeed in being diffused.

We can see how a technology that fulfils these five characteristics is more likely to be adopted and diffused (and hence, integrated). These characteristics could therefore be used to develop measures that possibly help predict the successful integration of future technologies developed by NAVFAC EXWC. This will be explored in the next chapter.

E. CORRELATING TECHNOLOGY CHARACTERISTICS TO MOES

Correlation is a mathematical technique used in statistics to measure the strength and direction of linear relationship between two variables (Montgomery and Runger 2014). Besides developing consistent MOEs to determine the level of integration of developed technologies, a major goal of this study is to determine the correlation between a technology's characteristics and its level of integration (as measured by the MOE). The presence of a strong correlation would suggest that the characteristic can serve as an indicator to predict the likelihood of successful integration of future NESDI projects.

Characteristics that have been identified to correlate with the MOEs can then be used as predictor variables to develop initial predictive models through multiple linear regression. In general, the dependent variable or response Y is related to k independent predictor variables by the equation (Montgomery and Runger 2014):

$$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + \cdots + B_kX_k \ ,$$

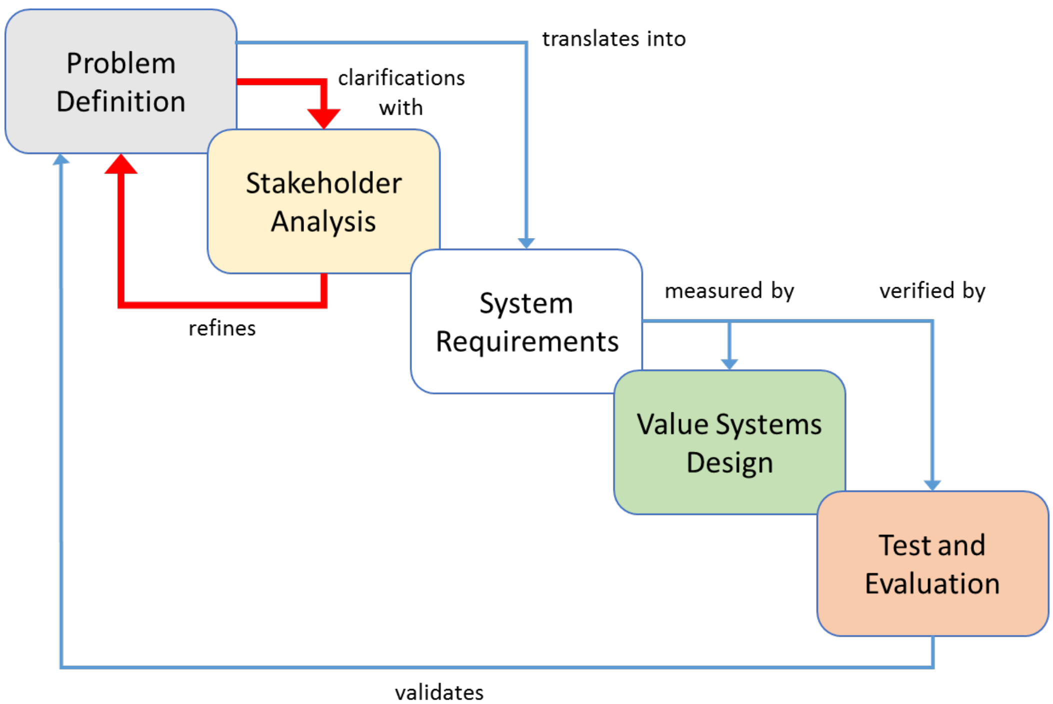
where Y is the predicted MOE score, and $X_1, X_2, X_3, \dots, X_k$ are the independent characteristics that correlate with the MOE

For small sample sizes, it is not feasible to perform purposeful statistical analysis. In such cases, Chambers' (1983) work listed several graphical approaches that may be considered as an alternative to analyze the limited data. This will be explored in detail in Chapters III and IV.

III. METHODOLOGY

This study follows a systems engineering approach comprising five key steps of problem definition, stakeholder analysis, system requirements, value systems design, and test and evaluation. The systems engineering approach serves as a step-by-step guide to systematically and progressively address the thesis objectives. The results for each step will be discussed in Chapter IV. Figure 3 depicts the overview of the systems engineering process tailored for the purpose of this thesis.

Figure 3. Modified Systems Engineering Process for Technology Integration Study



A. PROBLEM DEFINITION

The systems engineering process, in general, begins with the identification of a need based on an existing gap (Blanchard and Fabrycky 2011). As highlighted by the red arrows in Figure 3, problem definition is an iterative process to continually scope and refine the problem statement such that it is consistent with the system needs of the stakeholders.

In his study, the boundary of the problem was scoped using a context diagram to identify the key external systems and their interactions with the SOI. This will be discussed in Chapter IV. The problem statement for this study was defined in Chapter I, and the SOI in this study is NESDI's technology integration process.

B. STAKEHOLDER ANALYSIS

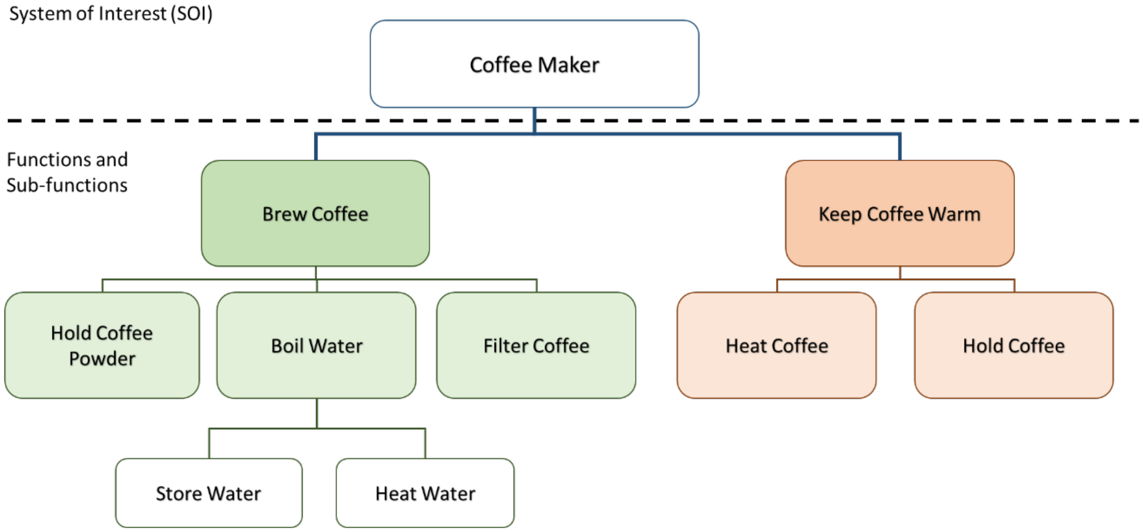
The next step involves performing stakeholder analysis to identify the key stakeholders of this study and their respective concerns. Based on the stakeholders' inputs, the problem is further refined to ensure that this study addresses the needs of the stakeholders.

In this study, stakeholder interactions were performed through correspondences via emails, meeting with NAVFAC EXWC representatives, and a field visit to Port Hueneme to meet with various stakeholders (e.g., program managers, PIs, technology integrators, and end users). A stakeholder matrix was developed to understand each stakeholder's wants, concerns, and priority levels, as well as how they fit into the integration process. The stakeholder analysis was performed to facilitate better understanding of NAVFAC's processes, and provided various perspectives that helped to refine the problem statement.

C. SYSTEM REQUIREMENTS

The wants and concerns identified in the stakeholder analysis are then translated into requirements of the SOI. This is then followed by performing a functional analysis to determine the key functions that the system needs to perform. For example, a coffee machine system needs to perform the functions of: "brew coffee" and "keep coffee warm." Figure 4 illustrates an example of a functional decomposition for the coffee maker.

Figure 4. Example of Coffee Maker Functional Decomposition



For this study, a similar functional decomposition for the NESDI technology integration process was performed once the system level requirements were developed. This will be discussed in Chapter IV.

D. VALUE SYSTEMS DESIGN

Based on the identified functions and sub-functions, a value hierarchy diagram can be generated to formulate a set of MOEs which can be used to measure the effectiveness of the key functions. For this study, one of the objectives aim was to compare the developed MOEs against the identifiable characteristics of a technology to analyze if there exists significant correlation between the two. Characteristics with strong correlation to the MOEs could then be used to predict the likelihood of integration of future technologies and projects.

