# A FRAMEWORK FOR CONDITION ASSESSMENT AND ASSET MANAGEMENT PRACTICES FOR THE MARINE (FERRY) INDUSTRY

by

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ABSTRACT

DAXIL KANAIYALAL RAJA. A Framework for Condition Assessments and Asset Management Practices for the Marine (Ferry) Industry. (Under the direction of DR. GLENDA MAYO)

The North Carolina Department of Transportation (NCDOT) and the North Carolina Ferry Service (NCFS) Division is responsible for extensive infrastructure which includes numerous assets. As with any organization with an extensive list of assets, it is imperative that owners establish a methodology to manage those assets. Although the NCFS has an established QC program and efficiently managed operations, research to further assess, benchmark, develop and formalize methods to manage assets was explored. The transportation industry has several established life-cycle costing methods utilized for the asset budgeting process; however, there are no specific guidelines for planning for asset management for the marine industry. The research provides a framework for the asset inventory process and additionally for conducting condition assessments. A case application for NCFS provides a “snapshot” of current conditions in the form of condition assessments for all 21 vessels, and the application of the condition assessments into an overall framework for their long-term asset management practices. The framework provides a foundational platform for DOT marine transportation divisions to incorporate the DOT reporting needs for the State of Good Repair (SOGR).

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The person with the greatest indirect contribution to this work is my mother, Kavita Raja, who always believed in me. Special thanks to her, my father, my sister, and my friends for their constant encouragement.

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| | |
|---|---|
| AMP | Asset Management Plan |
| APTA | American Public Transportation Association |
| ASTM | American Section of the International Association for Testing Materials |
| BTS | Bureau of Transportation Statistics |
| CI | Condition Index |
| DOT | Department of Transportation |
| EL | Economic Life |
| EUL | Estimated Useful Life |
| FCA | Facility Condition Assessment |
| FTA | Federal Transit Authority |
| IFMA | International Facilities Management Association |
| IP | Investment Planning |
| ISO | International Standard Organization |
| LCA | Life Cycle Analysis |
| LCCA | Life Cycle Cost Analysis |
| MAP-21 | Moving Ahead for Progress in the 21$^{st}$ Century |
| NCFO | National Census of Ferry Operators |
| NCFS | North Carolina Ferry System |
| NIST | National Institute of Standards and Technology |
| NTD | National Transit Database |
| PSL | Predicted Service Life |
| RUL | Remaining Useful Life |

| | |
|---|---|
| SL | Service Life |
| SOGR | State of Good Repair |
| SWBS | Ship Work Breakdown Structure |
| TAM | Transportation Asset Management |
| TERM | Transit Economic Requirement Model |
| USCG | United States Coast Guard |
| USDOT | United States Department of Transportation |
| WSF | Washington State Ferry |

# CHAPTER 1: INTRODUCTION

The North Carolina Ferry System, a division of the North Carolina Department of Transportation (NCDOT), serves the residents of Eastern North Carolina's island and coastal communities. Of the hundreds of public and private ferry operators in the United States, NCFS ranks amongst the ferry industry's top 10 in several categories, including annual passengers, the number of terminals, and the number of vessels in operation (Steve et al., 2016). In addition, NCFS operates the second-largest state-owned ferry system in the United States operating seven routes with 21 ferries (and one new vessel under construction). These ferries operate over 200 daily trips and transport more than 1.1 million vehicles and 2.5 million passengers annually (Tsai et al., 2011).

In 1957, John Perry characterized ferries as an important aspect of American life, one which is "continually on the point of vanishing but which never quite disappears" (Wright, 1987). The USDOT Bureau of Transportation Statistics (Steve et al., 2016) published the results from a National Census of Ferry Operators (NCFO) survey which stated that ferries in the United States carried over 115 million passengers and over 30 million vehicles in 2013. This survey was conducted in 2014 with 128 ferry operators from 38 different states responding to the survey (not all operators responded). In the BTS report (Steve et al., 2016), it is stated that there is an estimated total of 499 vessels in the USA. This figure provides an indication of the importance of the ferry service in the public transportation sector. The BTS report (Steve et al., 2016) also reports that ferries are offering a "vital intercity transportation link between coastal communities and roadways separated by various bodies of water and these ferries not only serve tourists but daily commuters as well." These ferries are an integral part of the transportation system for commuters, freight carriers, travelers, and vacationers.

## RESEARCH PURPOSE

The North Carolina Ferry System (NCFS) has a fully operational shipyard with the ability to control maintenance levels and potentially extend the useful life of the vessel; however, the ferry industry lacks a standardized method to monitor vessel condition for overall asset management. Although the building industry has existing processes for assessing asset inventory and determining levels of condition, the marine industry is not established in terms of recommended on standardized processes.

The purpose of the research was to establish a systematic method to categorize and track the condition of the assets for 21 vessels and incorporate those results into reporting that will assist with long-term management of the NCFS assets. Ultimately, the purpose of a condition rating for any asset is to utilize the rating for future planning and budgeting. An essential and first step for asset management is a Facility Condition Assessment (FCA). According to Rugless (1993), the Remaining Useful Life (RUL) is defined "as a process of systematically evaluating an organization's capital assets in order to project repair, renewal or replacement needs that will preserve their ability to support the mission or activities they are assigned to serve." The FCA is an important part because it provides the initial step in the decision-making, whether to replace or repair the asset and it also helps to forecast the preventative or predictive maintenance (Mokashi et al. 2002).

The framework of this research has three innovative main fronts (Figure 1), primarily due to its application of general asset management to the marine industry: (1) development of a hierarchy for ferry vessel asset inventory (2) method for conducting condition assessments for ferry vessels; (3) exploration of the considerations of using assessment data for future asset planning for the estimated useful life. The combined contribution ultimately determines the suitable framework for establishing asset management practices which includes a thorough condition assessment – but with consideration of the required reporting needs and uses of the results for asset planning.

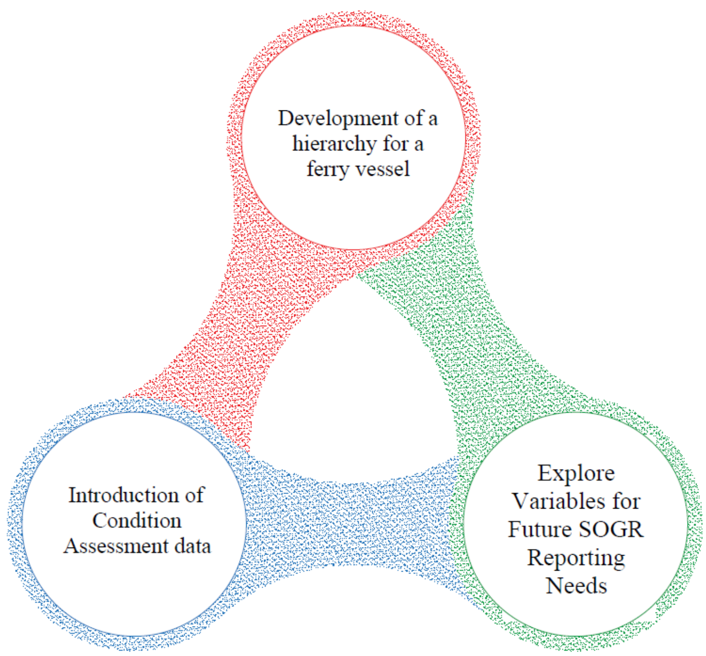



**Figure 1: Three Main Fronts for the Research**

The proposed framework is a benefit for both shipyard administration and practitioners who use the concept of life cycle analysis and condition assessment. The goal is to outline general methods for asset management, but additionally to provide a means to utilize a framework for a more inclusive method for determining useful life.

Often the decision for the longevity of an asset is made based on an estimated condition, or a manufacturer's estimated useful life. However, a combination of condition assessment and considerations for the use conditions allows for a more innovative methodology for vessel fleet management decisions. The goal of this project is to establish a framework for initial asset management objectives – but considering the future uses of the established condition index. The methodology used is an applied case study which explores various study methods. The methods were examined and then applied to the case application for the NCFS.

## PROBLEM STATEMENT

With increasing passenger expectations and limited state funding, NCFS must ensure the continuity of ferry operations. The planning for meeting these needs includes the operations to maintain the condition of the ferries, which will ultimately increase their useful life. Proper maintenance not only helps to keep the total life-cycle costs down, but it also contributes positively to the overall performance of the useful life (Waeyenbergh and Pintelon, 2002). An initial planning requirement is to assess the overall condition of the fleet to determine the long-term budgeting process for refurbishments and procurement of new vessels. But for the need to determine condition, the foundational problem is that the asset owner must know their asset inventory. Unlike the commercial construction industry, there is no standard for the listing of typical ferry assets. Also, since several of the vessels were similar in age, asset planning can assist to spread annual funding needs. Consequently, there is a need to determine a framework for conducting condition assessment, managing an asset inventory and lastly, this methodology must consider the data needs to ultimately identify a model to determine the remaining useful life of each ferry vessel.

