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THESIS

**PROOF OF CONCEPT FOR A SYSTEMS ENGINEERING
CONFIDENCE-TRACKING TOOL
FOR REQUIREMENTS REALIZATION**

by

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September 2018

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requirements for the degree of

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ABSTRACT

This thesis shows how a systems engineering-requirements confidence-tracking tool is useful in research and development (R&D) projects. The tool, which tracks confidence and requirements realization, was developed in Microsoft Excel and applied to an energy-related R&D project that was completed in October 2015. To achieve the primary objective, an analytical search for key SE activities was performed on interview data about the 2015 project. The search was conducted to provide a proof of concept of the tool and demonstrate how it could have been implemented during that project. The tool identifies a confidence score in a metric using red, yellow, and green charts created in Excel. Small R&D teams can use this inexpensive option for project-management requirements and provide more traceability of product production pace, which, in turn, can build stakeholder confidence. Furthermore, since Microsoft Office is a standard software package for the Department of Defense (DoD), the tool is accessible throughout DoD.

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LIST OF ACRONYMS AND ABBREVIATIONS

COTS	commercial-off-the-shelf
DoD	Department of Defense
DOE	Department of Energy
EERE	Office of Energy Efficiency and Renewable Energy
HAZMAT	Hazardous Material
HW	Hardware
IMPREL	Integrated Multi- Physics-Renewable Energy Laboratory
INCOSE	International Council of Systems Engineering
KWh	kilowatt-hour
NRL	Navy Research Lab
NREL	Office of National Renewable Energy Laboratory
PI	Principal Investigator
PP	process or policy
RD	Requirements Definition
R&D	Research and Development
SE	Systems Engineering
SEPIO	Systems Engineering and Program Integration Offices
SW	Software
TB	technology or budget
TBD	To Be Determined
TRL	Technology Readiness Level

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EXECUTIVE SUMMARY

Research and development (R&D) projects within the U.S. Navy have varying levels of complexity. This complexity can be mitigated through the use of systems engineering, which is “intended to be a disciplined process to establish needs, capabilities, and requirements that help guide the development of evolutionary and revolutionary technologies and help focus associated R&D activities” (Price et al. 2013, 207).

This thesis demonstrates the use of a software tool that can help R&D projects address the steps in the systems engineering (SE) process. This tool is based on a spreadsheet previously used by Dr. Karen Holness on a past Navy acquisition project. To demonstrate the tool’s ability to identify requirements previously not considered by stakeholders, initial confidence was established by selecting the requirements and displaying the real-time confidence in the development process throughout a R&D project. To demonstrate the use of the assessment spreadsheet tool, it was applied to an energy-related R&D project completed in October 2015.

This simple Microsoft Excel spreadsheet illustrates the value in using this SE confidence-tracking and requirements-realization tool. It provides a relatively simple Excel tool to enable systems engineers, design engineers, and other R&D developers to identify requirements and monitor the confidence in the management process and support requirements realization tracking. For further research, the author recommends modifying the current SE tool to a more generic spreadsheet tool, as the version created for this thesis was tailored specifically for the microgrid renewable energy system. The author also recommends analyzing the tool from a qualitative and quantitative approach to determine whether it is the optimum application for tasks such as determining if tracking confidence is the most appropriate metric to analyze. The reason for this recommendation is because analyzing risk could potentially offer additional insight to other blind spots not discovered with just analyzing confidence in the same manner to help reach success for R&D teams.

Reference

Price, Robert R., Bhupinder P. Singh, Robert J. MacKinnon, and S. David Sevougian. 2013. "The Application of Systems Engineering Principles to the Prioritization of Sustainable Nuclear Fuel Cycle Options." *Energy Policy* 53, no. (February): 205-217. <http://dx.doi.org/10.1016/j.enpol.2012.10.051>

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I. INTRODUCTION

A. BACKGROUND

Renewable energy is at the forefront of innovation for energy industry. According to an article written by Ochs (2014), renewable energy markets surged in the United States in the first half of 2018 despite uncertainty over federal tax credits. As a result, there is a large demand for Research and Development (R&D) projects where renewable energy is the primary focus. Moreover, R&D refers to a wide range of design activities that pertain to business, technology, governmental and various areas of academics in search of new knowledge. The purpose of R&D is to expand human understanding and to improve our society as a whole.

Renewable energy resources such as solar, wind, biomass, geothermal, hydrogen and water are consistently replenished at a rate more frequently than they would run out. The Earth intercepts approximately 173,000 terawatts per day, which is 10,000 times more than used by the entire Earth (Komp 2016). Obviously, there are several benefits to the development of resources to take advantages of renewable energy. According to Richardson (2018), by 2016, solar panels were present in outer space and could be seen powering office buildings, residential homes, and airplanes. Recently, the automotive electric manufacturer, Tesla, has developed a solar roof that serves as a full replacement roof for homes.

Apparently, the progresses achieved in understanding how to reap and employ renewable energy has motivated the energy industry to research new potential benefits each stakeholder may receive. Moreover, the objective for renewable energy research provides a way to lower cost and preserve nonrenewable resources such as, oil, coal, natural gas and nuclear is a tremendous goal. Tesla's solar roof is proof of members in the industry implementing these advancements to existing products. In addition, questions arise asking if the advancements are provide a significant advantage over current technology. For instance, what are the differences and benefits of the current generic solar panels model verses the Tesla solar roof? According to Tarbi (2018), Tesla's roof is a combination of

non-solar and solar-enabled glass tiles, while the current solar roof product uses panels that extend above the home's roof. Tesla's roof is a new product that provides a real roof appearance through its sophisticated design that gives the home a desirable appearance (Tarbi 2018). Tarbi includes that switching to Tesla's solar roof is not worth the premium if the customer desires to save on cost. However, he states, "if your current roof is coming up on the end of its useful life, then Tesla's solar roof may make more financial sense" (1). Therefore, this example of implementing renewable energy has several benefits.

Furthermore, a couple more things may come to mind when analyzing this industry. For instance, renewable energy efficiency, enhancement of performance capabilities and an increase in technological resources are all components of most corporate systems that forward thinking business strive to improve. As a result, many initiatives has begun to seek the benefits of renewable energy. Thus, the real question is how do we go from using standard solar panels stacked on rooftops to a replacement Tesla solar roof? The answer is through R&D. Research and development was the vehicle used to drive innovation and improvements to solar technology to produce the solar panels and eventually to produce a solar roof.

There is a demand for renewable energy R&D projects in the Department of Defense (DoD), specifically in the Navy (Snyder and Antkowiak 2010). The development of these projects occurs at all levels of complexity. Snyder explains that as a result from the push for more R&D, many projects are given to small teams or individuals who never receive the proper attention required to ensure R&D goals are satisfied. Also, these projects often experience a lack of quality project management and requirements realization tracking. Thus, there is a gap of continuity from proper experience being involved in each project. This lack of experience can be mitigated through the use of systems engineering (SE). SE is "intended to be a disciplined process to establish needs, capabilities, and requirements that help guide the development of evolutionary and revolutionary technologies and help focus associated R&D activities" (Price et al. 2013, 207–208). This tool affords a method of notifying senior management of what needs to be accomplished.

Snyder and Antkowiak (2010) stated that the issue presented here is the fact that R&D teams generally are unfamiliar with using systems engineering activities to achieve

their goals. He also said, “the R&D activities are mostly oriented toward technology development and refinement rather than toward development of a specific deployable system” (3). While classical systems engineering (SE) activities should be applicable in some degree throughout the entire system life cycle, Snyder explains that with respect to the systems engineering “V,” R&D lacks the phases conducted at the bottom of the “V.” Which is portion of the “V,” where the component design and testing are performed.

Additionally, many other benefits come as a result when applying systems engineering principles for any project. The SE principles provide guidance for which activities to perform to ensure both the quality of work and project success. The concept of performing SE activities to ensure success are deeply rooted in the processes for development and refinement of products produced in many successful businesses, from the civilian automobile manufacturer Toyota to the National Aeronautics and Space Administration (NASA). The high level of risk to human life that exists when a failure occurs in both organizations requires a high level of traceability in the design disciplines and mitigation to minimize the level of ambiguity. Hence, some of the benefits of utilizing SE activities can provide better products to the customer, reduced design time for the developers, improved reliability, and enhanced transparency in the decision-making processes.

Moreover, any industry stands to gain similar benefits when properly implementing the SE activities concept to achieve their objectives. Therefore, the focus of this thesis is to highlight how the concept of using SE activities was performed through the development phase in a renewable energy-related R&D project. In addition, it aims to propose a proof of this concept through a confidence-tracking tool that could have been used during that particular project.

B. OBJECTIVES

The primary research question for this project was this: How would an SE requirements confidence-tracking tool be useful in R&D projects? The goal of this project was to show how such a software tool could be used as a supplemental tool for addressing the steps in the SE process. This tool is based on a version of such a spreadsheet previously

used by my thesis advisor on a past Navy acquisition project. Additionally, to demonstrate how the tool can identify requirements not seen by the stakeholders, I established initial confidence in selecting the proper requirements and displaying the real-time confidence in the development process from the start and throughout any R&D project. To demonstrate the usefulness of the assessment spreadsheet tool, it was applied to an energy-related R&D project completed in October of 2015. The goal is to show how this tool would have been implemented had such a tool existed before the start of the project. In addition, the benefits of using the tool before the start of this particular R&D project are identified throughout this report. The result will show how this confidence assessment spreadsheet is a software tool that aims to answer the need for an easier and more effective way to ensure the success of any R&D Project.

C. ORGANIZATION

In the first chapter, the focus shifts to the benefit of the study. There is a discussion on how this tool would also provide more traceability of the production pace of projects. Chapter II covers the following (1) review of the literature, which provides insight into the use of SE in R&D from supporting research. (2) Develops an understanding of the state of mind R&D teams operating while going through each R&D phase. Lastly, Chapter II explains how their developmental phases were included to identify the key factors and processes for designing the SE tool for proof of concept. Chapter III provides a proof of concept of the analysis of the framework of the NPS R&D project used. Following is a summary of the previously collected interview data about the NPS R&D project. Moreover, the detailed analysis of the interview displays the results of the search for the following SE methods of design. This analysis provides the information to modify the generic spreadsheet to reflect the factors, processes, and policies that are specific to the NPS R&D project. Following that is a detailed explanation providing how an SE requirements confidence-tracking tool would be useful in R&D projects. Chapter IV provides a conclusion and summary of results in which the answer to the research question is given. Additionally, a list of future research explains what a new researcher can do to continue the work.