1. Measuring Level of Integration for Developed Technologies

The NESDI SOP highlighted several criteria used to determine the integration of a project (U.S. Navy 2010). Six criteria relevant to this study were identified and translated into four areas that could be potentially measured to determine if a developed technology has been adopted or diffused. The identified areas were: usage, training, ROI, and extent of diffusion.

a. Usage

Chapter I defined technology adoption as the phase in which a technology continues to be used by the client organization (Carr 1999). Hence, it is intuitive for usage to be potentially measured to indicate the level of technology adoption. A higher usage level would be consistent with a higher level of technology adoption.

b. Training

Similar to usage, the level of training achieved provides an indication to the level of adoption of a developed technology. A client organization that has adopted a developed technology would need to commit to continuous operator training to maintain the steady-state level of personnel required for the continued use of the technology. Hence, training could be potentially measured to indicate the level of technology adoption. A higher training level would be consistent with a higher level of technology adoption.

c. Return-on-Investment (ROI)

Technologies are developed with the purpose to improve efficiency, reduce errors, save resources, or make processes more environmentally-friendly. During the project development phase, estimates would have been made for these benefits (e.g., expected time savings, cost savings, or cost avoidances) to justify the ROI of the project. In this regard, measuring the achieved ROI of a developed technology gives an indication of the level of adoption within the client organization. A higher ROI percentage would be consistent with a higher level of technology adoption.

d. Extent of Diffusion

Chapter I defined technology diffusion as the phase in which the developed technology is extended beyond its original intended user to general use and application (Carr 1999). Based on this definition, the extent of diffusion of a developed technology could be measured to determine if the technology has been successfully diffused.

Table 2 summarizes the identified areas translated from the NESDI SOP (U.S. Navy 2010). The next step would be to develop relevant, measurable, and precise MOEs to quantitatively measure each identified area. Each MOE would be assigned a numerical score based on the measured range of values, and a swing weight based on the stakeholders' assessment of the MOE's relative importance compared to other MOEs.

Table 2. Identified areas based on NESDI SOP and phased definition of integration. Adapted from U.S. Navy (2010).

NESDI SOP Criteria	Phase of Integration	Area to be Measured
"The stakeholders have accepted the technology"	Adoption	Usage
"The use of the technology has been implemented (regardless of pathway)"	Adoption	
"The former technology has been replaced or eliminated"	Adoption	
"A training plan has been developed and Fleet personnel have been trained"	Adoption	Training
"Benefit metrics have been re-assessed and validated"	Adoption	ROI
"A marketing strategy is in place"	Diffusion	Extent of Diffusion

2. Predicting Level of Integration for Future Technologies

The case study technique of cross-case synthesis seeks to strengthen or refute generalizations made by comparing the evidence gathered from multiple case studies (Yin 2014). This technique was used in this study to identify technology characteristics that potentially correlate with the developed MOEs for technology integration. As discussed in Chapter II, there were five key characteristics of technology used for the purpose of this study. Of these, recall that the characteristics complexity, relative advantage, and compatibility were associated with impacting the likelihood of a technology to be adopted, while observability and trialability were associated with impacting the likelihood of a technology to be diffused. In general, we expect a technology with low complexity, high relative advantage, and high compatibility to have a higher likelihood of adoption, and a technology with higher degrees of trialability and observability to have a higher likelihood of diffusion.

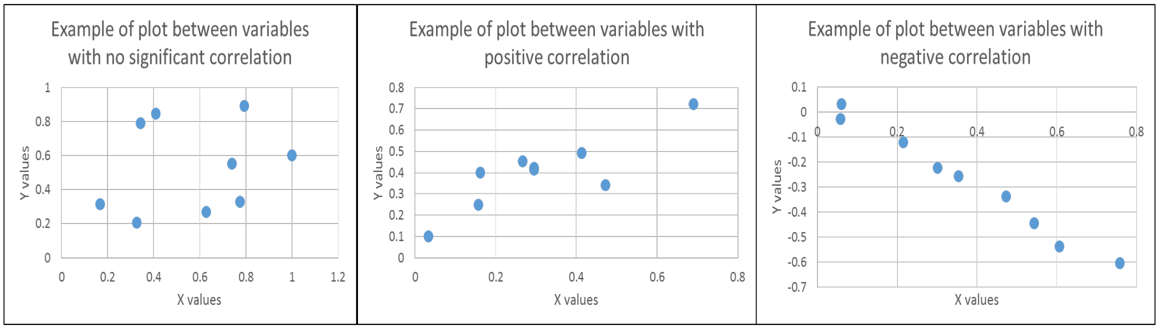
In addition to these five characteristics, three other characteristics were identified and assessed to affect the likelihood of technology adoption and diffusion based on discussion with NAVFAC EXWC stakeholders. First, the characteristic “cost” was assessed to affect the likelihood of a technology being adopted. More specifically, it refers to the cost required for the end user to continue using the technology. In general, a lower cost is expected to result in a higher likelihood for adoption.

Second, the characteristic “degree of need” was assessed to affect the likelihood of technology diffusion. For example, a technology that fulfils a mandatory requirement (e.g., operational impact, safety, legal or environmental regulations) is more likely to be diffused than a technology that improves administrative processes but is not necessarily required (i.e., a must-have versus a good-to-have).

Third, the level of “command emphasis” given to a technology was also identified as an important characteristic affecting the likelihood of both adoption and diffusion. For example, a technology that has garnered the support of a Fleet Commander would be more likely to be adopted and diffused compared to the case if it was only recognized by the ground supervisor. This is in line with Rogers’ (2003) study on authority innovation-decisions, where decisions to adopt or reject a technology reside with those with power or status.

Once the characteristics have been identified, measures were likewise developed for each characteristic and assigned a numerical score. The characteristics’ measures were then correlated against the integration MOEs to determine if significant correlation exists between a particular set of MOE and characteristic. Multiple linear regression modelling could then incorporate the characteristics which possess strong correlation with the MOE to develop predictive models that could be used to estimate the likelihood of adoption and diffusion for future technologies. This will be discussed in Chapter IV. Figure 5 respectively illustrates examples of plots with no correlation, positive correlation, and negative correlation.

Figure 5. Examples of Correlation Plots



Due to time constraints and security restriction considerations, the number of case studies available for analysis were limited. This in turn resulted in limited data points to make meaningful quantitative analysis through correlation and regression. In view of this limitation, a nonparametric graphical approach was also explored. For example, based on analysis of the case studies provided, bar charts were used to qualitatively illustrate the significant characteristics present in technologies that were assessed to have been successfully adopted and diffused. This approach presents the stakeholders with a "success profile" that could be used as a reference for future technologies.

E. VERIFICATION AND VALIDATION: TEST AND EVALUATION

The next step in the systems engineering process is to perform test and evaluation. For this study, this step aims to verify that the developed MOEs were sufficiently robust to be used to determine the level of integration for different developed technologies, as well as validate the predictive models in their ability to predict the likelihood of adoption and diffusion of future technologies. This was done via a qualitative approach through the analysis of completed NAVFAC EXWC projects as case studies.

Verification and validation of the results comprised two steps. First, the level of technology integration measured by the MOEs was compared against NAVFAC EXWC stakeholders' assessment of the case studies' level of integration to verify that the results match. The second step involved extracting the characteristics of the NAVFAC EXWC project, identifying significant characteristics, and using the characteristics to predict a technology's likelihood of integration. Using the case study technique of pattern-matching

(Yin 2014), the results from the prediction were then compared to the level of integration determined by the MOEs earlier to assess if they were consistent.

For the approach using correlation and regression analysis, technology characteristics that possess a correlation coefficient of > 0.75 (i.e., suggesting moderately strong positive liner relationship) (Montgomery and Runger 2014) were assessed as significant for the purpose of this study, and used as prediction variables in the regression prediction model.[3] NESDI may define significant correlation differently to meet their purposes. Pattern matching, which compares findings from case studies with a predicted outcome made before the collection of data (Yin 2014), could then be applied to assist in validating the developed model. This could be done by determining the level of integration of a NAVFAC EXWC case study using the developed MOEs, and then comparing the obtained results with the predicted results using the prediction models to evaluate if the two results match.

For the approach using bar charts, characteristics were considered significant if they possess a minimum score of 3 across all case studies. This criteria served two purposes. First, it ensured that only characteristics with relatively high scores (3 or more) were considered. This was intuitive, as characteristics with low scores would imply that they had no significant impact on technology adoption. Second, it ensured consistency by eliminating characteristics with widely fluctuating scores. For example, if Projects A and B were assessed as having achieved technology adoption, but scored 5 and 1 respectively for the same characteristic, then it suggests that the characteristic may have had no significant impact on technology adoption (since the projects achieved adoption regardless of a high or low score). Likewise, pattern matching was applied to validate the success profile generated. This was done by determining the level of integration of a NAVFAC EXWC case study using the developed MOEs, and comparing the obtained results against the success profile using to determine if the results match.

Lastly, depending on the test and evaluation results, limitations of the study and improvements or recommendations for future work will be discussed in Chapter V.