Transportation legislation's Moving Ahead for Progress in the 21st Century (MAP-21) serves several important goals, including the reporting of the state of good repair, safety, and performance and program efficiency. MAP-21 puts more weight on restoring and replacing the aging public transportation infrastructure by creating a new needs-based formula program in their new asset management requirements (FTA, 2012). In addition, MAP-21 contains various provisions for better asset management planning. From those sections, under 49 USC §5335 in sub-section 20025 of MAP-21, it specifically mentions that the agencies must report an asset inventory, condition, and any assessments conducted to the National Transit Database (NTD). In addition, Under 49 USC §5326, the document states that this transit asset management system means a "strategic and systematic process of operating, maintaining, and improving public transportation assets effectively throughout the life cycle of such assets" (APTA, 2012).

## RESEARCH GOALS AND OBJECTIVES

The primary objective of this research is to establish the methodology for asset management with regards to inventory and condition assessments. Additionally, considerations for the future uses of the Condition Index (CI) were also considered. To achieve this objective, the following steps were required:

I. Identify the asset inventory and a hierarchy for ferry vessel assets.

II. Establish the process for conducting condition assessments of ferry vessels and to summarize and represent the condition of the overall ferry fleet.

III. Explore "next steps" for the incorporation of the CI into the determination the operational needs and the remaining useful life of the ferry fleet.

The research aims to assist the NCFS (state-owned shipyard) to establish mature levels of asset management. As Figure 2 depicts, an asset's performance will decline because of its age and its use. The lack of proper maintenance and funding support compromises the longevity of an owner's assets. Maintenance is a critical component of asset management, but an owner must first know what their assets are, and the condition of those assets to develop to mature asset management levels. Overall, the goal is to assist the NCFS with recommendations for further development of mature asset management practices. Additionally, this research may assist the ferry industry with notable industry needs for better asset management.


**Figure 2: Effects on Performance (adapted from Gallaher et. al., 2004)**

## SIGNIFICANCE OF STUDY

Managing and assessing numerous assets is "rife with conflicting priorities" (O'Connor, 2014). For any owner, regardless of the industry, the initial steps in effective asset management are often difficult. For the ferry industry, this is especially true given that there is a lack of precedence in terms of standards and documented recommendations. The lack of asset management planning (operations and maintenance planning) can influence the budgeting and subsequent decisions such as the conflict of the appropriate time invested to maintain the ferry and when vessel should be replaced. At the operational level, this leads to organizations resorting to emergency and reactive maintenance practices as opposed to an effective predictive and preventative maintenance program. The research explored the current practices in the marine industry and the recommendation for the appropriate steps to initiate an effective program. Furthermore, it includes an industry summary regarding long-term use of the condition assessment data to be used for the aim of developing an initial framework for determining the estimated useful life of a vessel.

The result of this study provides the steps in establishing an effective asset management program, and a method for conducting the condition assessments for long-term planning use. The development of an asset hierarchy and a method for condition assessments will provide the NCFS with a foundation for operational decisions. The resulting condition index (CI) may be used as an operational maintenance tool, and ultimately provide an initial framework for the prediction of the remaining useful life.

## LIMITATIONS

I. The available literature on Life Cycle Analysis and asset management is limited as it relates specifically to the ferry vessel industry. Information pertaining to other trans-model assets like heavy highway equipment, bus and, train are more advanced in their established standards and recommendations.

II. Data has only been maintained and tracked for approximately 1 year in the NCDOT enterprise data tracking system (SAP) so there is limited data for listed for specific components as well as the historical data needed to assess condition based on failures and work requests.

III. Condition assessments for the marine industry are difficult to conduct as there is generally no data connectivity to allow for electronic assessment methods. Furthermore, for assets that are not fixed, there are disadvantages in conducting assessments both while the vessels are in operation as well as while they are in the yard - therefore introducing issues regardless of which method is chosen. Due to the constraints of the NCFS and the UNC Charlotte researchers, the condition assessments were completed over a period of a year and were conducted either:

a) In drydock at the Manns Harbor shipyard or
b) At various ferry terminals while the vessel was in operation

The advantages of assessments completed while in drydock include:

- Noting maintenance tasks occurring while in drydock.
- A more updated assessment based on planned and/or completed work.

The disadvantages of assessments completed while in drydock include:

- Often, there were assets that were not available on the vessel (removed for refurbishment).
- Could not assess assets based on sound or heat while operating. For example, noisy bearings or sheaves.
- Do not have access to crew members to discuss daily operations and concerns.
- If corrections were already made, there is a lack of collected data regarding potential issues to be addressed for that particular asset.

IV. Lastly, regarding the long-term use of CI data for replacement decisions, the NCFS may choose to eliminate a vessel based on factors that do not pertain to the condition. For example, the smaller fleet size (Hatteras class) is nearing obsolescence due to an increase in the need to carry more passengers.

## RESEARCH APPROACH

In collaboration with the North Carolina Ferry Division, the research utilized a case study to apply the review of various industry methods to achieve a solution for the initial stages of asset management and the implementation of condition assessments for long-term planning objectives.

To achieve the objectives and goals of this research, the research was conducted by utilizing the following steps:

<u>Step: 1: Review of existing literature:</u> An extensive search was carried out to examine the existing practice of Condition Assessments (CA) within different industries. Based on the literature review, the needs for conducting condition assessment were identified. The study will describe the most important first step of conducting the CA which is developing an asset hierarchy and asset inventory. Literature also provided a means to select a condition rating scale which was utilized in the proposed condition assessment framework (step 2) for the marine industry. In addition, the variables with respect to eventually determining the estimated useful life of the ferry vessel were identified for further analysis.

<u>Step: 2: Development of a system for conducting the condition assessment:</u> To improve the process of tracking the condition of the assets using a simplified and standardized internal procedure was determined based on methods used by similar

industries and operations. The method utilized an extensive literature review and the formation of a summary data collection form. The proposed form was based on the requirements and needs to track the condition of the assets for the marine industry and a resulting asset management plan.

Step: 3: Development of a system hierarchy for tracking assets: To conduct a condition assessment, there is a need to first establish an asset list. An asset hierarchy was determined based on the literature review, industry uses, and a summary of the collected assets after visual inspections. The summary was sub-divided based on internal discussions with the quality assurance professionals with NCFS.

Step: 4: Case Study application: The proposed framework was successfully conducted for the 21 ferry vessels of North Carolina Ferry System. The use of this framework will be beneficial for the marine industry but more applicable for the ferry industry. An internal analysis of the resulting condition assessment data indicated the potential uses and reporting metrics as well as recommendations for improving asset management maturity levels.

## DEFINITION OF TERMS

According to Schneider et al. (2006), the meaning of asset management "is to operate a group of assets over the whole technical lifecycle guaranteeing a suitable return and ensuring defined service and security standards". This definition is similar to the goals utilized at the beginning of a project when using Life Cycle Analysis (LCA), which is also referred to as Life Cycle Assessment. There are similarities to asset management, but LCA is a tool for analyzing the environmental performance of products or processers over their life cycle including from manufacturing to disposal to recycle in a systematic way and is typically a process used for early purchase decisions. LCA often defines its process as a “cradle to grave” approach to assess the environmental impacts (Cabeza et al., 2014). LCA should be considered when developing an asset management plan because purchase decisions can have lasting impacts on an asset management plan for an organization.

Condition Assessments are completed after the purchase of an asset and the process is most often defined in terms of the commercial building industry. However, the definition is applicable to other industries as well. “It is a process whereby the organization’s facility systems, components, and sub-components (if applicable) are evaluated as to their condition” (Lewis & Payant, 2000).

The life of an asset can be defined using various metrics. There are many acronyms that have similar meaning but are beneficial in understanding and measuring assets as they relate to time. The Remaining Useful Life (RUL), according to Si et al. (2011), may pertain to an asset or system as an asset, and is the total time duration from the current date to the end of the useful life. Similarly, the Reference Service Life (RSL) is defined as a service life for any asset for the “projected lifespan in a certain set of in-use conditions” (Hovde, 2005). Also pertaining to time is the Estimated Useful Life (EUL).

This service life can be calculated by taking in consideration of materials, design, environment, use, and maintenance and adjusting the reference service life based on in-use condition (Hovde, 2005). This research will primarily reference the EUL the RUL which is a metric that owners use to plan for the anticipated replacement timeframe.

State of Good Repair (SOGR)

A state of good repair refers to a desirable operating condition of an asset or system (VDOT, 2016). The result of SOGR is based on the numerically based system used by Transit Economic Requirement Model (TERM) (TERM is developed by Federal Transit Administration) to estimate the condition of mass transit assets. Every asset may have a deterioration schedule, which is based on such factors as its age, maintenance and repair/refurbishment. TERM assigns the ratings based on these factors and uses the condition rating scale from 1 through 5, with 1 indicating the poor condition and 5 at an excellent condition.

## ORGANIZATION OF THESIS

The remainder of the thesis is structured as follows:

Chapter 2 represents the comprehensive literature review of the traditional and most recent methodologies to asset in the development of a hierarchy and inventory, condition assessment and data collection, and the related methodologies for the use for the CI index for future planning.

Chapter 3 contains the research methodology and supplemental information needed to explain the methodology. Chapters 4 and 5 contain the results and conclusions of the study, and additionally, the recommendations for the future research providing several “next steps” to assist the ferry industry with the development of mature asset management practices.