II. LITERATURE REVIEW

To develop a basis for the value in using a systems engineering process to create the SE spreadsheet tool, it is important to know how SE is used in general. According to the International Council on Systems Engineering (INCOSE), the purpose of systems engineering is to begin the development cycle by defining customer needs, ideal functionality and recording requirements. From there, researchers can begin designing the system while having a greater understanding of the entire picture (International Council on Systems Engineering [INCOSE] 2018). The focus in systems engineering is to help mitigate issues and increase project success (INCOSE 2018). In addition, there are several studies supporting those benefits received from using the SE process.

When exploring the R&D process for renewable energy environment, it is best to begin with the definition for R&D. R&D is the studies and tests that are done to design new or improved products (*Merriam-Webster* 2018). When examining the research and development process in the renewable energy environment, Snyder and Antkowiak (2010) said, “the work is being conducted in a culture that is generally unfamiliar with systems engineering” (1). Instead of figuring out a precise deployable system, the R&D activities are typically concerned with developing a particular type of technology (Snyder and Antkowiak 2010).

For example, the fact that there is not a physical object or metrics to determine what success looks like makes developing system requirements for renewable energy projects very difficult (Snyder and Antkowiak 2010). Therefore, in order to improve the project management goals of the R&D process in renewable energy, significant tailoring of the SE process is required (Snyder and Antkowiak 2010). Additionally, Snyder and Antkowiak (2010) notes that there are many benefits that come from addressing unknowns during the beginning of development through using more detailed simulation methods. Hence, this literature review provides a synthesis of the literature expressing the cases for the reasoning behind these two paradigms.

One example of such a study was conducted by Price et al (2013) regarding applying the principles of systems engineering to prioritizing sustainable nuclear fuel cycle options. In his paper, he asserts that using the systems engineering approach accomplishes the objective of clearly outlining and justifying the necessary work done on research and development necessary to “deploy sustainable fuel cycle technologies for a given set of national policy objectives,” (205). Price uses systems engineering with the intent to identify needs, abilities, and necessities to shape expansion or creation of new technologies and focus R&D activities.

Price et al. (2013) illustrates a model of the systems engineering process, which he breaks down into seven steps:

(1) Define and understand the objectives, (2) define what the system must do, i.e., its functions, (3) specify requirements and evaluation criteria that provide measures for determining “how well” a system achieves objectives, (4) develop a set of alternative systems and related architectures, (5) evaluate each alternative relative to the criteria, (6) identify those alternatives that best meet objectives and those that do not, and (7) verify that the evaluations and assessment of alternatives meet requirements and criteria. (207)

The steps outlined above are reinforced by supplementary organization activities, which are (1) technical integration, (2) interface control, and (3) risk management (Price et al. 2013).

Price concludes his study by showing how using the correct systems engineering principles allows his specific program to quickly and easily adapt to any changes in policy or relative importance that should occur in the future.

A different study, conducted by Rhodes, Valerdi and Roedler (2008), focused on systems engineering leading indicators to assess technical and program effectiveness. Rhodes, Valerdi and Roedler defines leading indicators as procedures to appraise how effective systems engineering activities are on programs in a way that shows material describing the system’s performance goals are likely to be affected. Rhodes, Valerdi and Roedler states leading indicators are intended to give insight into what is likely to occur in the future, which gives projects the opportunity to mitigate issues before they may arise.

The purpose of Rhodes' research is to give the baseline for further research on how to create a larger comprehension of the best way to start and use leading indicators in the context of a specific program.

Additionally, Rhodes, Valerdi and Roedler discusses how leading indicators are envisioned to give leadership assistance in providing value to customers and end users while also eliminating any squandered effort. Leading indicators tend to rely on trend information that allows the ability to predict future outcomes. Rhodes, Valerdi and Roedler states this can sometimes lead to pitfalls in interpretation, as data collection is very time consuming, and not necessarily effective in situations where there is little historical information on which one can base these trends.

Lastly, a study conducted by White, Lacy, and O'Hair (1996) was done on another process called the requirements definition. White, Lacy, and O'Hair's study focuses on refining the requirements definition (RD) concept in system development. White, Lacy, and O'Hair says this is imperative when it comes to making processes and efficiency better, as describing this work as a time consuming and perplexing task. White, Lacy, and O'Hair further documents these as serious issues within the RD concept and states there are several instances where defining the RD was unsuccessful due to these issues. This study provides an example of a mismanaged systems engineering process that leads to the downfall of several projects.

Reviewing the literature has proven there is a need for a system engineering spreadsheet tool. To illustrate this point, following is a brief review of the Department of Energy (DOE) stance on developing new products, when and why the DOE incorporated the full Systems Engineering and Program Integration offices (SEPIO) or ignored the SE process altogether. Finally, it explains how the literature influenced this project in articulating the tie-in of the benefits from the spreadsheet tool.

First, the DOE is one of many developers that have too many projects that are underway despite the understanding of the value of the SE process. The responsibility of the DOE and many other developers to produce quality products for customers promptly is a vital duty.

The DOE expressed a great need to invest in new projects to remain among the leading originations for renewable energy. The DOE provides an example of a leader in technology developing products under the paradigm of ignoring the need for an SE process. For instance, the U.S. Navy considers current systems conventional in comparison to the pace at which the technology of the world is changing. Hence, it has been determined as a necessity to invest resources in the development of renewable energy sources (Snyder and Antkowiak 2010). The DOE has subset offices: the Office of National Renewable Energy Laboratory (NREL) and Office of Energy Efficiency and Renewable Energy (EERE). NREL has assigned the SEPIO to work with EERE to develop new methods to become more energy efficient and improve the budget with current products available (Snyder and Antkowiak 2010). While this effort promotes innovation in renewable energy, it has produced some projects that disregarded the proper use of the classical SE process for developing new products. Thus, proper use of the SE process begins with an analysis of the project from the conception and develops a plan to the mothball phase (Blanchard and Fabrycky 2011). In the beginning, a detailed requirements analysis is conducted and defined to ensure the new system is designed to achieve the stakeholder needs and fill a capability gap. Conducting business in the way the DOE has assigned to EERE may lead to more budgets problems, insignificant improvements in energy use, or missing the target altogether (White, Lacy, and O’Hair 1996). This issue leaves the responsibility of defining its benefits to the users and more rework for the systems engineer.

There are numerous cases showing the lack of using SE processes is the leading cause of failure in projects. It is important to note that no matter how well designed the process; any poorly managed project has the potential to fail regardless of its assumed simplicity. Hence, even an ill-managed SE process is likely to lack proper identification of requirements for the system (Rhodes, Valerdi and Roedler2008). Thus, amongst the two, there are philosophies of the benefits of the SE process. The other, more proven philosophy reinforces the importance of using the SE process to design an appropriate system, which not only achieves the requirements but also achieves desires that may not be apparent to the stakeholder at the time of conception (Moses 2004). The SE process utilizes best

practices, allows innovative means to be implemented, life cycle events to be addressed, and gives the appropriate attention to the disposal or sequestration of the system.

There are numerous examples throughout history showing when people want anything fast, the likelihood of receiving a good design product lowers. Examining the auto industry, one can see several examples of this paradigm failing to yield positive results. For that reason, this SE confidence-tracking tool provides the busy developers an easy and systematic approach to reduce the risk of not achieving R&D goals by aiding in and identifying and tracking SE requirements throughout the duration of any R&D project. Thus, making a systems-engineering version of the spreadsheet described in this thesis has great potential, when used correctly, to be an asset for R&D designers and systems engineers in rushed projects assigned from the DOE. In addition, this thesis demonstrates how the SE version of the Manpower spreadsheet tool verifies, tracks confidence in the established requirements and identifies operational requirements realization by using a recently completed renewable energy-related R&D project. The creation of this confidence-tracking tool will be discussed more in depth in the following chapter.

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III. PROOF OF CONCEPT

A. SYSTEMS VIEW

To understand the motivation for the SE tracking tool and its development, one must first understand the NPS renewable energy R&D project that was examined. Hawxhurst (2016) describes the system as an Integrated Multi-Physics Renewable Energy Laboratory (IMPREL). He further explains the IMPREL energy system as an experiment focused on using renewable energy to demonstrate a different method of generating, storing, and transporting energy (5). The system is located in the Gas Dynamics Laboratory at the Navy Research Lab (NRL) in building 216 near the Monterey Regional Airport. This location provided the opportunity to prove the usefulness of the system for developing safe and cheap energy, cooling and heating storage. Additionally, the IMPREL system used a wind turbine as its renewable energy source that fed power into the microgrid system to reduce cost of operation and power dependency from a larger intergraded Macro-grid system, providing thermal storage to the facility when necessary, thereby increasing overall energy efficiency of the Macro-grid system by utilizing renewable energy sources for power generation more effectively.

A representation of the systems concept is shown in Figure 1.

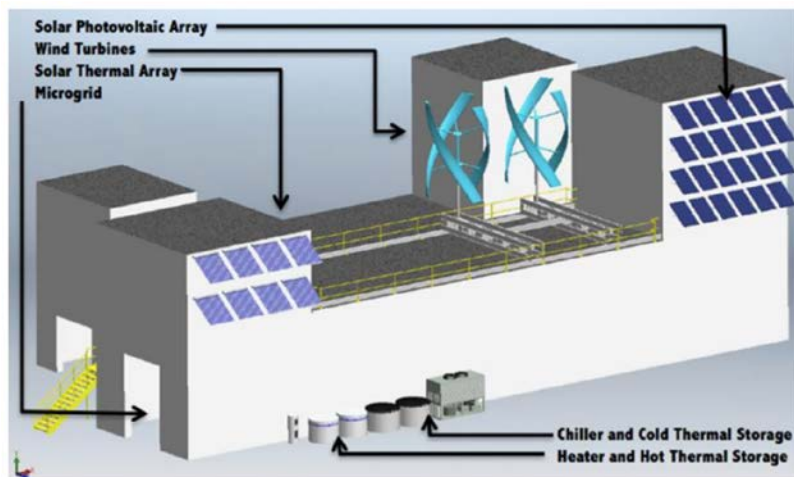


Figure 1. IMPREL System Design Concept. Source: Hawxhurst (2016).