[3] The client can determine the strength of correlation that they wish to use and adjust the correlation coefficient accordingly

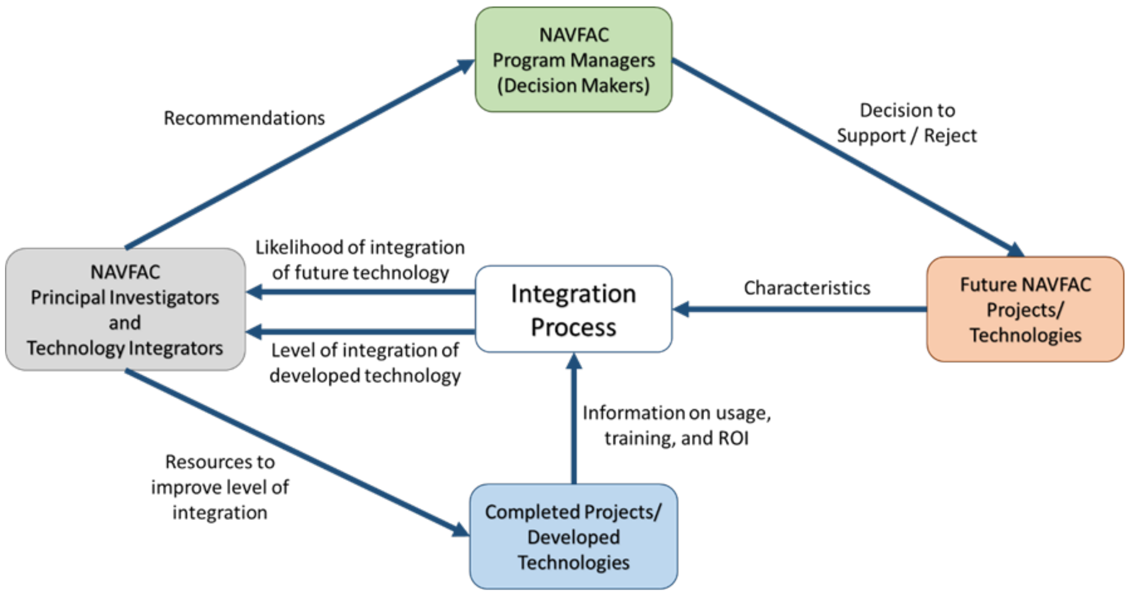
IV. ANALYSIS OF RESULTS

The previous chapter discussed the methodology used in this study, which follows a systems engineering process. This chapter details the analysis of the research results from these same five steps. Using the developed MOEs in this study, we found that the measured level of technology integration based on our earlier definition for the case studies in this thesis are consistent with the assessment made by NAVFAC EXWC stakeholders. Also, the correlation approach identified significant characteristics which could be used to generate predictive models for each MOE: "complexity," "compatibility," and "command emphasis" strongly correlate with the MOE "training"; "relative advantage" strongly correlates with the MOE "ROI"; "relative advantage," "trialability," and "degree of need" strongly correlates with the MOE "extent of diffusion." The graphical approach identified "relative advantage" and "degree of need" as significant characteristics that affect the likelihood of both technology adoption and diffusion. Lastly, this combination of "relative advantage and "degree of need" indicate a significant interaction.

A. PROBLEM DEFINITION

Effective scoping of the problem is crucial for the development of measures that are relevant in addressing the needs of the stakeholders. In this study, a context diagram was developed to identify the key external entities and their interactions with the SOI. Figure 6 shows the context diagram used in this study.

Figure 6. Context Diagram



From the context diagram, we see that the two key outputs of the integration process are: the level of integration of a developed technology; and the likelihood of integration of future projects. The problem was thus scoped to be a lack of MOEs for the NESDI integration process to determine the level of integration of a developed technology, as well as the means to predict the integration of future technologies. The level of integration of a developed technology can assist PIs and technology integrators to identify areas and channel resources accordingly to improve the level of integration. Likewise, the predicted likelihood of integration of a potential future technology can assist the PIs and technology integrators to make recommendations to the program manager on whether it is worthwhile for the project to be supported in the first place. For the purpose of this study, the projects used for case study analysis were limited to completed NAVFAC EXWC environmental sustainability shore facility-based projects.

B. STAKEHOLDER ANALYSIS

A stakeholder matrix was developed to understand each stakeholder's wants, concerns, and priority levels, as well as how they fit into the integration process. The matrix lists each stakeholder's wants and concerns to ensure that the SOI can meet all stakeholder requirements. Priority levels were also assigned to each stakeholder to prioritize system needs. The stakeholder matrix is shown in Table 3.

Table 3. Stakeholder Matrix

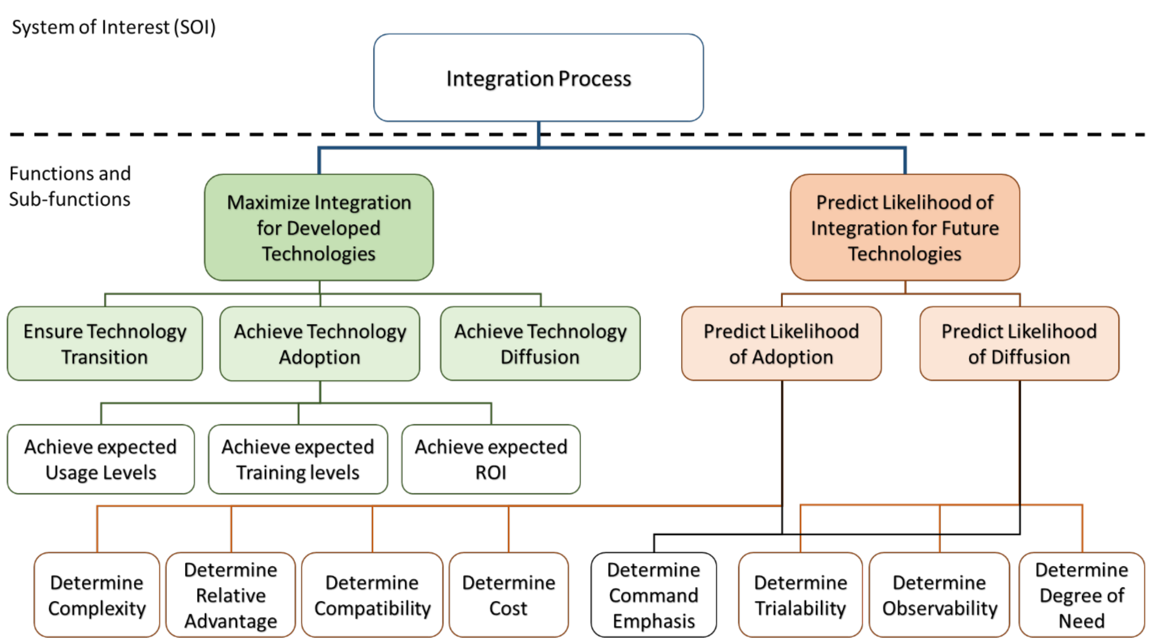
Stakeholder	Type	Want / Need	Concern	Priority
Program Manager	Decision maker	- maximize number of legitimate user requests supported - maximize number of technologies that are integrated	- reduction in budget to fund projects - wasting resources to fund projects that are eventually not integrated	High
Principal Investigators	User	- develop solution for end users - end user to continue using the developed technology	- lack of user requests - developed technology not continued to be used	High
Technology Integrator	User	- maximize number of technologies diffused - garner external interest for developed technologies	- lack of budget to carry out marketing strategy - insufficient information on project success to convince potential external users	High
Technology End User	Client	- Simple and affordable solutions to their problems - prefer to remain status quo unless change is mandatory	- budget to continue using developed technology - extensive time and effort to train on using developed technology	Low

C. SYSTEM REQUIREMENTS

Based on the stakeholders' needs and concerns identified through the stakeholder matrix, the requirements for the SOI (i.e., the NESDI integration process) were developed. From Table 4, the stakeholders' wants and needs were condensed into one key requirement: to maximize the integration of developed technologies. Similarly, the stakeholders' concerns can be summarized into the key requirement of predicting the likelihood of integration for future technologies. With a good prediction of whether a future technology is likely to be integrated, the program manager could decide in advance whether the project is worth investing in, hence preventing wastage of resources to develop projects that are unlikely to be integrated at the intended level. Similarly, a good prediction reduces uncertainty on whether a proposed technology would continue to be used, and could assist the technology integrator in his role to convince potential external users.

Chapter III discussed the four areas of measurement (usage, training, ROI, extent of diffusion) for technology integration, as well as the potential characteristics (complexity, relative advantage, compatibility, trialability, observability, command emphasis, cost, degree of need) of technologies that could be used to predict the degree of integration for future technologies. As such, the two key requirements were further decomposed into their respective sub-functions (Figure 7).

Figure 7. Functional Decomposition of the NESDI Integration Process



D. VALUE SYSTEMS DESIGN

Based on the identified functions and sub-functions, a value hierarchy diagram was generated to formulate a coherent set MOEs which is centered on stakeholder desires. The aim was to effectively compare the derived MOEs and against the identifiable characteristics of a technology, and analyze if there exists significant correlation between the two. A strong correlation would suggest that the characteristic could be used to predict the likelihood of integration of future technologies and projects.