# CHAPTER 2: LITERATURE REVIEW

## INTRODUCTION

There are numerous terms that describe methods of reviewing the overall performance of an asset. LCCA is a process of evaluating the economic performance of a building or a particular asset over its entire lifetime (Stanford University, 2005). Fuller and Petersen (1996) mentioned the definition of LCCA in NIST (National Institute of Standards and Technology) handbook 135, which states LCCA as "the total discounted dollar value of owning, operating, maintaining and disposing of an asset" over a period of time. Sometimes LCCA is defined as "total cost of ownership" which defines the process as a "Cradle-to-Grave" perspective (Lindqvist, 2012). Furthermore, the term can be applied to the construction, transportation, and the marine industry, to name a few. The concept of Life Cycle Cost Analysis is proven to be the integral part of financial management for all businesses (Teicholz, 2001). However, for the marine industry, ships or ferries are more difficult to evaluate for the following reasons: they are large in scale, complex and different use of materials and function, and is a movable asset.

Overall, there is a growing interest in LCCA in the specific industries and there is a realization that an organization can achieve meaningful reductions in the system's long-term costs. Some concepts are an effort to improve reliability; others have been aimed at a specific problem such as increasing useful life of the asset (Gupta, 1983).

Although LCA methods are valuable methods to establishing the total costs, the NCFS has a need to determine planning methods for the estimated useful life of assets for budgetary planning. Therefore, models for LCCA which often utilize costs in the methodologies, are not effective for establishing how long the asset will ultimately last.

The background information provided below summarizes the existing strategies after the purchases of an asset to assist with establishing a list of assets, determining their condition levels, and then utilizing this data in a new framework for establishing the long-term planning uses of the data.

## APPLICABLE STANDARDS IN THE BUILDING INDUSTRY

To determine the best practices for asset management, there are existing standards and methods for data collection, data organization, and data uses. The following sections summarize the literature for existing standards and established industry methods. There are several existing standards to address methodologies for tracking assets and working to ensure the life expectancy of an asset. The ISO15686 standard, titled "Service Life Planning" is the standard procedure for assessing the service life of a building or building components. Although this standard addressed building structures, many of the sections are broad and can also be applied to marine assets. Another standard that is focused on the life cycle costs is the ASTM standard (ASTM, 2015) E917 titled "Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems" which is the standard facility industry procedure for analyzing life-cycle costs of designing, purchasing, constructing/installing, operating, maintaining, repairing, replacing, and disposing of a particular system (ASTM, 2015). Least applicable but worth mention is, the National Institute of Standards of Technology Handbook 135 (Fuller and Petersen, 1996) is a Life-Cycle Costing Manual designed to apply LCC for energy sector for Federal projects.

The commercial building industry is similar to other industries with regards to an owner's need to track assets. Building assets signify a substantial portion of the infrastructure capital held by federal, state, and local agencies, as well as private organizations (Grussing et al., 2009). Because of the complex nature and the importance of these building components, a building must be hierarchically decomposed into its main components to enable reporting and historical analysis at the component levels. The same need and structural application is required for other industries as well.

Based on the study conducted by Uzarski and Burley, in 1997, a building can be divided into their main components, systems or disciplines (electrical, plumbing, structure, etc.), that can be further divided into the more detailed component level. (windows, flooring, ceiling, etc.). The grouping of components into sub-components in the hierarchy is done to reflect similar characteristics and also similar inspection needs. A study conducted by Elhakeem (2007) proposed the asset hierarchy for educational facilities as shown in Figure 3. Additionally, he describes the benefits of having an asset hierarchy.

a) It simplifies the process of revising assessed components
b) It helps to organize the allocation of funds among various systems based on the preferences of the organization
c) Allows the evaluation of the performance of each department or category to ensure the components are maintained.

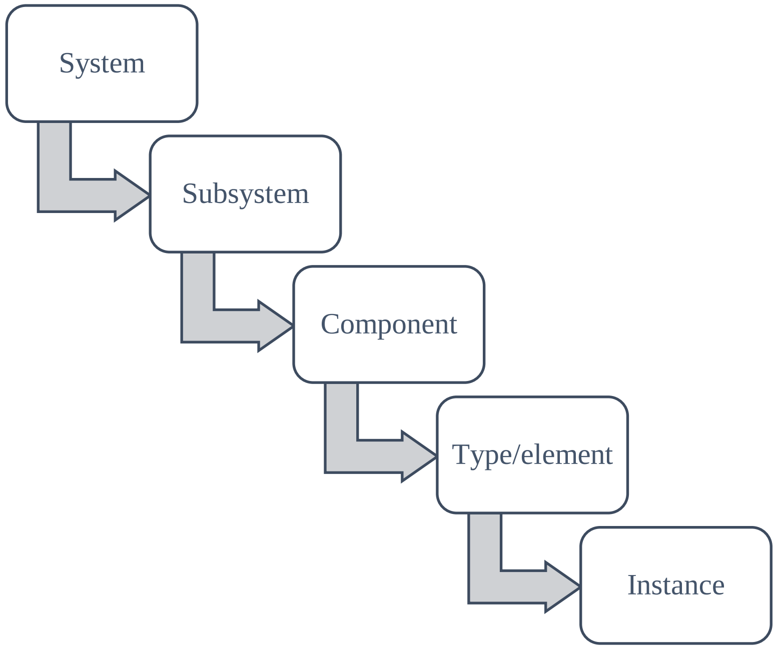



**Figure 3: Asset Hierarchy Adapted from Elhakeem (2007)**

Regardless of the industry, an important and essential step is to create the asset hierarchy as a means to conduct the condition assessment. The hierarchy is intended as a means to classify and cluster the components in different categories (Ahluwalia, 2008). According to Thompson (2013), creating an asset inventory is the same as building the foundation for any manmade structure. In addition, it helps to differentiate the equipment and the number of installed components, and it creates the base for preventative maintenance, predictive maintenance, space utilization, and capital asset replacement analysis (Lewis and Payant, 2000).

APPLICABLE STANDARDS IN THE TRANSPORTATION INDUSTRY

The Federal Transit Authority (FTA) recommends that the condition assessment data must be gathered on all facilities and the National Transit Database (NTD, 2015) policy manual categorized eight types of facilities.

I. Administrative Facilities: This includes typically offices which includes accounting, finance, engineering, legal, security, customer services and so on.

II. Maintenance Facilities: This includes two types of maintenance facilities. Sometimes some agencies use the same facility to serve them both.

   a. General Purpose Maintenance Facilities: A building or garage where mechanics perform routine maintenance and repair.

   b. Heavy Maintenance Facilities: This also serves somewhat the same meaning as a general purpose but in a building, mechanics perform major rebuilds and is for larger agencies.

III. Ownership Types: Transit agencies sometimes own the facility but they may also lease it from a public agency or private agency.

IV. Size Types: This type is divided based on the number of revenue vehicles that can be serviced. First, under 200 vehicles, second, 200 – 300 vehicles and third, more than 300 vehicles.

V. Shared Facilities: Sometimes some transit agencies share facilities between multiple modes of the type of services.

VI. Passenger and Parking Facilities: All rail passenger facilities, light rail, cable car and those facilities that have platforms. It also includes all transportation, transit or transfer centers, and enclosed structure for ticketing, restrooms, concessions, and telephones.

This list does not include ferry vessels specifically but is noted to address the application of the transportation building industry to the needs of the NCFS condition assessment process. Based on the types of the facilities, FTA have published forms to create the asset inventory and to collect condition data (Form A-10, Appendix C). This form as well as the field and description is shown in summary (Table 1) as provided in the FTA Guidebook (FTA, 2016).

**Table 1: Administrative and Maintenance Facilities Asset Inventory Data Fields (Adapted from the FTA's Facility Condition Assessment Guidebook, (FTA, 2016))**

| Form | Field | Description |
|---|---|---|
| Agency Information | NTD Identification Number | 4 Digit number assigned to the agency by FTA |
| | Agency Name/Acronym | Trademark or familiar name |
| | Mailing Address | Agency mailing address |
| | Urbanized Area | UZA number(s) as identified by US Census |
| Administration and Maintenance Facilities (A-10) | Facility Name | Name of administrative or maintenance facility |
| | Section of Larger Facility | Mark if the age of different facility pieces varies significantly |
| | Street Address | Several location fields regarding address or the nearest approximation |
| | Primary Mode | Mark primary mode served at the facility |
| | Facility Type | One of six maintenance facility types or one of two administrative facility types |
| | Year Built or Replaced | Specific year in which the asset or facility has been replaced or reconstructed |
| | Square Feet | Best available measurement |
| | Percent Capital Responsibility | Reflects ownership and funding responsibility |
| | Estimated Condition Assessment | Estimated rating based on the age |
| | Condition Assessment | Overall condition assessment of the facility performed |
| | Estimated date of Condition assessment | Month and year in which the facility condition assessment was conducted |

To determine the overall condition of an administrative or maintenance facility, FTA has determined the highest level of an asset hierarchy for a condition assessment agency to inspect and assess the following facility components (at a minimum):

- Substructure
- Shell
- Interiors
- Elevators and Escalators
- Plumbing
- HVAC
- Fire Protection
- Electrical
- Equipment
- Site

Transportation Asset Management (TAM) helps to maintain and manage the infrastructure assets throughout their life cycle in a strategic and systematic way, focusing on business and engineering practices for resource allocation and utilization. This is achieved by using data and analysis to improve decision making, with the objective of providing the required level of service in the most cost-effective manner (Thompson, 2013). Most of the DOTs have at least a partial inventory of its assets and Thompson (2013) summarized research surveys conducted by Markow (2007) having 38 responses and Hawkins and Smadi (2013) with 43 responses, for the number of states found to have inventories and condition data for several types of assets.