The concept in Figure 1 displays a unit that focuses on using wind and solar power as its renewable energy source. The design uses a thermal storage system to mitigate wind intermittency by using ice storage, which is \$33 per kilowatt-hour (KWh) versus the current \$150 per KWh required when batteries are used. Thus, this proposed control strategy aims to provide load-matching power demands to power generation. Additional storage for excess power generation in a battery bank for electrical services and thermal storage devices for heating and cooling services.

B. SUMMARY OF INTERVIEW

This thesis used interview data previously collected by Dr. Karen Holness and Gary Parker in March 2017. The interview was broken into two separate parts. The first part asked questions to the Principal Investigator (PI) of the IMPREL R&D project to describe activities related to the past execution of the project, such as the system hardware and software (HW/SW) capabilities, system configurations and the R&D goals of the project. These questions served as insight for identifying system capability requirements and a detailed review of the factors, policies, and processes required for successful execution of the project.

The second part of the interview focused on the installation activities described for the project. The key researcher addressed various factors that affected the ability to achieve their project goals. For each applicable factor that had an impact on completing the activities, he described the particulars regarding the impact. Additionally, the PI spoke about the confidence level of the impact each factor had on the project and if it could be mitigated or eliminated. Additionally, the PI provided a rating for the degree of confidence the team had while completing the activity using a scale of one equals low impact and five equals high impact.

The responses from the interview state that wind is the renewable power source used to power a chiller system and to use ice tanks for thermal storage. Additionally, the interview identified some activities that influenced which factors, task, policy, and processes were addressed. Therefore, Figure 2 illustrates the systems view and configuration of the interview results conducted in March 2017.

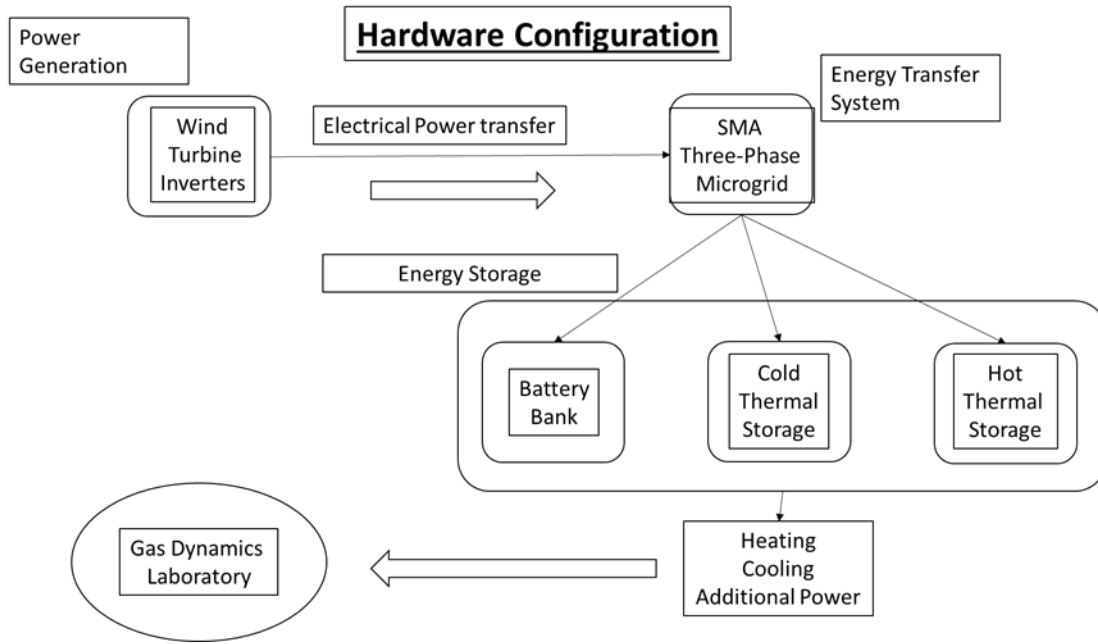


Figure 2. Systems View of the Renewable Energy R&D Project

Figure 2 is an illustration of the configuration for the renewable energy system and the incorporation of each sub-system. This configuration is similar to the system concept described earlier. However, the following description is a depiction of the configuration from the interview. Beginning from the top left corner with power generation phase on the configuration are the wind turbines - wind is the renewable energy source used to generate power for this configuration. Next, the electrical power transfer phase, where electricity is transferred from the wind turbine to the distribution phase, which is a three-phase electric microgrid system (Hawxhurst 2016). The microgrid coordinates the generated power to the appropriate source and transfers the power to the appropriate load as necessary. Next is the storage phase, which stores unused energy from the microgrid (18). The unallocated energy divides among one of three storage systems - the battery bank for either electrical storage; the chiller for cooling and storage; or the thermal storage unit for heating. Standby electrical power is retrieved from the battery bank and supplied to the microgrid system when the renewable energy power source is too low to generate electricity (19). Thermal energy storage takes heat generated from the electrical energy transfer and exchanges it into thermal storage to apply thermal energy when needed (23).

During the interview, the PI also described the processes the R&D team used to achieve their R&D goals. He stated systems thinking used for taking systems that were established for other purposes versus looking at developing entirely new methods to produce the microgrid. Following the decision to use commercial-off-the-shelf (COTS) products, the PI expressed the team-developed objectives, requirements, architecture, and approach for developing the IMPREL microgrid.

The primary installation activities were acquiring and incorporating the appropriate microgrid, handrails, chillers, wind turbines, ethylene glycol management, control system, battery bank and thermal storage units.

C. STRUCTURE OF THE ORIGINAL CONFIDENCE TRACKING SPREADSHEET

The original spreadsheet used on the previous Navy acquisition project was comprised of the following tab sheets:

- **Instructions:** explains how to use the tool. It also describes how to modify the tool if necessary to fit an additional row to ensure the proper formulas are present.
- **Definitions:** provides detailed explanations of the terminology and components of the confidence tracking and scoring mechanisms.
- **Sample calculations:** demonstrate how the tool calculates a confidence score for each configuration change factor, entered into the spreadsheet. It shows how each output column equation is weighted and calculated and provides a red, yellow and green colored chart that represents the relationship of the impact rating with the corresponding confidence rating. Figure 3 shows a full-screen snapshot of the Sample Calculations Tab is provided.

- Confidence summary: all the data summarized from the primary data tables in the spreadsheet: Technology Changes and Process Policy Changes, which are described in more detail later. The data collected in the confidence summary table is then taken to report the confidence findings via three color-coded percentage pie charts. These charts are used to illustrate the confidence of the decision makers had at a particular moment that their goal could be achieved for risk analysis purposes.
- Graphs and charts: the confidence score pie charts are created using the data from the Confidence Summary tab.
- Technology Changes: tab is comprised of 15 columns to address the impacting categories changing technology. This is where data is entered for each change enabler category, type of change, the status of change for system X, completion of change, level of uncertainty of change, impact score and HW/SW Technology Readiness Level TRL.
- Process Policy Changes: tab had the same basic structure as the Technology Changes tab. However, only process and policy factors were entered; no TRL data was entered.
- Definition score master and color code master: tabs contained the data tables and functions to support the operation of the Technology Changes, Process Policy Changes, and Graphs and Charts tab. If the user desired to change the terminology to describe a ranking option, but did not want to change the preceding confidence calculation, then the definition master sheet is where this activity is performed.

The data collected in the confidence summary table is then taken to report the confidence findings via three color-coded percentage pie charts. These charts are used to illustrate the confidence of the decision makers had at a particular moment that their goal could be achieved for risk analysis purposes.

This section explained how the original spreadsheet generated a confidence score per technology, process and policy factor. The following section discusses the modification of the original tool to address the concerns for IMPREL R&D project. Also, a description of what and why changes were made from the original tool is provided.

D. SPREADSHEET CREATED FOR THE IMPREL PROJECT

The original spreadsheet version served as the basis for the SE version. There were numerous changes made to address and identify SE process activities for this particular R&D project. The process to change was an iterative process to ensure the tool reflects the most accurate SE activities expressed in the interview data. The changes to the original version were completed in four stages of review. First, a thorough review of the version provided was conducted to establish a strategy for mapping the SE principles. Second, identify exactly what to modify, delete and add from the original spreadsheet. The original version was constructed without purposeful consideration to use systems thinking or approach because it focused on Manpower, so in order to serve as desired the terminology was written to reflect the application of SE principles.

Additionally, this step required modifications to capture general R&D activities applied identified in the interview. Thirdly, a detailed review was done to understand the math and reasoning used to formulate the calculation for each of the individual confidence scores. Also, the combined summary scores and pie charts that display the summary were reviewed. The final stage was to review the entire tool to identify any other necessary changes to verify any SE logic used during the previous stages was implemented correctly, and as intended, so it could be a useful SE tool.

The SE spreadsheet serves as a supplement for the absence of the appropriate resources for a robust SE team or department for individuals and small teams in R&D. The benefit of this tool is to track the developmental process, provide a confidence metric for each project management factor, and illustrate a total confidence summary via a color-coded pie chart. Furthermore, this tool has the potential to help the R&D team with realizing additional operational requirements. To demonstrate the application of the SE

tool, this section of the paper offers the results from two snapshots in the R&D timeline of how the use of this tool could appear.

For this demonstration, analysis of the interview data from the microgrid renewable energy system provides the impact, status of completion, and uncertainty levels of each factor in the early and later phases that influenced R&D efforts. The early phase snapshot primarily focuses on identifying technology factors and activities, planning processes, systems architecture, requirements realization and other efforts that are required in the early stages of any R&D project. Consequently, the early phase had many factors identified and planned but not started with higher factor uncertainty levels, which represents an undeveloped system. Following, the later phase snapshot primary focus is to show how the SE tool could appear when the R&D team was three-quarters complete with the developmental process. The only changes made in this phase are reflective of the impact ranking, TRL's, status of completion and factor uncertainty levels. Accordingly, this phase depicts a partially complete system. Table 1 through Table 5 illustrates a snapshot of the first five factors from of the Technology Factor Tab in the early phase spreadsheet. For the full early phase Technology Factor table and the associated Process Policy table, see Appendix A.