1. Measuring Level of Adoption

As discussed in Chapter II, good MOEs need to be relevant, measurable, and precise. Hence, the areas to measure technology adoption identified in Chapter III were further refined to ensure alignment to these criteria.

a. Usage

The actual usage of the technology was measured against its expected usage (estimated during project phase) using operating hours as an indicator to determine whether the developed technology was being used as intended.[4] A higher usage percentage was consistent with a higher level of technology adoption.

b. Training

Training was measured by the percentage of intended operators that have met training requirements. This compared the actual number of trained personnel against the required number of trained personnel (estimated during project phase) to provide an indication to the level of adoption of a developed technology within the client organization. A higher percentage of trained personnel was consistent with a higher level of technology adoption.

[4] While the term "operating hours" is generally used for the purpose of this study, it also applies to technologies that are operated on a frequency basis (e.g., four times a year).

c. Return-on-Investment (ROI)

As discussed in Chapter III, technologies are developed mostly with the purpose of improving efficiency, reducing errors, saving resources, or making processes more environmentally-friendly. These benefits were translated into measurements in terms of time savings, cost savings, or cost avoidances. In this regard, measuring the actual amount of savings achieved against the expected amount of savings (estimated during project phase) showed the level of realized benefits of the developed technology, and provided an indication to the level of adoption within the client organization. A higher ROI percentage was consistent with a higher level of technology adoption.

2. Measuring Level of Diffusion

a. Extent of Diffusion

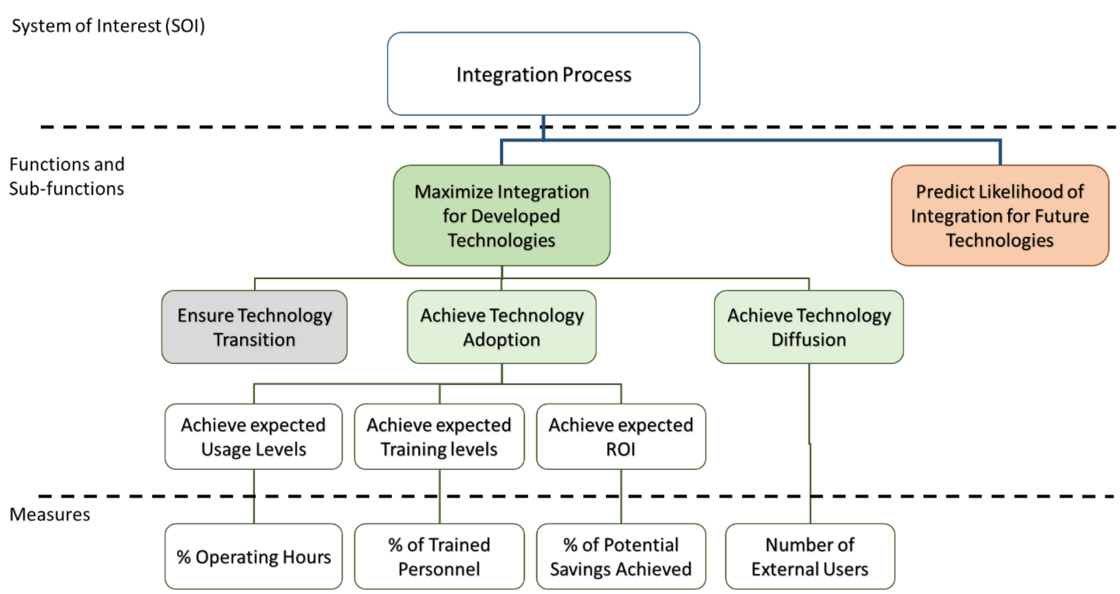
Based on our definition of technology diffusion as the phase in which the developed technology is extended beyond its original intended user to general use and application (Carr 1999), the extent of diffusion of the technology was measured in terms of the number of external users, which in this study was also the only measure to determine if the technology has been successfully diffused.

A score between 1 to 5 was computed for each MOE for each of the four case studies. The purpose of the scores was to compute a correlation coefficient between a set of MOE and a technology characteristic (to be discussed in subsequent sections). The correlation coefficients would indicate the characteristics that significantly correlate with a MOE. This then allows the creation of an expression, using multiple linear regression, for the MOE in terms of the significant characteristics. Table 5 summarizes the MOEs for technology integration and their scoring criteria. Figure 8 shows the value hierarchy diagram based on the developed measures.

Table 4. Summary of MOEs and Scoring Criteria for Technology Integration

Area	Area of Measure	Objective	MOE	Scoring Criteria
Adoption	Usage	Maximize	% Operating hours of developed technology	1: <20% 2: <40% 3: <60% 4: <80% 5: >80%
	Training	Maximize	% of trained personnel	1: <20% 2: <40% 3: <60% 4: <80% 5: >80%
	ROI	Maximize	% of potential savings achieved	1: <20% 2: <40% 3: <60% 4: <80% 5: >80%
Diffusion	Extent of Diffusion	Maximize	Number of external users of developed technology	1: none 3: one 5: two or more

Figure 8. Value Hierarchy Diagram (Measuring Level of Integration)



3. Measuring Characteristics of Technologies

Similarly, considering that good measures need to be relevant, measurable, and precise, each of the characteristics identified in Chapter III were further refined and assigned measures to ensure consistency and alignment to these criteria. The measures were similarly assigned a score of 1 (worst) to 5 (best).

a. Complexity

The complexity of a technology was measured in terms of the estimated amount of time required to learn to use the technology. A less complex technology would require less time to learn and use, more likely to be adopted, and hence given a higher score.

b. Relative Advantage

Relative Advantage was measured in terms of the benefit that the technology was expected to bring. Depending on the technology, the expected benefits were measured in terms the percentage of time savings, man-hours savings, cost savings, cost avoidances, reduction in error rates, or reduction in environmental waste as compared to the end users' existing processes. A higher percentage of potential savings was given a higher score.

c. Compatibility

Compatibility was measured in terms of the level of changes that an organization is required to make to incorporate the technology into its operations. This could range from no changes to existing processes or infrastructure (high compatibility), to a totally new process or operational procedure (low compatibility). A technology with high compatibility requires few changes to existing processes or infrastructure, is expected to translate to better integration, and was hence given a higher score.

d. Trialability

Trialability was measured in terms of the expected amount of resources (e.g., time, money) required to perform a trial of the technology at a site. A technology requiring a lower amount of resources to trial was given a higher score.

e. Observability

Observability was measured in terms of the number of avenues that the technology was marketed in. These avenues included social media, magazines, journals, conferences, newsletters or intranet sharing. A technology that was marketed in more avenues was given a higher score.

f. Cost

Cost was measured in terms of the annual budget or funding required to continue to use the technology. A technology that required lower amount of funding was more likely to be adopted and hence given a higher score.

g. Degree of need

The degree of need of a technology was measured by the area that the technology addresses. A technology that affected the area of operations and safety was more likely to be diffused, and hence given a higher score, as compared to a technology that affects administrative processes but was not necessarily required.

h. Command Emphasis

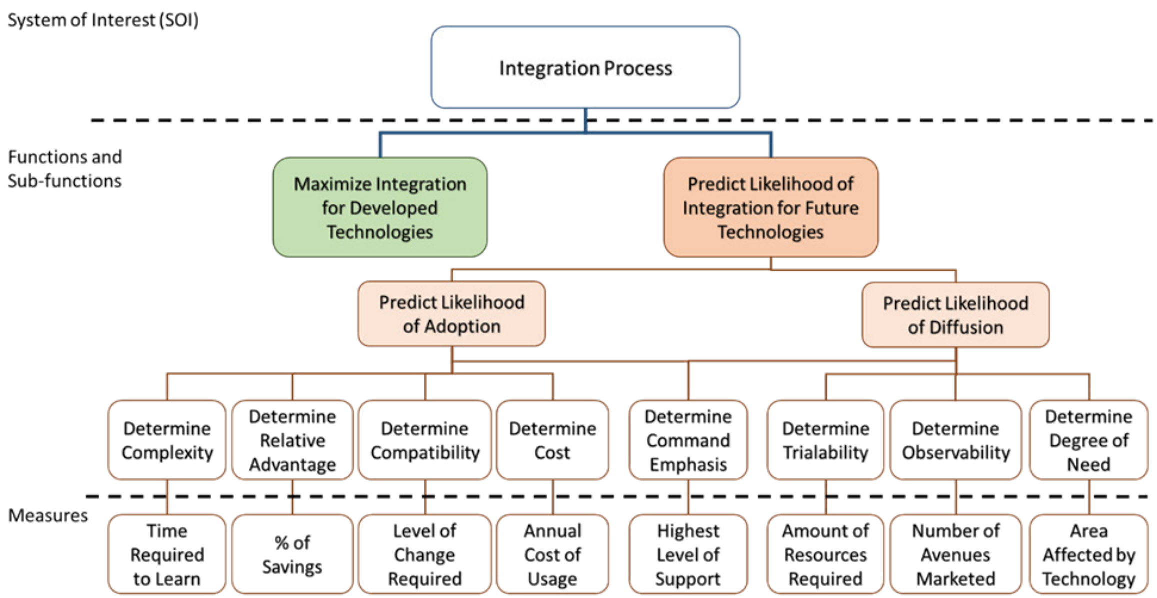
Command emphasis given to a technology was measured in terms of the highest level of support granted received. A technology that has garnered the support of a Fleet Commander was more likely to be diffused, and hence given a higher score, as compared to the case if it was only recognized by the ground supervisor.