**Table 2: Percent of agencies having inventory and condition of each asset type (adapted from Thompson, 2013)**

| Information Field | % of asset inventory | | % with condition survey | |
|---|---|---|---|---|
| **Asset type** | **2007** | **2012** | **2007** | **2012** |
| Signs | 56 | 91 | 28 | 86 |
| Guardrails | - | 81 | - | 72 |
| Traffic Signals | 78 | - | 35 | - |
| Drainage Culverts | 70 | 72 | 50 | 67 |
| Roadway Lighting | 69 | 70 | 22 | 65 |
| Pavement Markings | 61 | 60 | 42 | 63 |
| Retaining Walls | - | 49 | - | 47 |
| Side Walks | 31 | - | 18 | - |

The results of this survey represent that signage inventories have become nearly universal in recent years, and other types of asset inventories are very common as well. The use of condition assessment has increased dramatically in the past five years for the asset types mentioned in the survey. (Thompson, 2013).

In addition to tracking the condition, there are other types of data to be maintained as well. The Alaska Department of Transportation has conceived a list of general attributes to help in creating the asset inventory and the technical requirements of each asset class, which may be unique in nature (Thompson, 2013).

I. Identification: Any unique name which can help to identify and delineate the asset for inspection, for instance, route number, road and/or facility name.

II. Location: Latitude/longitude and linear referencing.

III. Description: It requires to have more detailed information for the asset. For instance, physical classification, dimensions, manufacturer, age, and any other data which is useful for condition forecasting and cost estimation.

IV. Network: Routes for the vehicles.

V. Jurisdiction: District, maintenance area, functional class, city, county, owner agency, maintenance responsibility.

VI. Utilization: Vessel type, traffic volume.

VII. Physiography: any geographic features such as rivers, climate zone geology, and hydrology.

VIII. Cross-references: Linkages to other assets which are adjacent or related.

The building industry as well as the transportation industry have both made progress toward better asset management practices, but it is obvious that these efforts are somewhat segmented and owners must refer to multiple examples and standards to begin their own practices.

## FACILITY CONDITION ASSESSMENT

Most organizations have significant accumulations of facility renewal and replacement needs (Teicholz & Edgar 2001). Likewise, for many organizations, major issues of service delivery are “repair and renew” rather than “design and build” (Johnson and Clayton, 1998). To get a better understating of the condition of the facility (or asset) or to know the extent of the deferred maintenance backlog, a Facility Condition Assessment (FCA) is needed. IFMA (2009) stated the definition of a condition assessment as a “complete review of the current state of a building to determine the current condition and estimated the cost to correct any deficiencies. It is provided in a report format, often including photographs and diagrams outlining problem areas, needed updates or improvements, and problems”. Likewise, the Department of Public Works in Australia (2018) stated the definition of Condition Assessment (CA) as “the technical assessment of the physical state of building elements and services and to assess the maintenance needs of the facility." This definition is applicable to the marine industry because it addresses the purpose of information. The CA process for built assets should, as a minimum, rate asset condition, determine the risks associated with letting an asset remain in that condition, and identify maintenance work needed to restore to and retain an asset in its required condition." According to Vanier (2000), condition assessment records the deficiencies of a system or component, the extent of the defect, as well as the urgency of the repair work and in few cases, the estimated replacement cost is also recorded. The data generated by CA is better able to develop optimal plans for maintenance and repair.

The Condition Assessment uses a rating scale for assets to categorize the condition levels and the amount of required repair. The rating scale is often different based on the type of asset or industry. For an instance, National Centre for Education Statistics (NCSE, 2003) has used 1-8 (1 being excellent and 8 being emergency condition) as a condition scale for buildings and Department for Education and Skills (DfES, 2003) uses A-D (A being good and D being bad) as a condition scale for buildings. Table 3 summarizes the literature in terms of application areas and their rating scales.

**Table 3: Condition Rating Scale Used in other Areas of Industry**

| Authors | CA Application Areas | Condition Rating Scale |
|---|---|---|
| Abbott et al., 2007 | Buildings | Scale 1 to 5 (1 =Very Bad , 2 = Bad, 3 = Fair, 4 = Good, 5 = Very Good) |
| VDOT, 2016 | Highways | Scale 0 to 100 (49 and below = Very Poor, 50-59 = Poor, 60-69 = Fair, 70-89=Good, 90 and above = Excellent) |
| Thompson, 2013 | Transportation Assets | Scale 0 to 100 (0 to 25 = Poor, 26 to 50 = Fair, 51 to 75 = Good, 76 to 100 = Excellent) |
| Owen, 2012 | Transportation Vehicles | 1 being poor and 5 being excellent |
| Price and Kosnak, 2012. | Underground Construction | Scale 1 to 5 (1 = Best and 5 = immediate action required) |

## FACILITY COMPONENTS AND SUB-COMPONENTS

Before beginning the CA, the Asset Hierarchy or list of assets (inventory) is needed. The hierarchy is intended as a means to organize and cluster the individual assets in the specific categories. For instance, a ferry vessel can be divided into the different system based on its assets. Consequently, a structured, standardized and consistent format is helpful in not only collecting the assessment data but also for reporting and sharing the information within the organization.

The development of the database is important for the foundation of tracking assets and the established hierarchy is therefore crucial. A benefit in establishing the asset hierarchy is the ease of finding and labeling information in a parent-child relationship and the ability to charge costs to lowest possible asset level, thereby providing a means to identify where maintenance dollars are actually being spent (Keady, 2013). Malafsky and Newman (2009) define the hierarchical organization of information as a taxonomy. Taxonomies are the classification scheme used to categorize a set of information items. They represent an agreed vocabulary if topics are arranged around a particular discipline. Additionally, once the asset hierarchy parent-child relationship has been established, field technicians and engineers can write work notifications to the correct asset level and not to a general area. This helps develop historical data that can be used to identify the actual "bad actors" that are creating the maintenance burden (Langan, n.d.).

Before performing any assessment, it is essential to define what assets must be assessed (FTA, 2016). The ISO 55000 (2014) states that an organization may choose to manage assets as a group by asset types, asset systems, or asset portfolios. To create a system that works for each asset owner, a categorical system for use in database documentation and tracking assets uses a standard classification system to ensure that assets are listed in a specific structure to eliminate any chance of duplication and to assist with database searches. Kong et al. (2016) recognized a similar need to establish an inventory database for a water supply system to eventually begin tracking life-cycle costs. His research supports the typical starting structure for a discipline or organization as they are beginning their strategic organizational planning. In this case study, the organization's needs were outlined with what the Kong called the "inventory inheritance tree" which was to imply a database of assets that the organization had identified. His research defined a process whereby a detailed asset object list was established into a hierarchy and then unified to eliminate redundancy, and lastly was structured and stored to realize efficiency in processing data searches. They utilized different levels of information so that the decision could be made about how far into those levels the owner will want to eventually document.

Specific to ferry assets, a 1997 document developed for the U.S. Navy is a published Standard Access Database, developed by the University of Michigan (Department of Navy, 1997). This system is often referred to as SWBS or Ship Work Breakdown Structure. As the title implies, it was developed for shipbuilding, not ferry operations. Additionally, this database is no longer accessible but the SWBS structure is still used. The database was developed for naval ships and would require significant modifications for ferry vessels. The Naval System utilizes one level of asset numbers with assignments from 000 to 997 (Department of Navy, 1997). The Washington Ferry Service developed an asset tree that originally attempted to follow this guideline and their modified scheme is as follows:

- Level 1: Ferry Fleet (e.g., Fleet Type)
- Level 2: Vessel Class (e.g., Vessel Class)
- Level 3: Vessel (e.g., M/V Name)
- Level 4: SWBS Digit #1 (e.g., Group 2 = Propulsion)
- Level 5: SWBS Digit #2 (e.g., 230 = Propulsion Components)

- Level 6: SWBS Digit #3 (e.g., 233 = Component such as Internal Combustion Engine)

The NCFS uses a system within SAP however, SAP does not provide hierarchical capabilities and the assignments in SAP are not utilized throughout all shops and for all purposes. Additionally, staff members are working to add more levels of information into SAP and many of the items at the component level are not yet entered. The results of the established hierarchy are further discussed in Chapter 4 and are also provided in full in the Appendix.

Once the levels of the assets to collect within each category are determined, the next step is to collect, store and maintain the asset inventory (APTA, 2013).