Table 1. Early Phase TB1 - TB5 Snapshot of Factor Category, Type, Completion Evidence and Impact Level

Technology / Budget Factor #	Task/Activity	Factor Category	Type of Factor	Completion Evidence (What we track)	Impact of Factor to the Microgrid development or implementation
TB1	Ethylene Glycol (HAZMAT) Management	Technology	Hardware/Software design change	Type of Chiller Identified	4. Moderate/High Impact
TB2	Handrail Identification	Technology	R&D Goals Impact	Type of Handrails Identified	1. Low Impact
TB3	Acquiring Handrails	Budget	Cost & Schedule	Arrival of Handrails	2. Low/Moderate Impact
TB4	Handrail Instillation	Technology	Site & Lab Impact	Installed Handrails	4. Moderate/High Impact
TB5	Thermal Storage Unit Identification	Technology	R&D Goals Impact	Type of Thermal Storage Identified	1. Low Impact (Other elements Impacted)

Factor TB5, Thermal Storage Unit Identification, is the particular line item used as an example to explain and show how the user could fill in each category. In Table 1, TB5 Thermal Storage Unit Identification is a part of the technology influence on this project, so it was categorized as technology. The definition used to address completion for this line item is actually the Thermal Storage Unit on site ready for installation. This step is important to address because it was necessary to identify one that met the performances needs of the project. I the impact level 1 was selected because the PI stated his confidence in achieving this task was low due to knowing the technology exist, very mature with several options available. Thus, identifying the desired thermal storage unit is an elementary level task.

Table 2 contains a description of the TRL ranking and explains the justification for selecting a level of 8. Level 8 was chosen because of the confidence expressed by the PI in knowing the technology existed and understood how it is implemented for commercial use.

Table 3 described the status as being in progress but off schedule because despite being familiar with the technology, the PI expressed a bit of difficulty with finding a Thermal Storage Unit with the performance needs of this particular R&D project. Moreover, the PI stated a level of 3 out of 5 of confidence with being able to modify the existing technology to support their R&D project objectives.

Finally, Table 4 illustrates the collective summary of the unweighted Impact, Confidence and Impact, Status and Uncertainty score and color codes provided from the levels provided by the interview data. Overall, the confidence scores represent the R&D team was not confident is themselves in achieving the desired objectives early in the developmental phase. For example, TB5 shows the confidence and impact color-code as yellow-green. Which reflects the team knows the technology exists and is used in real-world activities, but did not have the confidence that identifying the thermal storage unit was definitely going to happen.

Table 2. Early Phase TB1 - TB5 Snapshot of TRL and TRL Justification

Technology / Budget Factor #	Task/Activity	TRL Level of Hardware/Software Design Change for the Microgrid	TRL Justification
TB1	Ethylene Glycol (HAZMAT) Management	8. Actual system completed and qualified through test and demonstration (For SW, also mission qualified in an operational environment)	Commercial Off The Shelf (COTS) equipment
TB2	Handrail Identification	9. Actual system proven through successful mission operations	Commercial Off The Shelf (COTS) equipment
TB3	Acquiring Handrails	8. Actual system completed and qualified through test and demonstration (For SW, also mission qualified in an operational environment)	Commercial Off The Shelf (COTS) equipment
TB4	Handrail Instillation	8. Actual system completed and qualified through test and demonstration (For SW, also mission qualified in an operational environment)	Commercial Off The Shelf (COTS) equipment
TB5	Thermal Storage Unit Identification	8. Actual system completed and qualified through test and demonstration (For SW, also mission qualified in an operational environment)	Commercial Off The Shelf (COTS) equipment

Table 3. Early Phase TB1 - TB5 Snapshot of Factor Status and Uncertainty Level

Technology / Budget Factor #	Task/Activity	Status of Factor (On target to complete TARGET DATE or MILESTONE (TBD))	Status Justification	Factor Uncertainty	Uncertainty Justification
TB1	Ethylene Glycol (HAZMAT) Management	1. Not Started/Planned	The PI planned for a hazmat evaluation	4. Low/Moderate Uncertainty	Because the chiller and thermal storage requires hazardous material regardless of application
TB2	Handrail Identification	1. Not Started/Planned	Beginning of R&D Project	5. Low Uncertainty	Current component Capability implemented real world use
TB3	Acquiring Handrails	1. Not Started/Planned	Beginning of R&D Project	5. Low Uncertainty	Current component Capability implemented real world use
TB4	Handrail Instillation	3. In Progress (On Schedule)	In the planning phase	3. Moderate Uncertainty	Current component implemented in Real World use
TB5	Thermal Storage Unit Identification	2. In Progress (Off Schedule)	Beginning of R&D Project	3. Moderate Uncertainty	Despite the technology being available more research was required to support the larger operational cycle of 72 Hr. vs. 24 Hr.

Table 4. Early Phase TB1 - TB5 Snapshot of Unweighted Impact, Confidence and Impact, Status and Uncertainty Scores and Color Codes

Technology / Budget Factor #	Task/Activity	Impact Score (Low = Good)	Confidence and Impact Score	Change Status Score	Uncertainty Score
TB1	Ethylene Glycol (HAZMAT) Management	4	Red Yellow	1	4
TB2	Handrail Identification	1	Yellow Green	1	5
TB3	Acquiring Handrails	2	Yellow Green	1	5
TB4	Handrail Instillation	4	Yellow	3	3
TB5	Thermal Storage Unit Identification	1	Yellow Green	2	3

Table 5. Early Phase TB1 - TB5 Snapshot of Weighted Impact, Confidence and Impact, Status and Uncertainty Scores and Color Codes

Technology / Budget Factor #	Task/Activity	Status Weighted Score	Uncertainty Weighted Score	Confidence Score % (against best possible)	Confidence Range Score (High = Good)	Impact Score (Low = Good)	Confidence & Impact Score
TB1	Ethylene Glycol (HAZMAT) Management	10	40	56	3	4	Red Yellow
TB2	Handrail Identification	10	50	67	4	1	Yellow Green
TB3	Acquiring Handrails	10	50	67	4	2	Yellow Green
TB4	Handrail Installation	30	30	67	4	4	Yellow
TB5	Thermal Storage Unit Identification	20	30	56	3	1	Yellow Green

In Table 5, TB5, the Thermal Storage Unit Identification, shows a snapshot of the weighted score and the color code for the Impact, Confidence & Impact, Status and Uncertainty levels. The weighting value is arbitrarily selected, and it is 10. The confidence scores are based on the confidence calculation and the associated color code. Using Equation 1, the confidence score calculation is:

Equation 1: Status Weighted Score = status score * status weight

Uncertainty Weighted Score = uncertainty score * uncertainty weight

Then, Confidence Score Totals = score total/best total

$$2(10) + 3(10) = 50\%$$

$$50\% \div 90 = 55.556\% = 57\%$$

The corresponding color code is yellow-green, which means the PI's description provided enough information to calculate he was confident that identifying the Thermal Storage Unit was low. For more details on the color coding process, see "Sample Calculation" tab in Appendix A.

Once each factor was analyzed individually to calculate a confidence score and color code, the confidence scores were collected in the "Confidence Summary" tab. The values were shown as a collective color code and divided up by percentages that were reflected in three separate charts in the "Graphs and Charts" tab (See Appendix A for the confidence summary table for both phases). Hence, there are three-color code charts, which depict individual percentages for technology factors, process policy factors, and all factors combined; Figures 4, 5, and 6 illustrate these three charts respectively for the early phase. See Appendix B for the charts from the later phase.

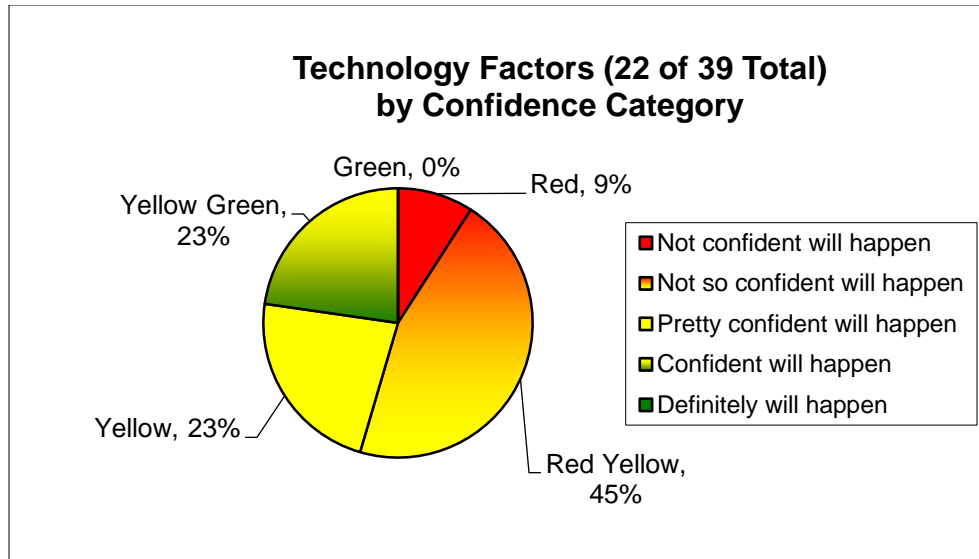


Figure 4. Early Phase Technology Factor Confidence Score Percentages

Figure 4 is a pie chart that provides information about the confidence summary of the 22 technology factors for the R&D project percentages along with color-coded categories for early in the development phase. Largely, in the earlier period of development, the team's confidence in completing the technology requirements was very low and believed they would not happen. In addition, despite the TRL for the larger components being high, the team did not believe any technology factor definitely was going to be achieved. Red Yellow is the largest sector describing the team believed 45 percent of the technology factors were not so confident those factors would happen. While the team was confident that 23 percent of the technical factors would happen. Overall, it is clear that the R&D team had a low amount of confidence in the ability to achieve technology requirements.