Table 5 summarizes the technology characteristics, their respective measures, as well as their scoring criteria. Figure 9 depicts the value systems hierarchy diagram for the characteristics.

Table 5. Measures and Scoring Criteria for Technology Characteristics

Affecting Degree of Integration	Characteristic	Measures	Scoring Criteria
Technology Adoption	Complexity	Time required to train/learn	1: > 1 month 2: < 1 month 3: < 2 weeks 4: < 5 days 5: < 2 days
	Relative Advantage	Estimated % of time savings, cost savings, pollution reduction, or error reduction compared to existing process	1: <20% 2: <40% 3: <60% 4: <80% 5: >80%
	Compatibility	Level of change to existing processes	1: totally new work process 2: major modification required 3: minor modification required 4: adaptation of existing process 5: no change
	Cost	Annual Cost of using the technology	1: >$50,000 2: <$50,000 3: <$30,000 4: <$10,000 5: <$5000
	Command Emphasis	Highest level of support achieved	1: Ground supervisor 2: OIC or equivalent 3: CO or equivalent 4: Base Comd or equivalent 5: Fleet Comd and above
Technology Diffusion	Trialability	Amount of resources required for trial	1: > 1 month prep or $15,000 2: < 1 month prep or $15,000 3: < 2 weeks prep or $10,000 4: < 5 days prep or $5,000 5: < 2 days prep or $2,000
	Observability	Number of avenues marketed (e.g., social media, magazines, intranet, conferences)	1: less than 2 3: 2 to 4 5: 5 or more
	Degree of Need	Area affected by technology	1: Administrative 2: Training 3: Environmental regulation 4: Legal regulation 5: Operations and Safety
	Command Emphasis	Highest level of support	1: Ground supervisor 2: OC or equivalent 3: CO or equivalent 4: Base Comd or equivalent 5: Fleet Comd and above

Figure 9. Value Hierarchy Diagram
(Measures for Technology Characteristics)



E. TEST AND EVALUATION: VERIFICATION AND VALIDATION

Four projects were provided by NAVFAC EXWC for the purpose of case study analysis. The projects were: Project 288 - No Foam Fire Suppression System, Project 341 - Zinc Removal in Compwater, Project 356 - Real-time Water Quality Monitoring System, and Project 428 - Bilge and Oily Wastewater Treatment System. All four projects were completed, shore facility-based technologies, and deemed by NAVFAC EXWC stakeholders to have been successfully adopted by their respective client organizations. In addition, the technologies developed through Projects 288, 428, and 356 were agreed by NAVFAC EXWC stakeholders to have to have been extended to other external organizations, and meet this study's definition of technology diffusion.

1. Verification and Validation of MOEs for Technology Integration

The four case studies were scored using the developed MOEs for technology integration. This included scoring each project in the areas of Usage, Training, and ROI to determine the level of technology adoption, and then scoring each project's Extent of

Diffusion to determine the level of technology diffusion. Table 6 shows an example of the scoring of each project under the MOE "Usage."

Table 6. Example of Scoring under the MOE "Usage."

	Usage			
Project	Estimated operating hours	Actual operating hours	% of operating hours	**Score**
288 - No Foam Fire Suppression	4x a year	as estimated	100	**5**
341 - Zinc Removal in Compwater	6 Mgal/year	as estimated	100	**5**
356 - Real-time Drinking Water Quality Monitoring	24 hrs 7 days	as estimated	100	**5**
428 - Bilge and Oily Wastewater Treatment System	10-14 Mgal/year	within 10% of estimated	~90	**5**

Scoring Criteria
1: <20%
2: <40%
3: <60%
4: <80%
5: >80%

Data provided by PI

Scores derived from scoring criteria

Adapted from R. Kudo, S. Maga, S. Fann, and T. Torres, email to author (7 June 2018).

As there were three MOEs measuring the level of technology adoption, they were first assigned swing weights in a Parnell 3x3 matrix (Trainor and Parnell 2011) based on the stakeholders' assessment of their relative importance. The matrix listed the MOEs based on their relative importance, and their variation in range.[5] Table 7 shows the swing weights for the adoption MOEs. There was no need to perform weighting for "extent of diffusion" as it was the only MOE for technology diffusion in this study.

[5] Variation in range is used to assess if a measure is effective in distinguishing between the performances of the different projects. In this case, all projects scored 4 or 5 in the three areas of Usage, Training, and ROI, and were all hence categorized as having low variation in range.

Table 7. Swing Weights for Technology Adoption MOEs.

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="3">Importance of Measure</td></tr>
<tr><td>High</td><td>Medium</td><td>Low</td></tr>
<tr><td rowspan="3">Variation in Range</td><td>High</td><td></td><td></td><td></td></tr>
<tr><td>Medium</td><td></td><td></td><td></td></tr>
<tr><td>Low</td><td>Usage
50</td><td>Training
30</td><td>ROI
20</td></tr>
</table>

Source: M. McMorrow, email to author (5 July 2018).

The swing weights were then converted into measured weights, which are normalized to sum to one to be used to calculate the eventual weighted scores. The raw scores for each project under each MOE were multiplied by the MOEs' respective measured weights to obtain the weighted adoption scores for each project. For example, Project 341 attained raw scores of 5, 5, and 4 for the MOEs "Usage," "Training" and "ROI" respectively. The raw scores were then multiplied by the respective MOEs' measured weights (i.e., 5*0.5, 5*0.4, 4*0.2), and summed to obtain the final weighted adoption score (i.e., 5*0.5 + 5*0.4 + 4*0.2 = 4.8). Table 8 shows the weighted adoption scores of the four projects.

Table 8. Weighted Adoption Scores of Projects

MOE	Swing Weight	Measured Weight	Project Raw Scores			
			Project 288	Project 341	Project 356	Project 428
Usage	50	0.5	5	5	5	5
Training	30	0.3	5	5	4	5
ROI	20	0.2	5	4	5	5
Weighted Adoption Score = Sum(Measured Weight * MOE Raw Score)			5	4.8	4.7	5

Table 9 provides the interpretation of the scores on the level of technology integration, and Table 10 summarizes the assessment of integration achieved by the four projects. It should be noted that the classification of scores could be flexibly adjusted as necessary depending on NESDI/NAVFAC's needs, and it is important for NESDI/NAVFAC to agree on what the classification should be so that there is no ambiguity in the definition of whether a technology has been adopted or diffused. See Appendix for the detailed adoption and diffusion scores for each project.

Table 9. Interpretation of Scores

Adoption Score	Level of Adoption	Diffusion Score	Level of Diffusion
Less than 3	Low	1	No diffusion
3 to 4	Moderate	3	Some level of diffusion achieved
Above 4	High	5	Diffusion achieved

Table 10. Summary of Integration Scores Achieved by Projects

Project	Adoption Score (Maximum of 5)	Diffusion Score (Maximum of 5)	Remarks
288 - No Foam Fire Suppression	5	5	Adopted and Diffused
341 - Zinc Removal in Compwater	4.8	1	Adopted, not Diffused
356 - Real-time Drinking Water Quality Monitoring	4.7	5	Adopted and Diffused
428 - Bilge and Oily Wastewater Treatment System	5	3	Adopted and Diffused

Using the developed MOEs, the adoption scores for each project show that all four projects had achieved high levels of adoption by their respective client organization. Also, the diffusion scores show that all projects except Project 341 had been extended to at least one external user. In other words, the scores show that Project 341 was the only project out of the four case studies that had not been diffused. These results were consistent with the stakeholders' assessment of the four projects (Kudo, Maga, Fann, and Torres, email to author, April 2018).

2. Developing the Predictive Models

After validating the MOEs for technology integration, the next step was to score each project based on the identified characteristics of complexity, relative advantage, compatibility, cost, command emphasis, trialability, observability, and degree of need. Table 11 shows an example of the scoring of each project under the characteristic "Complexity," and Table 12 summarizes the scores achieved by the four projects. See Appendix for the detailed characteristic scores for each project.