The asset information required to create the asset inventory can be broken down into the following four groups (APTA, 2013):

1) Asset Attributes
    - Unique name, number, description, asset class/group
    - Asset nameplate (manufacture date, model, serial)
    - Location
    - The quantity of each item
    - Purchasing information (vendor, manufacturer, date, price, warranty, etc.)
    - Date placed in service
    - Expected useful life (projected, remaining, or planned)
2) Asset Criticality (Impact to the organization as a result of failure. Identified by assigning a risk rating to each asset)
3) Asset Condition (Snapshot of its current state to its expected state)

4) Asset History (Work Order Tracking, including ongoing maintenance and rehabilitation)

## CONDITION ASSESSMENT MEASURE

There are different ways to measure the condition of the asset. According to Uzarski et al. (2004), there are three types of condition assessment approaches:

1. <u>Distress surveys with distress quantities</u>: This method is used to get a detailed condition of the asset. It provides the type of distress present, and their severity levels (e.g. high/low), and their quantity.
2. <u>Distress surveys with or without sampling</u>: The process is similar but it is less accurate than the approach discussed earlier. In this process, the quantities are not normally recorded. Instead, the quantities are estimated based on the predefined range (e.g. 1-5%, 5-10%, etc.).
3. <u>Direct condition ratings with or without sampling</u>: This method is the fastest approach to conduct the condition assessment among three. In this method, each component-section is visually evaluated and gives the predefined condition rating based on the criteria for condition rating.

The Federal Transit Administration (FTA, 2016) Authority outlines a similar concept in the guidebook of Facility Condition Assessment which includes reporting and data requirements and condition assessment procedures for transit agencies. The guidebook explains procedures for “measuring and reporting facility conditions of administrative, maintenance, and passenger facilities to the National Transit Database (NTD)” (FTA, 2016). The condition measure that is mentioned by FDOT is based on the five-point scale.

**Table 4: Condition Assessment Scale (FTA, 2016)**

| Rating | Condition | Description |
|---|---|---|
| **5** | Excellent | New or near new asset, No visible defects |
| **4** | Good | Good condition, Slightly old in age, Slightly defective or deteriorated |
| **3** | Adequate | Might require maintenance, moderately deteriorated, |
| **2** | Marginal | Defective and in need of replacement or refurbishment |
| **1** | Poor | Exceeded useful life or past useful life, critically damaged or in need of immediate repair. |

## CONDITION ASSESSMENT PROCEDURE

Condition Assessment (CA) is the process of inspecting, analyzing or testing assets to collect data that is used to measure condition and performance (APTA, 2013). According to Vanier (2001), a condition assessment assists to set the benchmark for comparison, not only between different assets but also the same assets at different times. There is a different degree of involvement of the CA depending on the industry and there are different industry standards of practice for inspecting and monitoring condition. The size of the sample and frequency of inspection is directly propionate to the level of risk associated with the risk. For example, in the case of a ferry, the steering system of the vessel has the higher assigned risk, and, therefore, it requires more frequent inspections.

One of the prime reasons for conducting CA is to provide indicators of the likelihood that the asset will perform as intended (APTA, 2013). The process should be based on several factors including asset hierarchy, technology, and existing business practice, etc. However, there is no recommended methodology for condition assessments and therefore most owners must develop their method internally. However, FDOT provides following recommended steps are herewith offered in order to follow a relatively easy, seamless, affordable and understandable procedure in developing an asset condition assessment (Figure 4) but these steps also showcase the generic level guidance that is typically provided for owners.

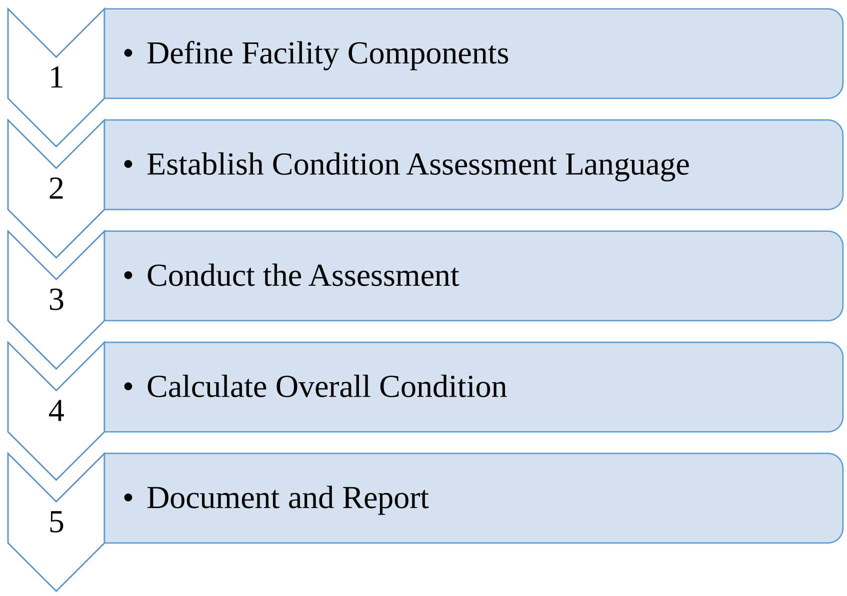



**Figure 4: Condition Assessment Procedure**

**(Adapted from Facility Condition Assessment Guidebook, FTA, 2016)**

## COLLECTION OF DATA FOR CONDITION ASSESSMENT

The condition assessment should report the degree of extent of physical deterioration and the work necessary to maintain the asset. According to the National Research Council Canada (1993) stated that CA gives a measure of the effectiveness of current maintenance programs because it helps to define the remaining useful life of components or systems and compares it with the full economic life expected. Although this is an older definition, it is very relevant to the needs of the NCFS.

A change in condition over time is completely expected and the impact of changes could depend on the physical and operational condition of the asset, which directly influences the performance of the vessel. Therefore, it requires conducting the condition assessments on a continual basis. As a result, each report will update the current information, provide for maintenance work done subsequent to the previous condition assessments and catch any substantial changes in condition before it can affect the performance of the vessel. According to the survey results by Karanja (2017), an expert panel responded to the question about how often condition assessments are conducted and reported an ideal time of 3 years between assessments and with the longest time at 5 years. In addition, Brandt and Rusmussen (2002) mentioned that FCAs can be done every three years or conducting a portion of the overall portfolio annually. However, due to the high cost associated with condition assessments (Kleiner, 2001), many are carried out every five years (Lewis and Payant, 2000). APTA (2013) reports that the transportation industry follows a five-year sequence (maximum) for conducting FCA's.

Collection of data is the part of the process and there are different technologies used to collect information. Sometimes the method can also depend on organizations and consultants. Electronic means for data collection and typically the tools are the same, regardless of the industry discipline because they are generally provided for use with a software package tool. Karanja (2017) reported that collection tools may include paper form, I-Pad, handheld computers, cameras and phone applications.

Owners of large organizations such as the department of transportation, shipyards, or any large municipal infrastructure have a responsibility to maintain the facilities and assets. According to Uddin et al. (2013), an asset management system is an operational package consisting of the methods, procedures, data, software, policies, decisions, which enable the carrying out of all the activities involved in asset management. Although the primary focus of the research was develop a systematic method to categorize and track the condition of the assets for 21 vessels, there is also the need to incorporate the condition assessment data into the operations of the NCFS. Ahluwalia (2008) lists five main fronts of an asset management operation.

i. Assessment of the current condition,
ii. Prediction of future deterioration,
iii. Selection of maintenance and repair strategies,
iv. After-repair condition improvement, and
v. Prioritization of building components for repair given the budget constraints.

The condition rating not only PROVIDES an idea of the asset or component, but it also plays a significant role in calculating the budget for maintenance, because as the condition depreciates the cost of the maintenance will increase (Abbott, 2007). The establishment of asset management procedures include prognostics.

Prognostics is a major challenge for industrial implementation of maintenance strategies where the remaining useful life estimation is an important task (Le Son et al. 2013). Prognostics can also be stated as a prediction of a system's lifetime and its principal objective is to predict the Remaining Useful Life (RUL) before any failure takes place. The RUL can be predicted by using current asset condition and historical operation or maintenance data (Ahmadzadeh, 2014). There are different definitions of prognostics shown in Table 5.

**Table 5: Different definitions for prognostics**

| First Author | Definition |
|---|---|
| ISO13381-1 (2015) | An estimation of time to failure and risk for one or more existing and future failure modes |
| Okoh et al., 2014 | Is defined as the estimation of remaining useful life (or time to failure) of a component or system which can be filtered by existing or future failure modes |
| Engel, 2000 | The capability to provide early detecting of the precursor and/or incipient fault condition of a component, and to have the technology and means to manage and predict the progression of this fault condition to component failure. |
| Hess et al., 2006 | Predictive diagnostics, which includes determining the remaining useful life or time span of proper operation of a component. |
| Baruah and Chinnam, 2005 | Prognostics builds upon the diagnostic assessment and are defined as the capability to predict the progression of this fault condition to component failure and estimate the remaining useful life (RUL) |

For Ferry Vessels, an accurate RUL estimation not only provides value to the cost savings but more importantly, it is of great significance in ensuring system reliability and preventing disaster. According to Son et al. (2012), the prognostic of the system, lifetime is a basic requirement for condition-based maintenance in many application domains where safety, reliability, and availability are considered of first importance and these factors are always considered as a prime concern for ferry vessels. However, in the case of ferry vessels, the typical life is relatively undocumented in terms of a specific figure to utilize for the anticipated life of a vessel. Steve et al. (2016) reported that the mean age of the current U.S. ferry fleet is 29 years and the median age is 25 years. With regards to the durability of the vessels, most data exist in historical reporting from various operations, for instance, the Washington State Ferry System reported in 2014 that the average age of their ferry fleet was 38, and they had a large portion of the fleet nearing 50 years of age. In 2009, the Washington State's Transportation secretary ordered the retirement of any vessels more than 80 years old.