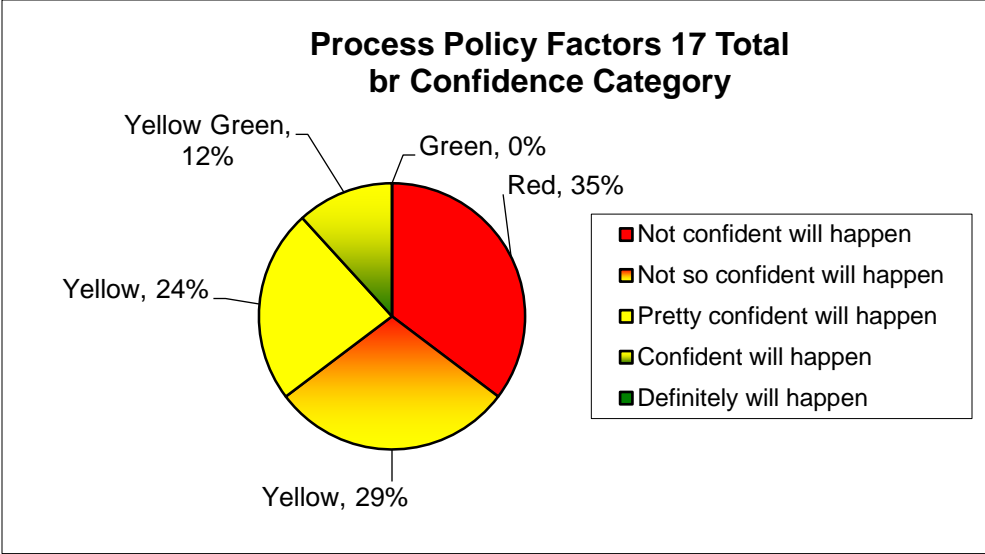


Figure 5. Early Phase Process Policy Factor Confidence Score Percentages

Figure 5 is a pie chart illustrating information about the confidence summary of the 17 process and policy factors for the R&D project percentages along with color-coded categories for early in the development phase. Similar to the technology pie chart, this chart reflects the earlier period of development the team’s confidence in completing the process and policy requirements were very low and believed they would not happen either. The lack of confidence is large because the teams needed to develop the processes because R&D projects require a significant effort towards innovation. Thus, Red is the largest sector describing the team believed 35 percent of the process and policy factors were not confident those factors would happen. While 12 percent of the process and policy factors are, Yellow Green, which the team was confident developing them would happen. Overall, it is clear that initially the R&D team had a very low amount of confidence in their ability to achieve the process and policy factors.

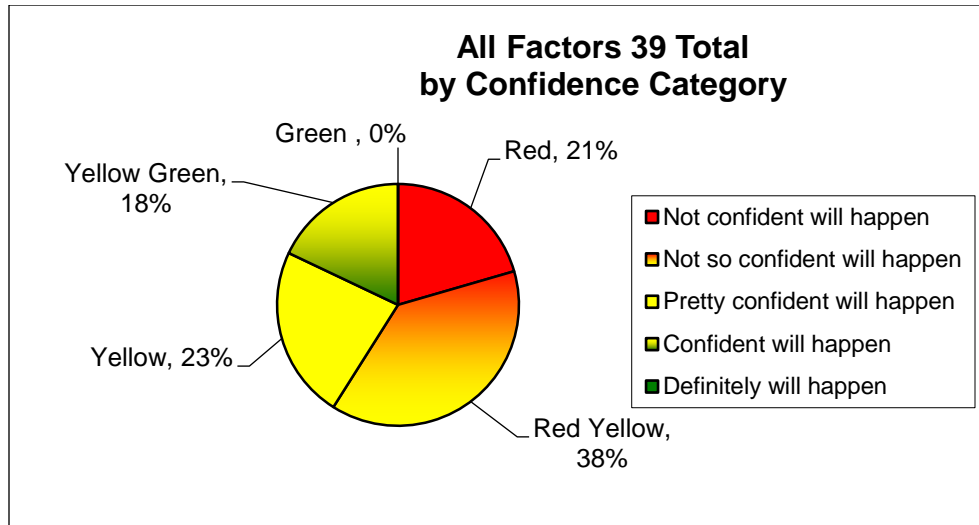


Figure 6. Early Phase Confidence Summary of All Factors

Figure 6 is a pie chart that displays information about the confidence summary of both the technology, process and policy factors for the R&D project percentages along with color-coded categories for early in the development phase. Similar to the previous two pie charts, this chart reflects the earlier period in the development phase where the team's confidence in achieving the required factors was low and believed some factors was in risk of not happening. Overall, Red Yellow is the largest sector describing the team was not so confident in 38 percent of all factors would happen. While 18 percent of the all the factors are, Yellow Green, which the team was confident developing them would happen. To summarize the reason for the low confidence displayed by the R&D team is largely due to the early phase requiring a number of planning tasks, requirement identification, securing contracts for specific jobs and modifying technology to produce the desired results.

The next two tables show a snapshot of the spreadsheet for the technology, process, and policy tabs respectively to serve as examples of how each factor could change throughout the course of the project. These two tables were compiled using the interview data, and the significant increase in confidence made in the later phase reflects the R&D projects successful integration and installation.

Table 6 displays both the status and factor uncertainty level improved later in the development period. Additionally, this snapshot demonstrates how the first five technology factors improved over time according to the interview data. Using TB5 again as an example notice the status changed from in progress but, off schedule in Table 3 to completed/implemented in Table 6. Along with the factor, uncertainty changed to low uncertainty whereas in Table 3 TB5 had a moderate uncertainty level. Table 6 shows the team's confidence increased as the R&D project grew closer to the end.

Table 7 shows a later phase snapshot of the first five processes and policy factors. Using PP5 as an example to show the changes made to the status and uncertainty levels, shows the team grew in confidence with fulfilling the process and policy factors. For the full listing of factors from the technology and process policy tabs from the later phase spreadsheet, see Appendix B. Figure 7 exemplifies what the confidence summary for all factors in the later phase of the R&D project.

Table 6. Later Phase Technology Status and Factor Uncertainty Levels

Technology / Budget Factor #	Task/Activity	Status of Factor (On target to complete TARGET DATE or MILESTONE (TBD))	Status Justification	Factor Uncertainty	Uncertainty Justification
TB1	Ethylene Glycol (HAZMAT) Management	3. In Progress (On Schedule)	The chiller and thermal are installed and not fully operational due to programming issues	5. Low Uncertainty	Resolved HAZMAT Plan
TB2	Handrail Identification	4. Completed/Implemented	Type of Handrails Identified	5. Low Uncertainty	Current component implemented in Real World use
TB3	Acquiring Handrails	4. Completed/Implemented	Arrival of Handrails	5. Low Uncertainty	Handrails are Installed
TB4	Handrail Instillation	4. Completed/Implemented	Handrails are identified and installed	5. Low Uncertainty	Handrails are Installed
TB5	Thermal Storage Unit Identification	4. Completed/Implemented	Thermal storage selected and acquired	5. Low Uncertainty	Thermal storage unit selected

Table 7. Later Phase Process and Policy Status and Factor Uncertainty Levels

Process/ Policy #	Process / Policy Description	Status of Process / Policy implementation (On target to complete TARGET DATE or MILESTONE (TBD))	Status Justification	Uncertainty level	Uncertainty Justification
PP1	Create system/design architecture diagram(s)	4. Completed/Implemented	Approved diagrams with best possible configuration	5. Low Uncertainty	Established procedures, adequate resources and qualified personnel in place to complete the task
PP2	Planning the physical integration process	4. Completed/Implemented	Approved plan	5. Low Uncertainty	The components selected have high tech maturity
PP3	Coordinating the contractors to install the major components (Chiller, Wind Turbine, Microgrid and Thermal Storage)	4. Completed/Implemented	Installation/Integration schedule with sequence of contractor work	5. Low Uncertainty	Contractors identified are competent
PP4	Researching the best chiller system to meet the cooling demands.	4. Completed/Implemented	Procurement of Chiller	5. Low Uncertainty	Chiller is on site and perform as expected
PP5	Conducting a HAZMAT evaluation of the ethylene glycol to ensure it meet the safety policy set by NPS's Public works	4. Completed/Implemented	Approved Safety Inspection	5. Low Uncertainty	Public works approves of the use of ethylene glycol

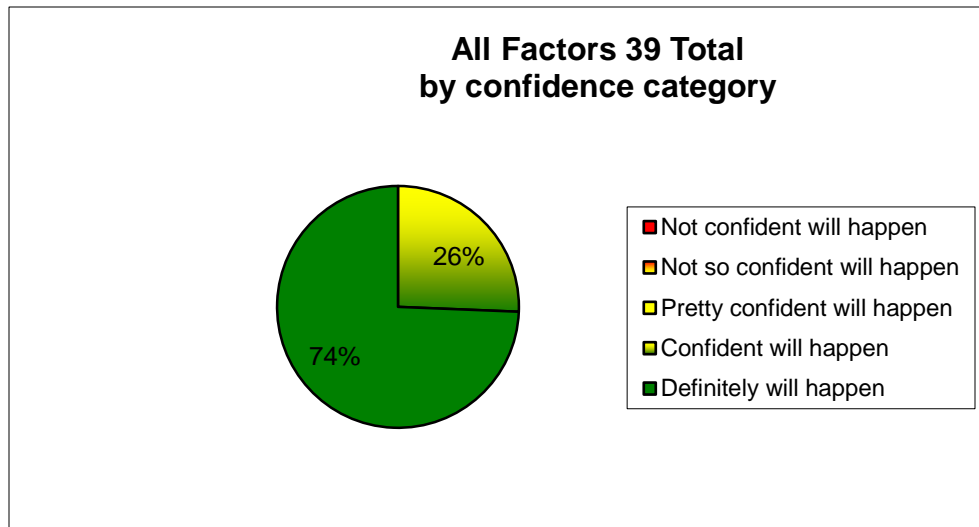


Figure 7. Later Phase Confidence Summary of All Factors

Figure 7 summarizes the team’s confidence for the entire factor listing from both spreadsheets. This phase is a snapshot of approximately at the three-quarters point in a development process. At this time in development, 74 percent of the factors are green which means the R&D team completed more tasks and definitely expected more factor to be achieved.