Table 11. Example of Scoring under the Characteristic "Complexity"

	Complexity	
Project	Time required for operators to learn	Score
288 - No Foam Fire Suppression	< 1 hour	5
341 - Zinc Removal in Compwater	2-5 days	4
356 - Real-time Drinking Water Quality Monitoring	1-2 years	1
428 - Bilge and Oily Wastewater Treatment System	2 weeks	3

Data provided by PI

Scoring Criteria
1: > 1 month
2: < 1 month
3: < 2 weeks
4: < 5 days
5: < 2 days

Scores derived from scoring criteria

Adapted from R. Kudo, S. Maga, S. Fann, and T. Torres, email to author (7 June 2018).

Table 12. Summary of Characteristics Scores Achieved by Projects

S/N	Characteristic	Scores (Maximum of 40)			
		288 - No Foam Fire Suppression	341 - Zinc Removal in Compwater	356 - Real-time Drinking Water Quality Monitoring	428 - Bilge and Oily Wastewater Treatment System
1	Complexity	5	4	1	3
2	Relative Advantage	5	4	5	5
3	Compatibility	3	4	2	3
4	Cost	5	1	2	1
5	Command Emphasis	4	3	2	5
6	Trialability	5	2	4	1
7	Observability	5	3	3	1
8	Degree of Need	5	3	5	3
Total		37	24	24	22

The characteristics scores across the four case studies were then correlated against the developed MOEs to identify significant characteristics using the selection criteria of correlation coefficient > 0.75 as discussed in Chapter III. Using the "CORREL()" function in Microsoft Excel, each set of characteristic score was correlated against each set of MOE score to obtain their respective correlation coefficients. Table 13 shows an example of correlation coefficient computed for the characteristic "compatibility" and the MOE "training." Table 14 shows the summary of correlation coefficients across the MOEs and characteristics, with the significant correlation coefficients.

Table 13. Example of Correlation between "Compatibility" and "Training"

Project	Training MOE Score	Compatibility Characteristic Score
288 - No Foam Fire Suppression	5	3
341 - Zinc Removal in Compwater	5	4
356 - Real-time Drinking Water Quality Monitoring	4	2
428 - Bilge and Oily Wastewater Treatment System	5	3
Correlation coefficient	**0.816**	

Table 14. Summary of Correlation Coefficients across MOEs and Characteristics

Characteristics	Adoption MOEs			Diffusion MOE
	Usage	Training	ROI	Extent of Diffusion
Complexity	N.A.	0.878	-0.293	-0.255
Relative Advantage	N.A.	-0.333	1.000	0.870
Compatibility	N.A.	0.816	-0.816	-0.853
Cost	N.A.	0.088	0.440	0.690
Command Emphasis	N.A.	0.775	0.258	-0.135
Trialability	N.A.	-0.365	0.365	0.763
Observability	N.A.	0	0	0.426
Degree of Need	N.A.	-0.577	0.577	0.905

It should be noted that all four case studies scored a maximum of 5 for the MOE "usage." As a result, no correlation analysis could be performed on the characteristics against the MOE "usage." Also, we found that some of the characteristics showed significant negative correlations with the MOEs. For example, "compatibility" had a correlation coefficient of -0.853 with the MOE "extent of diffusion." This was not intuitive, as a technology with high compatibility (i.e., requiring less changes to existing processes and infrastructure) should result in better integration. Again, this was most probably be due to the very small sample size of available case studies, which prevents any purposeful statistical analysis. It should be re-iterated that the focus of this study is not to provide a definitive solution but rather to demonstrate the approach to analyze the data. From Table 14, the following analyses can be made:

1. The characteristics "complexity," "compatibility," and "command emphasis" seemed to significantly correlate with the MOE "training," with correlation coefficients of 0.878, 0.816, and 0.775 respectively. This result is intuitive, as a technology that is less complex and more compatible with existing processes would tend to result in less training time required. A technology with high levels of command emphasis would also ensure that sufficient personnel are trained to continue using the technology.

2. The characteristic "relative advantage" seemed to significantly correlate with the MOE "ROI," with a correlation coefficient of 1. This result is intuitive, as a technology with a high relative advantage is expected to yield a large percentage of savings compared to existing processes, which would translate to a large percentage of ROI yielded subsequently.

3. The characteristics "relative advantage," "trialability," and "degree of need" seemed to significantly correlate with the MOE "extent of diffusion," with correlation coefficients of 0.870, 0.763, and 0.905 respectively. This result is intuitive, as a technology that has high potential savings, is easy to trial, and impacts operations and safety would tend to attract the attention of other potential adopters, hence improving the technology's likelihood to be diffused.

Regression models describe the relationship between the response variable and the explanatory variables. (Chambers et al. 1983) Using Microsoft Excel software, multiple linear regression could then be performed to obtain the predictive models for "training," "ROI" and "extent of diffusion" (response variables) using the identified significant characteristics (explanatory variables).

a. Predictive Models for Technology Adoption

As only four case studies were available for analysis, the data sample size was too small to perform an accurate analysis using correlation and regression. Regardless, this section demonstrates how predictive models could be developed using multiple linear regression. Table 15 shows an example of the results of multiple linear regression for the MOE "training."

Table 15. Regression Predictive Model Results for the MOE "Training"

Project	MOE	Characteristics		
	Training (Y)	Complexity (X1)	Compatibility (X2)	Command Emphasis (X3)
288 - No Foam Fire Suppression	5	5	3	4
341 - Zinc Removal in Compwater	5	4	4	3
356 - Real-time Drinking Water Quality Monitoring	4	1	2	2
428 - Bilge and Oily Wastewater Treatment System	5	3	3	5
Prediction Model Coefficients				
Intercept	3.000			
Complexity (X1)	0.091			
Compatibility (X2)	0.273			
Command Emphasis (X3)	0.182			

The predictive model for training could hence be expressed in the form:

*Training = 0.091*Complexity + 0.273*Compatibility + 0.182*Command Emphasis + 3*

Using this model as an example, the training score for future technologies could be predicted by determining their complexity, compatibility and command emphasis scores. For example, a future technology with a score of 3 in all three characteristics would yield an overall training score of 0.091*3 + 0.273*3 + 0.182*3 + 3 = 4.638.

The example illustrated how the identified significant characteristics could be used to develop predictive models for adoption MOEs using multiple linear regression. With sufficient data and sample size, refined predictive models could be developed for the respective MOEs of "usage," "training," and "ROI" to more accurately predict a future technology's scores in these areas, which in turn generates an overall score indicating the technology's likelihood of adoption. This would allow decision-makers to better gauge and decide if it is worthwhile to invest resources to develop the technology in the first place.

b. Predictive Models for Technology Diffusion

Likewise, a regression predictive model could be developed for the MOE "extent of diffusion" to predict a future technology's likelihood of diffusion. Table 17 shows an example of the results of multiple linear regression for the MOE "extent of diffusion."

Table 16. Regression Predictive Model Results for the MOE "Extent of Diffusion"

Project	MOE	Characteristics		
	Extent of Diffusion (Y)	Relative Advantage (X1)	Trialability (X2)	Degree of Need (X3)
288 - No Foam Fire Suppression	5	5	5	5
341 - Zinc Removal in Compwater	1	4	2	3
356 - Real-time Drinking Water Quality Monitoring	5	5	4	5
428 - Bilge and Oily Wastewater Treatment System	3	5	1	3
Prediction Model Coefficients				
Intercept		-10		
Relative Advantage (X1)		2		
Trialability (X2)		0		
Degree of Need (X3)		1		

The predictive model for training could hence be expressed in the form:

*Extent of Diffusion = 2*Relative Advantage + 0*Trialability + 1*Degree of Need - 10*

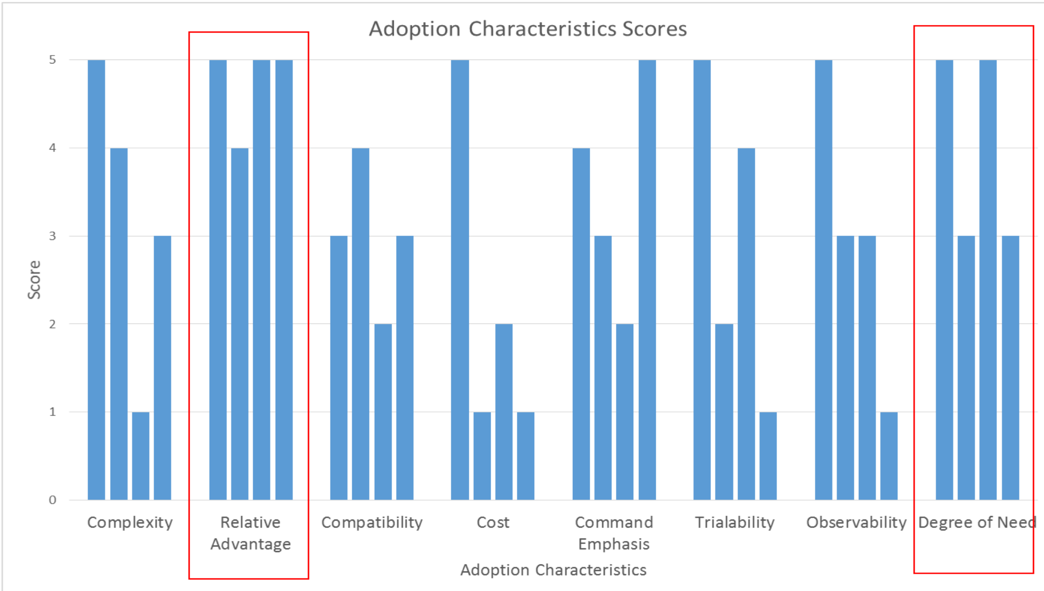
c. Limitations of Regression Predictive Models