John A. Volpe (Kay et al., 2011) uses a life cycle model that assumes a 25-year life cycle for ferry passengers and 40-year useful life for vehicle ferries. These numbers were based on their internal financial policies as well as the historical and average age of vessels as reported in a Washington Financial Management Survey. The average use of the vessel is also accounted for in their considerations of size, hull type, usage, and maintenance schedule.

Washington State replaces vessels at 60 years of use. Virginia's Department of Transportation announced the retirement of an 81year old vessel from their fleet (Zullo, 2017). In 2013, New York Ferry Department celebrated the 100th anniversary of the Adirondack ferry, but they note that in many cases, many of the long-lasting vessels do not have any of the original parts and assets (aside from structural) on the ferry. This example showcases the importance of the capital renewal efforts and extending its useful life. For North Carolina, the determination of the EUL is 30 years for ferry vessels. To date, the NC Ferry Operations have retired two ferries, the Herbert Bonner (Hatteras Class) at 47 years and the Pamlico (Sound class) at 52 years. In addition, NCFS's oldest ferry is 52 - the Silver Lake (Sound class). Although, they have changed the superstructure of this boat in 1995, the base structure (hull) of the ferry vessel is original.

To summarize, Peter Lauridsen (a consultant for the US-based Passenger Vessel Association) was quoted in an article by Gary Stoller and in the USA Today (2008) stating that “boats can continue to operate indefinitely if well-maintained.”

However, the general scenario of the budget is that there are rarely enough funds to continue effective operations which ensure that maintenance and capital renewal occurs during planned periods (Stoller, 2008). As the age of the vessel increase, the maintenance requirements begin to increase (Figure 5) and more often than not the maintenance budgets rarely can match with the increases. A public agency typically does not have financial flexibility, which may create constraints on the use of available funding and therefore affect maintenance and repair cycles of the fleet (O’Connor, 2014). Regardless of the industry sector, budgeting for maintenance is essential in order to keep it performing and functioning throughout its lifecycle. Ferry vessels have many of the same constraints and issues as any facility when viewed as simply an asset and regardless of the type of asset, management requires a full understanding of what assets exist, and the condition of those assets, as well as an anticipated life.

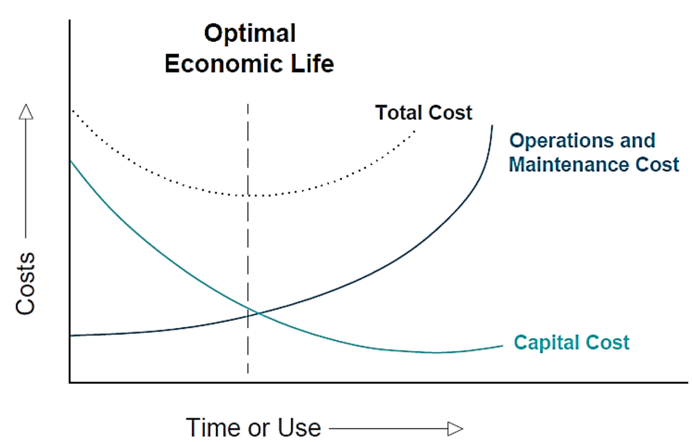



**Figure 5: Time vs Cost curve (Woodward, 1997)**

The estimation of remaining useful life (RUL) gives operators a potent tool in decision making by quantifying how much time is left until the functionality is lost (Saha et al. 2009). According to Moser and Edvardsen (2002), service life (SL) is a key metric that is utilized for economic decision making for return on investment or investment planning (IP) for maintenance. Asset owners realize the financial benefits of extending the life of an asset as long as possible, and in a planned manner (Keady, 2013). This focus with regards to economic asset analysis and equipment service life showcase the need for identified variables and data to assist in estimating the useful life (UL) for an asset.

Vorster (2017) states that all assets are candidates for replacement, or what he terms “defenders” because all assets should be ranked for replacement with reasons to defend that ranking. Additionally, a “challenger” is the consideration of a new replacement for the defender. Although this article was written specifically to address heavy construction equipment, many of the replacement decisions apply to any type of asset. Several of the metrics he recommends are age, increasing costs, decreasing reliability and lack of utilization. Successful techniques for establishing replacement should rely on more than just one of these metrics. The article summarizes the use of Total Cost of Ownership (TCO) in a three-step phased view. A part of this determination includes the consideration of a candidate for replacement when the asset is likely close to, at, or beyond its economic life (not useful life), meaning that cost determinations should be used for Vorster’s method. Figure 6 provides a useful categorization for the phases of an asset.

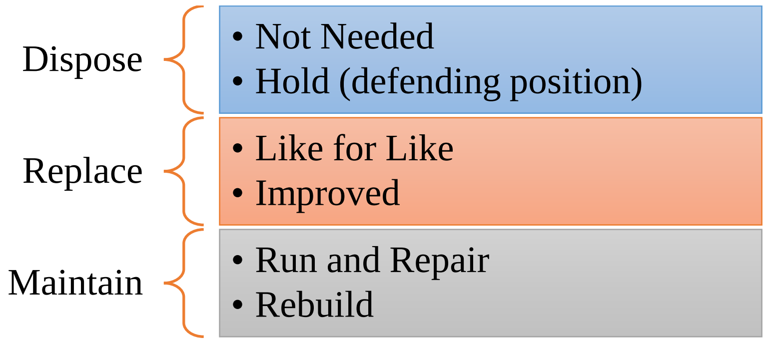



**Figure 6: Three phases of an asset (adapted from Vorster, 2017)**

As discussed earlier, determining remaining useful life is an essential step in order to plan the budget and make a firm decision about replacement/refurbishment of a vessel. There are various methods that can predict the service useful life, for instance, a probabilistic method which is based on probability and statistical data, and simpler engineering method based on reference service life and probability distribution functions of some key factor values (Hovde and Moser, 2004). Variables and factors used in calculating remaining useful life have been applied in methods such as the factor method, point scale system, the life cycle model, and the replacement process system.

## THE ISO FACTOR METHOD

The Factor method was originally developed by the Architecture Institute of Japan which was later adapted by International Organization of Standardization (ISO) Standard 15686 for Service Life Prediction. The International Standard also includes the factor method in "Service life planning" in 2000, in ISO/CD 15686 Part 1. Since then, many researchers have studied the method and it has become a familiar method for practitioners for the prediction of the useful life for any product or component.

Hovde and Moser (2004) provide three definitions which apply to the ISO factor method:

1. Design Life: planned service life, expected service life or service life intended by the designer.
2. Reference Service Life: Service life that a product or component would expect to work or predicted to work for a specific time.
3. Estimated Service Life: "Service life that a building or parts of a building would be expected to have in a set of specific in-use conditions, calculated by adjusting the reference in-use conditions in terms of materials, design, environment, use, and maintenance" (Hovde, 2005).

The purpose of the factor method is to provide an estimate of service life, which is different than service life prediction. By definition, "Estimated Service Life (ESL) is calculated for a set of specific in-use conditions, whereas Predicted Service Life (PSL) is a recorded past performance which should ideally be equal to the reference service life used during calculations" (Lacasse & Sjostrom, 2004; Hovde & Moser, 2004; Davies & Wyatt, 2004). The factor method is based on a reference service life and seven factors (Table 6) that relate to the specific condition of the asset and the reference service life is the estimated life in the conditions that generally assumed or apply to that type of asset or asset system.

**Table 6: Factor of materials and components (adapted from Aarseth & Hovde, 1999)**

| Factors | | Relevant Conditions (examples) | |
|---|---|---|---|
| Agent related to the inherent quality characteristics | A | Quality of components | Manufacture, storage, transport, materials, protective coatings (factory applied) |
| | B | Design level | Incorporation, sheltering by rest of structure |
| | C | Work execution level | Site management, level of workmanship, climatic conditions during the work execution |
| Environment | D | Indoor environment | Aggressiveness of environment, ventilation, condensation |
| | E | Outdoor environment | Elevation of the building, micro-environment conditions, traffic emissions, weathering factors |
| Operating Conditions | F | In use conditions | Mechanical impact, the category of users, wear and tear |
| | G | Maintenance level | Quality and frequency of maintenance, accessibility for maintenance |

Any of these or combination of these factors will affect the service life. The factor method can, therefore, be expressed as this formula (Aarseth & Hovde, 1999):

$$\mathbf{ESLC = RSLC \times A \times B \times C \times D \times E \times F \times G}$$

Where, ESLC = Estimated Service Life of the Component

RSLC = Reference Service Life of the Component

Currently, there are no specific factor values are assigned as a standard for the industry, and therefore the factor values may vary based on the industry need and the component. Aaeseth and Hovde (1999) assigned values ranging from 0.2 (extremely poor) to 5.0 (excellent in the condition). It is necessary to select a specific value for each of the factors, and then the multiplication of that value gives the value of the estimated service life. The result of this equation will be in a single number, which represents the estimated useful life of the component (in terms of years). This method is limited at the component level and therefore, is not optimum for use in determining RUL for ferry vessels. Because every ferry vessel has numerous components and sub-components under specific systems. For the NCFS, there are 21 vessels with over 1700 component level assets, further demonstrating the difficulty of utilizing the method at the component level.