There were no red factors and the yellow-green makes up the remaining 26 percent of the factors because they are still in progress and on schedule with low or moderately low uncertainty levels. A significant change in color from the early phase to the later phase charts showing a transition from red to more green is indicative of the team gaining confidence and leading to a successful R&D project For more detail, see appendix C for the later phase versions of the technology and the process or policy graphs. In summary, the pie charts and table are proof that this spreadsheet tool can be used to collect and track important SE activities while providing a visual representation that confidence can be tracked and illustrated through a color-coding process.

IV. CONCLUSION

A. SUMMARY OF RESULTS

In summary, examining at the microgrid at two distinct phases illustrates the primary benefit in using this SE confidence tracking and requirements realization tool. Because when looking at the later phase chart in comparison to the early phase chart, there is a significant change in color from red to green. This color change illustrates success, progress, and a decrease in uncertainty, which indicates proof of concept. The more complex the project, other R&D project teams may identify additional factors in the later phase. Additionally, the charts in the figures above are a visual representation that confidence can be tracked and illustrated through color-coding at any point in the development phase.

B. ANSWER TO THE RESEARCH QUESTION

To restate, the research question: “How would an SE requirements confidence-tracking tool be useful in R&D projects?” The tool would provide a relatively simple Excel tool to enable systems engineers, design engineers and other R&D developers to identify requirements and monitor the confidence in the management process and support requirements realization tracking. The intended users are small R&D teams that prefer a less expensive option for project management needs. The tool would also provide more traceability of the production pace of projects. Traceability will build confidence in stakeholders for the R&D project. Additionally, developing this tool in Microsoft Excel offers accessibility for stakeholders at any level in any company during the development process because Microsoft office is a standard software package in the DoD.

C. RECOMMENDATIONS FOR FURTHER RESEARCH

First, the recommendation is to modify the current SE tool to a more generic spreadsheet tool for any R&D project. The version created for this thesis was tailored specifically for the microgrid renewable energy system. Simply applying the tool for another R&D project is likely to lead to factors being overlooked and not identifying all

relevant factors. Factors are unique to every project; however, a future researcher taking a systems approach to identify factors and requirements would lower the risk of misidentification.

The second recommendation is to analyze the tool from a qualitative and quantitative approach to determine if the weights are being applied the best way. Determine if confidence is the most appropriate metric to measure. For instance, the risk could be used in the same manner to develop awareness of the pace of success from R&D teams. Lastly, a review of the equations used to calculate the confidence scores for specific projects is also recommended.

APPENDIX A. EARLIER PHASE SE SPREADSHEET TOOL

Type of Change	Confidence & Impact Score		41	Total			
Hardware/Software design change	Red Yellow			39	Colors	All Factor	
R&D Goals Impact	Yellow Green		Diff	0	Red	Not confident will happen	8
Cost & Schedule	Yellow Green		zero yellow value,		Red Yellow	Not so confident will happen	15
Site & Lab Impact	Yellow		then enter Diff value		Yellow	Pretty confident will happen	9 change this manually
R&D Goals Impact	Yellow Green		for yellow		Yellow Green	Confident will happen	7
Cost & Schedule	Red Yellow				Green	Definitely will happen	0
Hardware/Software design change	Red Yellow		match?		Total		39
R&D Goals Impact	Red Yellow				Graph will update automatically		
Cost & Schedule	Red Yellow						
Hardware/Software design change	Red Yellow				Total		
Hardware/Software design change	Yellow				22	Colors	Technology
Cost & Schedule	Yellow Green		Diff	0	Red	Not confident will happen	2
Hardware/Software design change	Yellow				Red Yellow	Not so confident will happen	10
Hardware/Software design change	Yellow Green				Yellow	Pretty confident will happen	5 change this manually
Cost & Schedule	Red Yellow				Yellow Green	Confident will happen	5
Site & Lab Impact	Yellow				Green	Definitely will happen	0
Site & Lab Impact	Red Yellow		match?		Total		22
Cost & Schedule	Red Yellow						
Site & Lab Impact	Yellow				Total		
Site & Lab Impact	Red				17	Colors	Process Policy
Cost & Schedule	Red Yellow		Diff	0	Red	Not confident will happen	6
Site & Lab Impact	Red				Red Yellow	Not so confident will happen	5
					Yellow	Pretty confident will happen	4 change this manually
					Yellow Green	Confident will happen	2
					Green	Definitely will happen	0
			match?		Total		17
R&D project impact	Yellow						
R&D project impact; System architecture	Yellow						
R&D project impact; Installation/Integration of components	Red Yellow						
R&D project impact; Installation/Integration of components	Yellow Green						
R&D project impact; Installation/Integration of components	Red Yellow						
Site & Lab Impact	Yellow Green						
HW & SW Impact	Yellow						
HW & SW Impact	Red Yellow						
HW & SW Impact	Red Yellow						
R&D project impact; Installation/Integration of components	Red						
R&D project impact; Installation/Integration of components	Yellow						
HW & SW Impact	Red						
HW & SW Impact	Red						
HW & SW Impact	Red Yellow						
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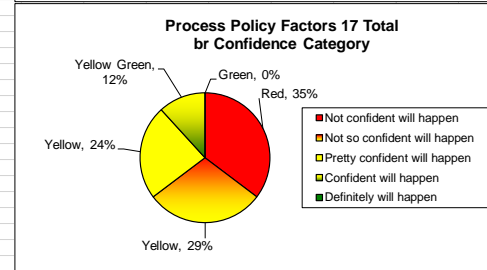
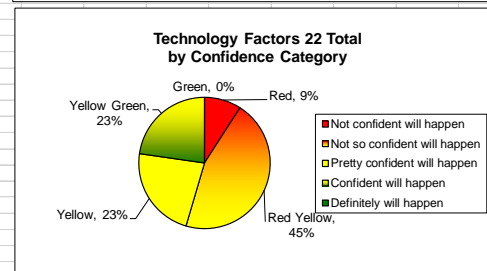
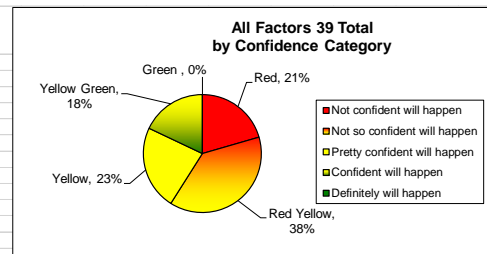


Table 8. Early Phase Technology Factor, Status and Uncertainty Level and Justification

Technology / Budget Factor #	Task/Activity	Status of Factor (On target to complete TARGET DATE or MILESTONE (TBD))	Status Justification	Factor Uncertainty	Uncertainty Justification
TB1	Ethylene Glycol (HAZMAT) Management	1. Not Started/Planned	The PI planned for a hazmat evaluation	4. Low/Moderate Uncertainty	Because the chiller and thermal storage requires hazardous material regardless of application
TB2	Handrail Identification	1. Not Started/Planned	Beginning of R&D Project	5. Low Uncertainty	Current component Capability implemented real world use
TB3	Acquiring Handrails	1. Not Started/Planned	Beginning of R&D Project	5. Low Uncertainty	Current component Capability implemented real world use
TB4	Handrail Instillation	3. In Progress (On Schedule)	In the planning phase	3. Moderate Uncertainty	Current component implemented in Real World use
TB5	Thermal Storage Unit Identification	2. In Progress (Off Schedule)	Beginning of R&D Project	3. Moderate Uncertainty	Despite the technology being available more research was required to support the larger operational cycle of 72 Hr. vs. 24 Hr.
TB6	Acquiring Thermal Storage Unit	3. In Progress (On Schedule)	Beginning of R&D Project	2. Moderate/High Uncertainty	Current component implemented in Real World use
TB7	Thermal Storage Unit Installation	2. In Progress (Off Schedule)	More analysis was required because of a lack of data from the manufactures	3. Moderate Uncertainty	Despite the component implementation there was more time used to determine if the data claims provided from the manufacturer was correct
TB8	Chiller Unit Identification	3. In Progress (On Schedule)	The PI knew which type he wanted because of the nature of renewable energy projects	2. Moderate/High Uncertainty	Current component implemented in Real World use

Technology / Budget Factor #	Status of Factor (On target to complete TARGET DATE or MILESTONE (TBD))	Status Justification	Factor Uncertainty	Uncertainty Justification
TB9	2. In Progress (Off Schedule)	The PI needed to request a budget increase	2. Moderate/High Uncertainty	Current component implemented in Real World use
TB10	2. In Progress (Off Schedule)	Beginning of R&D Project	2. Moderate/High Uncertainty	Technology maturity for a variable speed chiller was not there
TB11	3. In Progress (On Schedule)	Beginning of R&D Project	4. Low/Moderate Uncertainty	Current component implemented in Real World use
TB12	3. In Progress (On Schedule)	Beginning of R&D Project	4. Low/Moderate Uncertainty	Current component implemented in Real World use
TB13	1. Not Started/Planned	Beginning of R&D Project	5. Low Uncertainty	The wind turbine required surface modification to attach to the building
TB14	3. In Progress (On Schedule)	Beginning of R&D Project	4. Low/Moderate Uncertainty	Current component implemented in Real World use

Technology / Budget Factor #	Status of Factor (On target to complete TARGET DATE or MILESTONE (TBD))	Status Justification	Factor Uncertainty	Uncertainty Justification
TB15	3. In Progress (On Schedule)	Beginning of R&D Project	2. Moderate/High Uncertainty	Current component implemented in Real World use
TB16	2. In Progress (Off Schedule)	Because the microgrid could not do as the manufacture claimed it could do	1. High Uncertainty	The PI and his R&D Team had to program a software tool box for the Modbus controls
TB17	1. Not Started/Planned	Beginning of R&D Project	3. Moderate Uncertainty	Current component implemented in Real World use
TB18	3. In Progress (On Schedule)	Beginning of R&D Project	2. Moderate/High Uncertainty	Current component implemented in Real World use
TB19	1. Not Started/Planned	Beginning of R&D Project	5. Low Uncertainty	Current component implemented in Real World use
TB20	1. Not Started/Planned	Beginning of R&D Project	2. Moderate/High Uncertainty	The R&D team lacked experienced software engineers
TB21	3. In Progress (On Schedule)	Because the software was already identified and exist	2. Moderate/High Uncertainty	Current component implemented in Real World use
TB22	2. In Progress (Off Schedule)	Writing the software programs was a difficult task and it added 2 month of effort to complete the project	1. High Uncertainty	The R&D team lacked a skilled programmer to assist with the writing of code