Based on the four case studies analyzed, we have demonstrated the approach and methodology to develop the initial predictive models for technology adoption and technology diffusion. However, there are several limitations to consider when using this approach. First, correlation in itself is only a measure of linear relationship between two variables, and does not suggest cause and effect relationship between the two variables. Second, the correlation coefficient is highly sensitive to extreme data values, and a single extreme data point may result in a large change in the correlation coefficient. Third, because the correlation coefficient measures linear relationships, a low coefficient value does not necessarily mean that there is no relationship between the two variables (i.e., the variables may be non-linearly related). Fourth, as highlighted in Chapter III, a small sample size of four case studies was insufficient to provide purposeful quantitative analysis using correlation and regression. This does not mean that the predictive models are invalid - it means that there exists opportunities for future research to refine and improve the accuracy models by increasing the available data sample size (i.e., analysis of more case studies).

3. Graphical Approach: Using Bar Charts

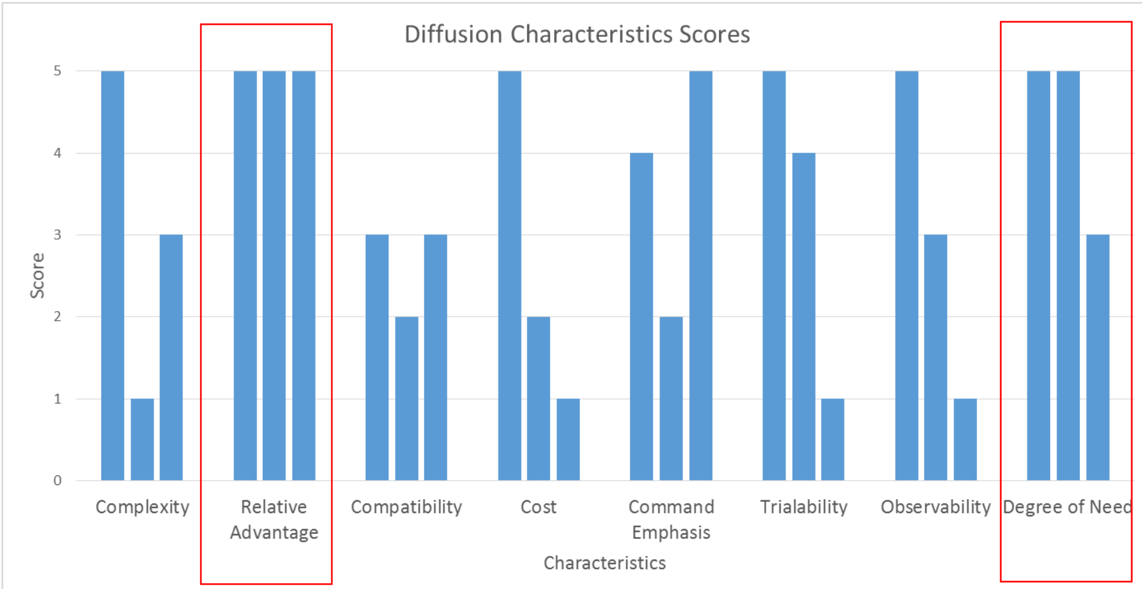
Given the small sample size of available case studies, an alternative approach may be to use bar charts to illustrate the significant characteristics that are present in adopted and diffused technologies. As all four case studies were assessed to have achieved technology adoption, the characteristic scores for all four case studies were hence analyzed to identify significant characteristics to develop a possible "success profile" for future technologies to reference to in order to increase their likelihood of achieving technology adoption. Figure 10 shows the adoption characteristic scores of the four case studies plotted on a bar chart. Based on the selection criteria discussed in Chapter III, the characteristics "relative advantage" and "degree of need" were identified as significant characteristics that contribute to technology adoption.

Figure 10. Adoption Characteristics Scores of Case Studies



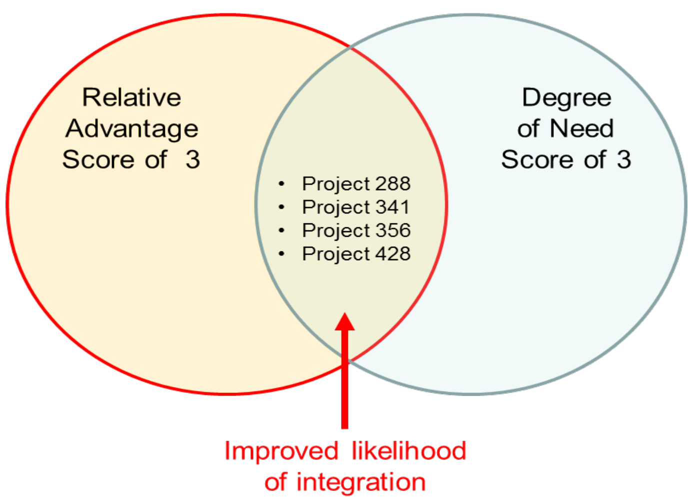
A similar approach and selection criteria was used to identify the significant characteristics that impact technology diffusion. In this case, only Projects 288, 356, and 428 were previously assessed to have achieved technology diffusion. Hence, only these three projects were used in the analysis for the success profile for technology diffusion. Figure 11 shows the diffusion characteristic scores of the four case studies plotted on a bar chart. Based on the selection criteria, the characteristics of "relative advantage" and "degree of need" were again identified as significant characteristics that contribute to technology adoption.

Figure 11. Diffusion Characteristics Scores of Case Studies



Based on analysis of the bar charts, we see that the success profile hence requires both the characteristics of "relative advantage" and "degree of need" to have a minimum score of 3 in order to have an improved likelihood of achieving both technology adoption and diffusion. Figure 12 illustrates the overall success profile for technology integration (adoption plus diffusion) using a Venn diagram.

Figure 12. Success Profile using Venn Diagram



The results of the above approach could be extended to future technologies, which could be compared against the success profile. If the future technologies' characteristics scores match or exceed that of the success profile, it suggests a good likelihood for these future technologies to succeed in achieving technology integration.

a. Validation of Success Profile

To validate the success profile generated, we could use the success profile to predict the likelihood of adoption and diffusion of one of the case studies, and assess if the prediction match the results determined by the developed MOEs for technology adoption and diffusion. In this case, Project 341 was used as a test case. Project 341 scored 4 and 3 for the characteristics "relative advantage" and "degree of need" respectively. Hence, it matched the success profile and was assessed to have a good likelihood of being adopted and diffused. However, this prediction differed from the results determined by the developed MOEs, which assessed Project 341 as "adopted, but not diffused." This result was not totally unexpected: the success profile was meant to serve as a reference to improve the likelihood of technology integration, and not guarantee the actual integration of the predicted case (i.e., predicting that a technology is likely to be integrated does not equate to the technology being in fact integrated). Continued collection of more data from other projects is a means to develop increasingly reliable predictive models and profiles.

b. Limitations of Graphical Approach

Through the use of bar charts, we have demonstrated an approach to develop a success profile for technology integration. Compared to the quantitative approach of correlation and regression, this graphical approach offered a relatively simple way for NESDI and NAVFAC EXWC stakeholders to predict the likelihood of successful integration of future technologies even with only a small sample size of case studies.

A drawback of this approach, however, was its inability to provide a quantitative gauge or scale of the likelihood of successful integration. Unlike the quantitative approach where the predictive model could generate a definitive score (e.g., 4 out of a maximum of 10), this approach only showed the stakeholder that a future technology which matches the success profile was likely to succeed in achieving technology integration, but is unable to define exactly “how likely.”

Another drawback lies with the accuracy of the success profile. Recall that we excluded the characteristics that had fluctuating scores across the case studies - this could result in a characteristic being excluded even when it is actually significant. For example, if a “success” characteristic had 99 cases scoring 5 and only one case (i.e., an outlier) scoring 1, that characteristic would have been excluded from the success profile even though it should have been significant as it was present in 99% of success cases.

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V. CONCLUSIONS

A. ANALYTICAL INSIGHTS

The analytical insights gained from this study are presented in accordance to the research questions:

1. How may we measure whether a technology has been successfully integrated into a client organization?

This study translated the criteria for technology integration stated in the NESDI SOP (U.S. Navy 2010) into four key areas of usage, training, ROI, and extent of diffusion. MOEs were developed to quantitatively measure the performance of any given technology in the four respective areas. Scores ranging from 1 to 5 were assigned to each key area and an overall adoption score (out of a maximum of 15) and an overall diffusion score (out of a maximum of 5) was then generated to determine the level of integration of the given technology.