## THE LCCA MODEL FOR THE ECO ISLAND PROJECT

The Eco-Island Ferry project was conducted by an industrial group from northern Denmark and SP, the Technical Research Institute of Sweden. The objective of the study is to compare two different types of ferry vessels and calculate the LCCA to determine which ferry should be replaced by new, more economical alternatives and having a less environmental impact. Although, the objective of the Eco Island Project is different than this study, the calculation of LCCA method can be useful for this research. According to Technical Research Institute of Sweden (Lindqvist, 2012), they have an eight-step approach for the LCCA model.

1. Establish the operating profile
2. Establish the utilization factors

3. Identify all the cost elements
4. Determine the critical cost parameters
5. Calculate all costs at current prices
6. Escalate current costs at assumed inflation rates
7. Discount all costs to the base period
8. Sum discounted costs to establish the net present value

Again, LCCA is not focused on the determination of an EUL but there are components of these methods that apply such as the use of utilization factors.

The John A. Volpe National Transportation Center (Kay et al., 2011) established a model for LCCA but it is less asset-oriented in terms of a full asset management approach. In summary, there is potential for adoption of the formula for vessel maintenance costs and also their used vessel value to assign a ranking based on the consumed life:

Used Vessel Value

(Percentage is representing the life consumed)

100% New

93% for 1-5 years

82% for 6-10 years

64% for 11-20 years

41% for 21 -30 years

20% for more than 30 years old

Annual Maintenance Expenditures

$$\mathbf{[M*F*P] + [(M*V*P) * H_{a} / H_{n})]}$$

Where, M =estimated total annual maintenance costs for the new vessel, (as a percentage of new vessel purchase price)

F = percent of maintenance cost that is fixed (does not vary with vessel hours)

P = new vessel purchase price

V = percent of maintenance cost that varies with vessel hours

$H_a$ = actual annual vessel hours operated

$H_n$ = nominal annual vessel hours (1,000 hours)

The Asset Inventory and Condition Assessment document by the American Public Transportation Association (APTA, 2013) outlined steps to create and/or improve asset management within a transit agency and more importantly, included not just procurement, but also disposal (throughout the life cycle) with three important steps:

1. Define and organize capital assets
2. Develop an asset inventory
3. Assessing condition of assets

Chicago Regional Transportation Authority recommends an LCA process as summarized in the graphic below:

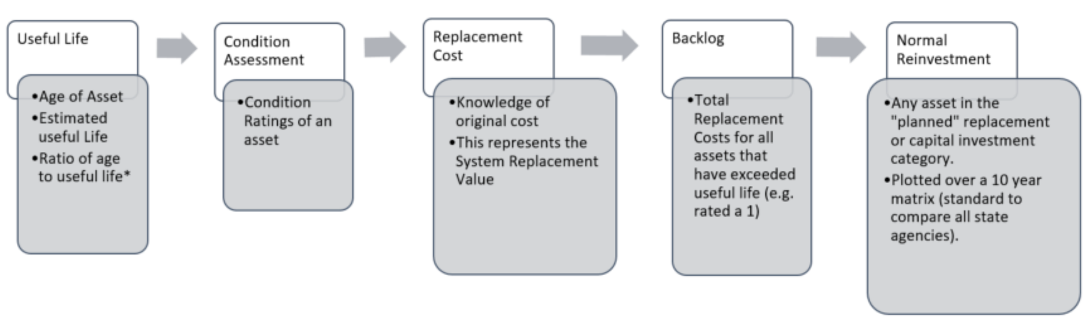



**Figure 7: Inventory Assessment Methodology developed by Chicago RTA (APTA, 2013)**

The Federal Transit Administration has developed a decision support tool TERM (Transit Economic Requirement Model) to estimate the capital funding for the entire U.S. transit industry. TERM was developed and used since 1995 to support preparation of the transit components of the periodic report on the condition and performance of the National's Highway, Bridges, and Transit (FTA, 2016). The State of Good Repair (SOGR) is based on TERM's numerically based system for evaluating transit asset condition. TERM helps to decide the deterioration schedules based on the asset's condition on a scale of 5 (excellent) to 1 (poor). In the assessment of National State of Good Repair Assessment (FTA, 2016), the study considers SOGR for an asset if the physical condition of that asset is at or beyond specific condition index rating of 2.5, likewise, if all the assets of the particular system has an estimated condition index rating is more than 2.5 or equal then the system would be considered in a state of good repair. The SOGR is the outcome of the addition of backlog and normal reinvestment. If the asset that exceeds useful life, it has to replaced and that cost counts as a backlog. Normal reinvestment represents any anticipated large capital investments.

**State of Good Repair (SOGR): Backlog + Normal Reinvestment**

**Annual Average SOGR Need: SOGR/10 year**

**This quantity can be compared to the System Replacement Value*

The Chicago Regional Transportation Authority has used this mentioned ratio of age to useful life can be used to group assets into equal age groups and these groups can then be used as simple measures of asset condition as follows (APTA, 2013):

<u>Ratio: Age to Useful Life</u>

5 = 25% of useful life consumed

4 = 26% to 50% of useful life consumed

3 = 51% to 75% of useful life consumed

2 = 76% to 100% of useful life consumed

1 = > 100% of useful life consumed

This ratio provides a useful rating for the NCFS due to its determination of the useful life consumed based on the flexibility of adaptation to any EUL in years utilized by an owner. For instance, Thomas A Baum ferry vessel was built in 1995 and when using 30 years of useful life, the plan will include a replacement in the year of 2025 - meaning that it has exceeded 73.33% of its useful life by the year 2017. Based on the age to useful life ratio, the assigned rating would be a 3.

## THE REPLACEMENT EVALUATION PROCESS

City of Eagan, Minnesota (MN) is utilizing a minimum replacement standard for all pieces of equipment. There are two requirements that must be met before equipment can be replaced. First is the age of a vehicle/equipment and second is mileage or hour requirement. As an example, categories include both a light vehicle (a sedan) and a heavy vehicle (backhoe). For the light vehicle, in order to be considered for replacement it must reach 10 years or 100,000 miles and for heavy vehicles, it must reach 20 years or 6000 hours of operation. After the mentioned minimum requirements have been met, the process then requires additional applications of information:

I. Vehicle Condition Index (which includes age, mileage and hours, reliability, maintenance and repair costs, condition, cost per mile and risk factor)

II. Age

III. Operational Consideration

After considering all these variables, the city employees will review and make the replacement decision. Furthering this decision would be a review and approval by city administrations as well (Gransberg, 2015).

## THE REPLACEMENT POINT SYSTEM

Charleston County government in South Carolina is using the Replacement Point System as a decision-making process to justify at which point the vehicle reaches the phase of replacement. Many organizations are using a variety of point or scale systems, but this method has the advantage of removing politics out of the replacement process (Owen, 2012):

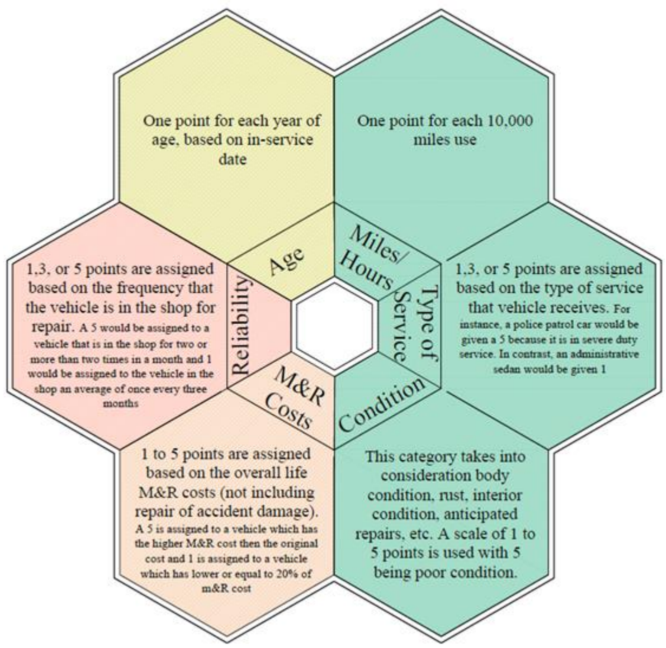



**Figure 8: Replacement Guidelines (adapted from Owen, 2012)**

As shown in Figure 8 the central portion describes the different factors that can affect the useful life and the outer portion represents the point scale for each factor. The result of this method would assign points to the specific asset and would fall under the designated point range and an example is shown below (Figure 9)