Table 9. Early Phase Process or Policy Factor, Status and Uncertainty Level and Justification

Process/ Policy #	Process / Policy Description	Status of Process / Policy implementation (On target to complete TARGET DATE or MILESTONE (TBD))	Status Justification	Uncertainty level	Uncertainty Justification
PP1	Create system/design architecture diagram(s)	3. In Progress (On Schedule)	The principle developer had experience with the large components that were used and how they would be integrated.	4. Low/Moderate Uncertainty	Experienced engineers and deep understanding of the components
PP2	Planning the physical integration process	3. In Progress (On Schedule)	The physical components have been in use independently for decades, so the task was relatively simple.	4. Low/Moderate Uncertainty	The physical components exist but the systems were not integrated the way they intended
PP3	Coordinating the contractors to install the major components (Chiller, Wind Turbine, Microgrid and Thermal Storage)	3. In Progress (On Schedule)	Most of the outside support came from commands on campus.	2. Moderate/High Uncertainty	Using contractors for R&D projects have higher levels of uncertainty because of reliance on their skills to perform a task.
PP4	Researching the best chiller system to met the cooling demands.	3. In Progress (On Schedule)	Chiller system technology already exists and was available for the R&D Team to modify.	4. Low/Moderate Uncertainty	Established procedures, adequate resources and qualified personnel in place to complete the task
PP5	Conducting a HAZMAT evaluation of the ethylene glycol to ensure it meet the safety policy set by NPS's Public works	3. In Progress (On Schedule)	The R&D Team knew there were HAZMAT management rules to follow.	2. Moderate/High Uncertainty	The plan for HAZMAT disposal are theories and not implemented for the project.
PP6	Verifying instillation of the handrails adhered to the safety policy set by public works	1. Not Started/Planned	The need to install handrails was not apparent until the R&D team met with publics works	5. Low Uncertainty	Public Works were skilled in completing this task.
PP7	Researching the best thermal Storage system to met the heating demand	3. In Progress (On Schedule)	Using COTS products	2. Moderate/High Uncertainty	The thermal storage units have not been configured to operate as the PI desired
PP8	Researching the best chiller system to met the cooling needs.	3. In Progress (On Schedule)	Using COTS products	2. Moderate/High Uncertainty	The chiller and thermal storage came on one contract

Process/ Policy #	Process / Policy Description	Status of Process / Policy implementation (On target to complete TARGET DATE or MILESTONE (TBD))	Status Justification	Uncertainty level	Uncertainty Justification
PP9	Researching the best wind turbine system to met the power demands.	3. In Progress (On Schedule)	Initial Phase of the research and development	2. Moderate/High Uncertainty	Established procedures, adequate resources and qualified personnel in place to complete the task
PP10	Researching the best microgrid system to met the power distribution loads.	2. In Progress (Off Schedule)	Configuration of the software cause delays	1. High Uncertainty	R&D chain lacked a qualified computer software engineer
PP11	Researching the best battery bank system to met the energy storage loads.	3. In Progress (On Schedule)	Initial Phase of the research and development	4. Low/Moderate Uncertainty	Battery technology is well established
PP12	Configuring the laptop to serve as base of software system control	2. In Progress (Off Schedule)	Require further research to understand how to write the code was necessary to have the components interact as desired.	1. High Uncertainty	The R&D team did not have a dedicated software engineer.
PP13	Configuring the Microgrid web box to communicate with the computer	1. Not Started/Planned	There was a 2-3 month learning curve.	2. Moderate/High Uncertainty	Because the software configuration needed modified to be compatible with the components
PP14	Configuring a Modbus interface to communicate with the web box of the Microgrid	1. Not Started/Planned	There was a 2-3 month learning curve.	1. High Uncertainty	Because the software configuration needed modified to be compatible with the components
PP15	Configuring BACnet for the Chiller	1. Not Started/Planned	There was a 2-3 month learning curve.	1. High Uncertainty	Because the software configuration needed modified to be compatible with the components
PP16	Configuring a National Instruments voltage generator to regulate the voltage signal to the chiller and provide control instrumentation	1. Not Started/Planned	Initial Phase of the research and development	2. Moderate/High Uncertainty	Configuring the voltage generator required little modification
PP17	Modify the file handling toolbox script in Matlab for Modbus, BACnet and National Instruments	1. Not Started/Planned	Initial Phase of the research and development	1. High Uncertainty	Because the software configuration needed modified to be compatible with the components.

APPENDIX B. LATER PHASE SE SPREADSHEET TOOL

Type of Change	Confidence & Impact Score		41	Total			
Hardware/Software design change	Green			39	Colors	All Factors	
R&D Goals Impact	Green	Diff	0	Red	Not confident will happen	0	
Cost & Schedule	Green	zero yellow value,		Red Yellow	Not so confident will happen	0	
Site & Lab Impact	Green	then enter Diff value		Yellow	Pretty confident will happen	0	change this manually
R&D Goals Impact	Green	for yellow		Yellow Green	Confident will happen	10	
Cost & Schedule	Green			Green	Definitely will happen	29	
Hardware/Software design change	Yellow Green	match?		Total		39	
R&D Goals Impact	Green				Graph will update automatically		
Cost & Schedule	Green						
Hardware/Software design change	Yellow Green			Total			
Hardware/Software design change	Green			22	Colors	Technology	
Cost & Schedule	Green	Diff	0	Red	Not confident will happen	0	
Hardware/Software design change	Green			Red Yellow	Not so confident will happen	0	
Hardware/Software design change	Green			Yellow	Pretty confident will happen	0	change this manually
Cost & Schedule	Green			Yellow Green	Confident will happen	4	
Site & Lab Impact	Green			Green	Definitely will happen	18	
Site & Lab Impact	Green	match?		Total		22	
Cost & Schedule	Green						
Site & Lab Impact	Yellow Green			Total			
Site & Lab Impact	Green			17	Colors	Process Policy	
Cost & Schedule	Green	Diff	0	Red	Not confident will happen	0	
Site & Lab Impact	Yellow Green			Red Yellow	Not so confident will happen	0	
				Yellow	Pretty confident will happen	0	change this manually
				Yellow Green	Confident will happen	6	
				Green	Definitely will happen	11	
		match?		Total		17	
R&D project impact	Green						
R&D project impact; System architecture	Green						
R&D project impact; Installation/Integration of components	Green						
R&D project impact; Installation/Integration of components	Green						
R&D project impact; Installation/Integration of components	Green						
Site & Lab Impact	Green						
HW & SW Impact	Green						
HW & SW Impact	Green						
HW & SW Impact	Green						
R&D project impact; Installation/Integration of components	Green						
R&D project impact; Installation/Integration of components	Green						
HW & SW Impact	Yellow Green						
HW & SW Impact	Yellow Green						
HW & SW Impact	Yellow Green						
HW & SW Impact	Yellow Green						
HW & SW Impact	Yellow Green						
HW & SW Impact	Yellow Green						

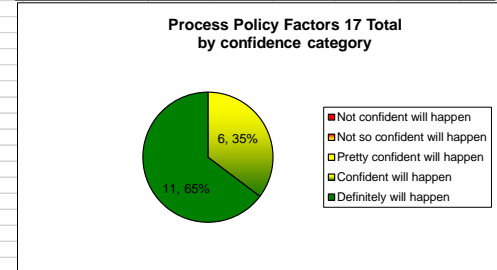
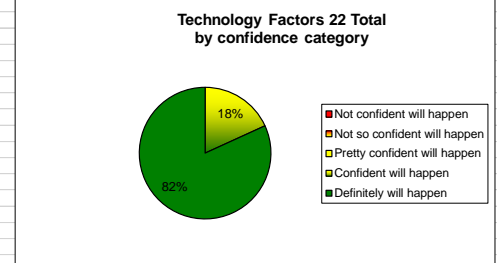
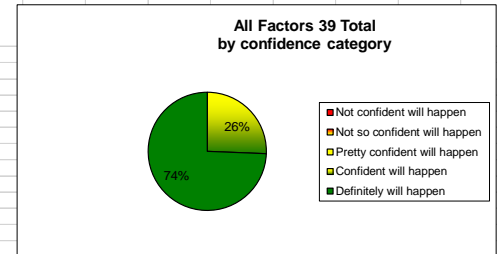


Table 10. Later Phase Technology Factor, Status and Uncertainty Level and Justification

Technology / Budget Factor #	Task/Activity	Status of Factor (On target to complete TARGET DATE or MILESTONE (TBD))	Status Justification	Factor Uncertainty	Uncertainty Justification
TB1	Ethylene Glycol (HAZMAT) Management	3. In Progress (On Schedule)	The chiller and thermal are installed and not fully operational due to programming issues	5. Low Uncertainty	Resolved HAZMAT Plan
TB2	Handrail Identification	4. Completed/Implemented	Type of Handrails Identified	5. Low Uncertainty	Current component implemented in Real World use
TB3	Acquiring Handrails	4. Completed/Implemented	Arrival of Handrails	5. Low Uncertainty	Handrails are Installed
TB4	Handrail Instillation	4. Completed/Implemented	Handrails are identified and installed	5. Low Uncertainty	Handrails are Installed
TB5	Thermal Storage Unit Identification	4. Completed/Implemented	Thermal storage selected and acquired	5. Low Uncertainty	Thermal storage unit selected
TB6	Acquiring Thermal Storage Unit	4. Completed/Implemented	Thermal storage selected and acquired	4. Low/Moderate Uncertainty	Thermal storage unit on site
TB7	Thermal Storage Unit Installation	2. In Progress (Off Schedule)	The chiller and thermal are installed and not fully operational due to programming issues	3. Moderate Uncertainty	SW impact modifications are still in progress
TB8	Chiller Unit Identification	4. Completed/Implemented	Chiller unit identified	5. Low Uncertainty	Current component implemented in Real World use
TB9	Acquiring Chiller Unit	4. Completed/Implemented	Chiller unit acquired	5. Low Uncertainty	Chiller unit on site
TB10	Chiller Unit Installation	2. In Progress (Off Schedule)	The chiller and thermal are installed and not fully operational due to programming issues	4. Low/Moderate Uncertainty	SW impact modifications are still in progress
TB11	Wind Turbine Unit Identification	4. Completed/Implemented	Wind Turbine Unit Identification	5. Low Uncertainty	Current component implemented in Real World use
TB12	Acquiring Wind Turbine	4. Completed/Implemented	Acquiring Wind Turbine	5. Low Uncertainty	Wind turbine on site