2. What are the identifiable characteristics of successfully integrated technologies?

Through literature research, stakeholder analysis and cross-case synthesis (Yin 2014), the eight characteristics of complexity, compatibility, relative advantage, cost, command emphasis, trialability, observability, and degree of need were identified as common characteristics in technologies. Using the four case studies provided by the NAVFAC EXWC stakeholders, two different approaches were used in this study to narrow down the significant characteristics of successfully adopted and diffused technologies.

The first approach correlated the characteristic scores of the four case studies with the developed MOEs, and characteristics with correlation coefficient of > 0.75 were assessed to be significant. The second approach presented the characteristic scores of the four case studies in the form of a bar chart, and characteristics that score a minimum of 3 across all cases analyzed were assessed to be significant.

3. Which characteristics correlate with the developed MOEs, and how can they be used to predict the successful integration of future technologies?

As only four case studies were available for analysis, the data sample size was too small to perform an accurate analysis using regression predictive models. Nonetheless, this study demonstrated how the identified significant characteristics could be used to develop separate predictive models for the MOEs of usage, training, ROI, and extent of diffusion respectively through multiple linear regression. With sufficient data, future work could continue to develop and refine the models.

In the second approach, relative advantage and degree of need were identified as significant characteristics present in technologies that have been assessed as successfully adopted and diffused. These characteristics were presented in the form of a Venn diagram to illustrate a success profile for future technologies to refer to in order to improve their likelihood of adoption and diffusion.

B. LIMITATIONS AND FUTURE WORK

This study presented the key methodology and approach to assess and predict technology integration. It should be noted that the aim of the predictive models developed in this study were not to guarantee the eventual and actual integration of future technologies, but rather to serve as references for decision makers to make better-informed decisions regarding whether resources should be invested on a project.

Limitations for both the regression and bar chart predictive models were discussed in Chapter IV. The correlation coefficient used to identify significant characteristics for the regression predictive model is highly sensitive to extreme data values, and a single outlier may result in a significantly different correlation coefficient. Also, the regression predictive model assumes that the variables and response are linearly related, which may not necessary be the case. Both limitations could be mitigated with more data points, and future work should look into refining and revalidating the model through the analysis of more available case studies.

The graphical approach, while simple to use, was unable to provide a quantitative gauge or scale of the likelihood of successful integration. Also, it possessed the risk of excluding a characteristic even when it is actually significant. With more available case studies for analysis, future work could look into revising the selection criteria for significant characteristics to possibly base it on a percentage of data points instead of an absolute score. This would help in excluding outliers in the data.

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APPENDIX. CASE STUDIES SCORES

A. MOES SCORES

	Usage			
Project	Estimated operating hours	Actual operating hours	% of operating hours	Score
288 - No Foam Fire Suppression	4x a year	as estimated	100	5
341 - Zinc Removal in Compwater	6Mgal/year	as estimated	100	5
356 - Real-time Drinking Water Quality Monitoring	24 hrs 7 days	as estimated	100	5
428 - Bilge and Oily Wastewater Treatment System	10-14Mgal/year	within 10% of estimated	~90	5

Scoring Criteria
1: <20%
2: <40%
3: <60%
4: <80%
5: >80%

	Training			
Project	Required trained personnel	Actual trained personnel	% of trained personnel	Score
288 - No Foam Fire Suppression	2 shifts	2 shifts	100	5
341 - Zinc Removal in Compwater	3	5	166.667	5
356 - Real-time Drinking Water Quality Monitoring	3	2	66	4
428 - Bilge and Oily Wastewater Treatment System	4 to 10	sufficient for operations	100	5

Scoring Criteria
1: <20%
2: <40%
3: <60%
4: <80%
5: >80%

	Return on Investment (ROI)			
Project	Estimated savings	Actual savings achieved	% of savings	Score
288 - No Foam Fire Suppression	100% of all AFFF concentrate	100% of all AFFF concentrate	100	5
341 - Zinc Removal in Compwater	$0.33/gal * 6Mgal = $2M/year	$1.5M (based on user claim of 50%)	75	4
356 - Real-time Drinking Water Quality Monitoring	> 95% of time (real-time vs 3 days for lab report)	as per estimated	100	5
428 - Bilge and Oily Wastewater Treatment System	$4.5M/year	within 10% of estimation	~ 90	5

Scoring Criteria
1: <20%
2: <40%
3: <60%
4: <80%
5: >80%

Project	Extent of Diffusion Number of external users	Score
288 - No Foam Fire Suppression	> 2	5
341 - Zinc Removal in Compwater	**0**	1
356 - Real-time Drinking Water Quality Monitoring	> 2	5
428 - Bilge and Oily Wastewater Treatment System	1	3

Scoring Criteria
1: none
3: one
5: two or more

B. CHARACTERISTICS SCORES

Project	Complexity Time required for operators to train or learn	Score
288 - No Foam Fire Suppression	< 1 hour	5
341 - Zinc Removal in Compwater	2-5 days	4
356 - Real-time Drinking Water Quality Monitoring	1-2 years	1
428 - Bilge and Oily Wastewater Treatment System	2 weeks	3

Scoring Criteria
1: > 1 month
2: < 1 month
3: < 2 weeks
4: < 5 days
5: < 2 days

Project	Relative Advantage Estimated % of savings (time, cost, error reduction) compared to existing process	Score
288 - No Foam Fire Suppression	1000 - 10000 gallons (100% AFFF saved)	5
341 - Zinc Removal in Compwater	~ 66% (only 1/3 of the cost with new technology)	4
356 - Real-time Drinking Water Quality Monitoring	>95% (real-time abnormality alert vs 3 days lab report)	5
428 - Bilge and Oily Wastewater Treatment System	~90%	5

Scoring Criteria
1: <20%
2: <40%
3: <60%
4: <80%
5: >80%

	Compatibility	
Project	Level of Change to Existing Processes	Score
288 - No Foam Fire Suppression	minor modification (valves, piping)	3
341 - Zinc Removal in Compwater	adaptation of existing processes	4
356 - Real-time Drinking Water Quality Monitoring	Data Network required (major mod)	2
428 - Bilge and Oily Wastewater Treatment System	new pad and berm	3

Scoring Criteria
1: totally new work process
2: major modification required
3: minor modification required
4: adaptation of existing process
5: no change

	Cost	
Project	Annual Cost of Using the Technology	Score
288 - No Foam Fire Suppression	<$5000 per set	5
341 - Zinc Removal in Compwater	$1,000,000 - 1,500,000, compared to ~$3M	1
356 - Real-time Drinking Water Quality Monitoring	$35000/year	2
428 - Bilge and Oily Wastewater Treatment System	$500000, compared to $5M	1

Scoring Criteria
1: >$50,000
2: <$50,000
3: <$30,000
4: <$10,000
5: <$5000

	Command Emphasis	
Project	Highest level of Support Garnered	Score
288 - No Foam Fire Suppression	Commander Navy Installation Command	4
341 - Zinc Removal in Compwater	Ops Officer (CO or equivalent)	3
356 - Real-time Drinking Water Quality Monitoring	Water system superintendent (OIC or equivalent)	2
428 - Bilge and Oily Wastewater Treatment System	Fleet Comd	5

Scoring Criteria
1: Ground supervisor
2: OIC or equivalent
3: CO or equivalent
4: Base Comd or equivalent
5: Fleet Comd and above

	Trialability	
Project	Amount of Resources Required to Trial Technology	Score
288 - No Foam Fire Suppression	¬1 day preparation	5
341 - Zinc Removal in Compwater	$700000	2
356 - Real-time Drinking Water Quality Monitoring	$400000	4
428 - Bilge and Oily Wastewater Treatment System	$1.2 mil	1

Scoring Criteria
1: > 1 month prep or $800,000
2: < 1 month prep or $800,000
3: < 2 weeks prep or $600,000
4: < 5 days prep or $400,000
5: < 2 days prep or $200,000

Project	Observability Number of Avenues Marketed	Score
288 - No Foam Fire Suppression	> 5	5
341 - Zinc Removal in Compwater	Currents magazine, Conferences	3
356 - Real-time Drinking Water Quality Monitoring	3	3
428 - Bilge and Oily Wastewater Treatment System	0	1

Scoring Criteria
1: less than 2
3: 2 to 4
5: 5 or more

Project	Degree of Need Area Affected by Technology	Score
288 - No Foam Fire Suppression	Impacts operational readiness of ARFF vehicles	5
341 - Zinc Removal in Compwater	UNDS regulation	3
356 - Real-time Drinking Water Quality Monitoring	Safety and security of water supply	5
428 - Bilge and Oily Wastewater Treatment System	Environmental regulation	3

Scoring Criteria
1: Administrative
2: Training
3: Environmental regulation
4: Legal regulation
5: Operations and Safety

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