Technology / Budget Factor #	Task/Activity	Status of Factor (On target to complete TARGET DATE or MILESTONE (TBD))	Status Justification	Factor Uncertainty	Uncertainty Justification
TB13	Wind Turbine Unit Installation	4. Completed/Implemented	Wind Turbine Unit Installation	5. Low Uncertainty	Wind turbine installed
TB14	Microgrid Identification	4. Completed/Implemented	Type of Microgrid Identified	5. Low Uncertainty	Current component implemented in Real World use
TB15	Acquiring Microgrid Unit	4. Completed/Implemented	Acquired Microgrid	4. Low/Moderate Uncertainty	Microgrid on site, but dependent on the SW configuration outcome
TB16	Microgrid Installation	4. Completed/Implemented	Installed Microgrid	4. Low/Moderate Uncertainty	Microgrid physically installed, but dependent on the SW configuration outcome
TB17	Battery Bank Identification	4. Completed/Implemented	Type of Battery Bank Identified	5. Low Uncertainty	Current component implemented in Real World use
TB18	Acquiring Battery Bank	4. Completed/Implemented	Acquired Battery Bank	5. Low Uncertainty	Battery Bank on site
TB19	Battery Bank Installation	2. In Progress (Off Schedule)	Battery bank Installed, but not operational due to the SW configuration delay	5. Low Uncertainty	Battery bank Installed
TB20	Computer / Control System Identification	4. Completed/Implemented	Type of Computer / Control system Identified	5. Low Uncertainty	Current component implemented in Real World use
TB21	Acquiring Computer / Control System	4. Completed/Implemented	Acquired Computer / Control system	4. Low/Moderate Uncertainty	HW/SW selected and on site, but requires a significant amount of programming
TB22	Computer / Control System Installation	2. In Progress (Off Schedule)	Requires a significant amount of programming	3. Moderate Uncertainty	Requires a significant amount of programming

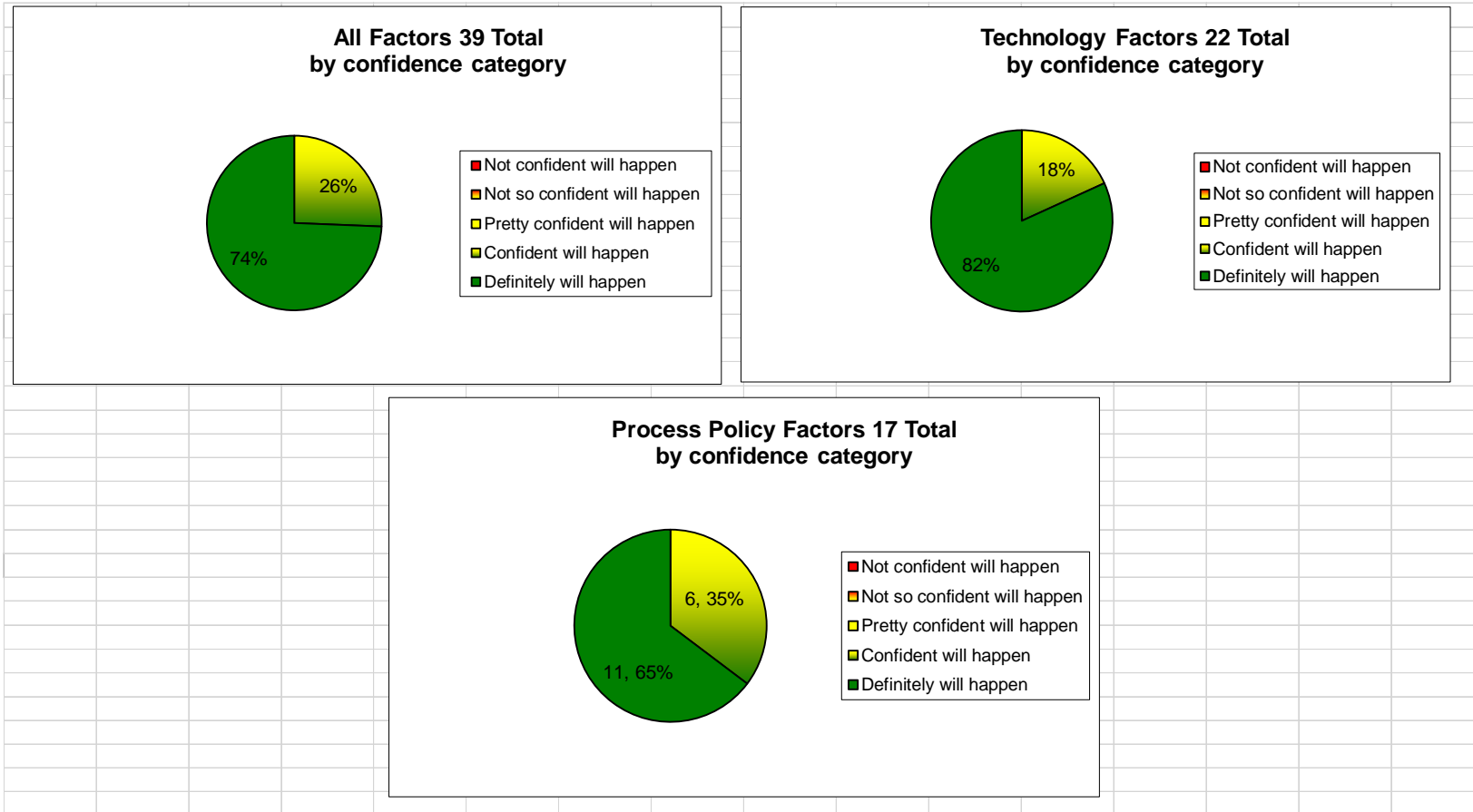
Table 11. Later Phase Process or Policy Factor, Status and Uncertainty level and Justification

Process/ Policy #	Process / Policy Description	Status of Process / Policy implementation (On target to complete TARGET DATE or MILESTONE (TBD))	Status Justification	Uncertainty level	Uncertainty Justification
PP1	Create system/design architecture diagram(s)	4. Completed/Implemented	Approved diagrams with best possible configuration	5. Low Uncertainty	Established procedures, adequate resources and qualified personnel in place to complete the task
PP2	Planning the physical integration process	4. Completed/Implemented	Approved plan	5. Low Uncertainty	The components selected have high tech maturity
PP3	Coordinating the contractors to install the major components (Chiller, Wind Turbine, Microgrid and Thermal Storage)	4. Completed/Implemented	Installation/Integration schedule with sequence of contractor work	5. Low Uncertainty	Contractors identified are competent
PP4	Researching the best chiller system to met the cooling demands.	4. Completed/Implemented	Procurement of Chiller	5. Low Uncertainty	Chiller is on site and perform as expected
PP5	Conducting a HAZMAT evaluation of the ethylene glycol to ensure it meet the safety policy set by NPS's Public works	4. Completed/Implemented	Approved Safety Inspection	5. Low Uncertainty	Public works approves of the use of ethylene glycol
PP6	Verifying instillation of the handrails adhered to the safety policy set by public works	4. Completed/Implemented	Installation/Integration schedule with sequence of contractor work	5. Low Uncertainty	Handrails installed
PP7	Researching the best thermal Storage system to met the heating demand	4. Completed/Implemented	Acquired & Installed Component	4. Low/Moderate Uncertainty	Thermal storage unit identified and on site, but waiting for SW configuration to be completed
PP8	Researching the best chiller system to met the cooling needs.	4. Completed/Implemented	Acquired & Installed Component	4. Low/Moderate Uncertainty	Chiller unit identified and on site, but waiting for SW configuration to be completed
PP9	Researching the best wind turbine system to met the power demands.	4. Completed/Implemented	Acquired & Installed Component	5. Low Uncertainty	Wind turbine installed and operational
PP10	Researching the best microgrid system to met the power distribution loads.	4. Completed/Implemented	Acquired & Installed Component	5. Low Uncertainty	Microgrid on site, but waiting for SW configuration to be completed
PP11	Researching the best battery bank system to met the energy storage loads.	4. Completed/Implemented	Acquired & Installed Component	5. Low Uncertainty	Battery Technology Maturity is high

Process/ Policy #	Process / Policy Description	Status of Process / Policy implementation (On target to complete TARGET DATE or MILESTONE (TBD))	Status Justification	Uncertainty level	Uncertainty Justification
PP12	Configuring the laptop to serve as base of software system control	3. In Progress (On Schedule)	The R&D team made significant progress gains toward the expected objective	4. Low/Moderate Uncertainty	The R&D team made significant progress gains toward the expected objective
PP13	Configuring the Microgrid web box to communicate with the computer	2. In Progress (Off Schedule)	Process start date delayed by two weeks waiting on completion of configuring the laptop (PP12)	3. Moderate Uncertainty	SW configuration and programming without a specified SW engineer
PP14	Configuring a Modbus interface to communicate with the web box of the Microgrid	2. In Progress (Off Schedule)	Process start date delayed because completion of configuring the Microgrid web box (PP13)	3. Moderate Uncertainty	SW configuration and programming without a specified SW engineer
PP15	Configuring BACnet for the Chiller	2. In Progress (Off Schedule)	SW configuration and programming without a specified SW engineer	3. Moderate Uncertainty	SW configuration and programming without a specified SW engineer
PP16	Configuring a National Instruments voltage generator to regulate the voltage signal to the chiller and provide control instrumentation	2. In Progress (Off Schedule)	SW configuration and programming without a specified SW engineer	3. Moderate Uncertainty	SW configuration and programming without a specified SW engineer
PP17	Modify the file handling toolbox script in Mat lab for Modbus, BACnet and National Instruments	2. In Progress (Off Schedule)	Process start date delayed because of the completion of configuring the BACnet and National Instruments voltage regulator (PP16)	3. Moderate Uncertainty	SW configuration and programming without a specified SW engineer

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APPENDIX C. LATER PHASE PIE CHARTS



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