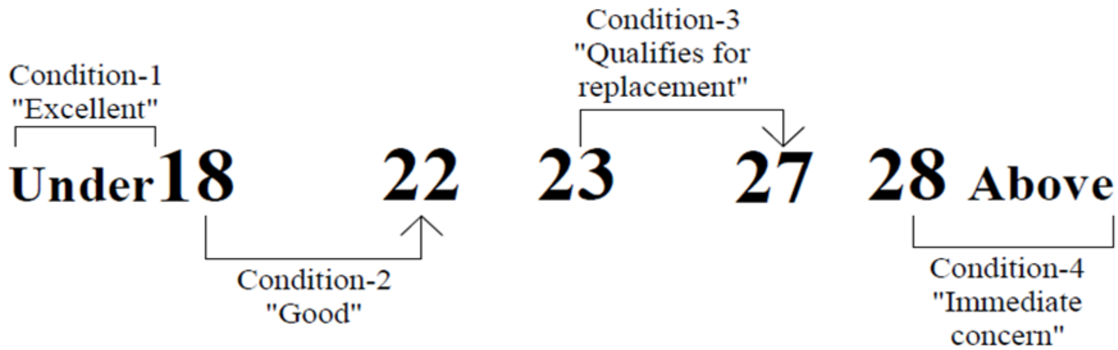



**Figure 9: Point Ranges (adapted from Owen, 2012)**

One example based on the above point system shows a used police patrol car that has 90,000 miles, is in poor condition, poor reliability and it already crossed 80% of its purchase cost to maintenance cost. Based on this scenario, the asset factors would total 32 as demonstrated in Table 7:

**Table 7: Assigns points to the factors**

| Factor | Points |
|---|---|
| Age | 5 |
| Mileage | 9 |
| Type of service (severe) | 5 |
| Reliability | 5 |
| M&R costs | 3 |
| Condition | 5 |
| **Total** | **32** |

The total points are representing the condition of the vehicle is a Condition 4 meaning that this vehicle is an immediate concern and is in the phase of replacement or refurbishment. This method establishes a level of condition and is applicable to the marine industry in terms of the considered variables.

## THE LIFE CYCLE MODEL

The Washington State Ferries (WSF) utilizes a different methodology that is simple but highly effective. The WSF has used a methodology for ferry terminals (not vessels) to know the remaining life and condition of structures. Although it applies to the ferry terminal, it can applicable to ferry vessels as well to determine the remaining life. The methodology has four basic steps (Petrie et al. 2004).

1. Structure Inventory: The first step of the analysis begins with an inventory of basic information which includes a general description of the terminal and the structure, importance category, basic life cycle, year built, replacement life cycle and replacement cost.
    - General Description includes structure type, location, the material of construction and any additional description
    - Importance category which is vital (represents important structures to the terminal) and non-vital (represents all others)
    - Basic life cycle (LC) can be derived from the experience and the industry standards
    - Year built or placed into the service
    - Replacement life cycle means the basic life. The decided age of which the asset or component should be replaced because of the end of the useful life
    - Replacement cost means the capital cost of the new asset or component.

2. Condition Adjustment: This is based on the current condition assessment and from that it represents existing damage and deterioration of the structure to date.
3. Service Adjustment: This represents the service dependent factors meaning the more usage of the structure the less the useful life and vice versa. It denotes an approximation of the future damage and deterioration a structure might tolerate.
4. Remaining Life Calculation: By keeping the year of built and the adjusted life cycle, it can calculate the next work date and to calculate the adjusted remaining life, to be deducted from the next work date (year) to the actual current year.
5. Needs Analysis: After each regular period, the number of structures coming of age and their replacement cost are summed and by using these, capital investment needs can be predicted. The vital subset represents the minimum funding is essential to maintain the functionality of the structure/asset and non-vital describes work to be performed when there is an additional funding available.

Above mentioned methodology used by WSF to determine the remaining life for the ferry terminals, includes Facility Condition Assessment (FCA) as one of the prime factors of their System Condition Rating (SCR). Petrie et al. (2004) stated that "Life cycle analysis, coupled with condition assessment, is a key tool that enables engineering staff and capital planners to systematically focus on those facilities most in need." The WSF method of incorporating condition assessment information as a prime factor in calculating remaining useful life provides a more accurate and realistic result. Using similar considerations, Opus (2012) provided a framework for vessel replacement for British Columbia's ferry system using considerations for safety, service, obsolescence, and fleet renewal.

## RISK ANALYSIS

Risk is the product of probability and consequence and defined by an exposure to loss. For any asset, there are instances of a high probability of failure but low risk, or conversely, low probability but high risk. Considerations for assigning risk include the frequency of loss, consequences, extent of the loss, and the perception of the loss to the ultimate needs of the organization. This risk can be managed but must first be understood. Typical terms that describe risk impacts are safety, equipment, or environmental damage.

## SUMMARY

Based on the literature review for condition assessments, there are many techniques and technologies that can be applied to perform condition assessments, but the visual inspection technique suits the nature of ferry assets because of the diversity of the components involved. A summary of the different industry requirements for asset inventory field types are provided in Table 8 and compared to those in the proposed use by NCFS.

**Table 8: Summary of the information to create the asset inventory**

| Field Type | Building Industry | Department of Transportation | NCFS |
|---|---|---|---|
| Identification | ● | ● | √ |
| Description | ● | ● | √ |
| Location/Address | ● | ● | √ |
| Network | | ● | |
| Primary mode | ● | | |
| Type of the facility/asset | ● | ● | √ |
| Year built or replaced | ● | ● | √ |
| Square Feet | ● | | |
| Condition Assessment | ● | ● | √ |
| Date of condition assessment | ● | | √ |
| Jurisdiction | | ● | |
| Utilization | | ● | √ |

An additional portion of the literature served the purpose of exploring a framework for the use of the condition data, and its use in establishing the remaining useful life. Different agencies and state departments are using a variety of variables to determine the estimated useful life. Table 9 represents the summary of the variables used by different agencies compared to the potential variables for NCFS's ferry vessels to establish a framework to calculate the RUL of their assets.

**Table 9: Summary of the variables which was used by different agencies**

| Variables | Factor Method | Charleston, SC | City of Eagan, MN | WSF | NCFS |
|---|---|---|---|---|---|
| Age | ● | ● | ● | ● | √ |
| Mileage | | ● | ● | | |
| Type of service | | ● | ● | ● | √ |
| Reliability | ● | ● | ● | | |
| M&R costs | ● | ● | ● | ● | √ |
| Condition Assessment | | ● | | ● | √ |
| Vehicle Condition Index | | | ● | | √ |
| Cost per Mile | | | ● | | |
| Risk Factor | | | ● | | |
| Operating Hours | | | ● | | |
| Location | | | | ● | √ |
| Indoor and Outdoor Environment | ● | | | | |
| Design Level | ● | | | | |

# CHAPTER 3: RESEARCH METHODOLOGY

## INTRODUCTION

In chapter two, the literature supports the importance of condition assessment data for asset management and the related efforts. Chapter 2 also includes the different approaches to determine the estimated useful life. This research utilized an applied methodology (case study) to study existing industry practices as applied to the direct needs of the NCFS and the ferry industry.

To support the condition-based asset management plan for NCFS, a recommended framework is proposed to help to conduct condition assessments for the ferry fleet and initiate internal methods for asset management. The framework is focused on developing the asset hierarchy, an asset inventory and a method for conducting condition assessments. The content of this chapter is divided into the main three fronts for this research (Figure 10).

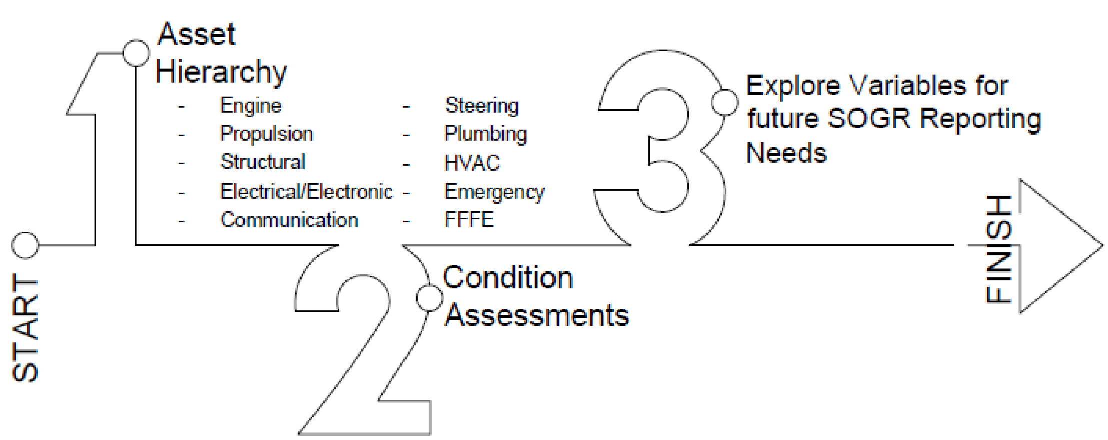



**Figure 10: Scope of Work**

The research compared existing methods with the needs of the NCFS to assist in developing an internal asset management plan, and for ultimately the aim of finding appropriate variables to estimate the remaining useful life and life cycle analysis.

## FIRST DELIVERABLE: ASSET HIERARCHY

The first deliverable includes an asset hierarchy. Keady's (2013) and the FTA's (2018) recommendation for condition assessments begin with the task to "Define Facility Components." The NCFS has a regimented quality control system and specific needs with regards to the information to be tracked for regulatory purposes. One of the most important contributions to a strategic asset management plan is the initial setup of the inventory that constitutes the overall list of assets. Keady (2013) stated that the equipment inventory is the core data and the foundation for almost every task performed in maintenance management. For the case of marine assets, the Naval SWBS breakdown (1997) provides a general list of assets but they include armory and assets not relative to the passenger vessel industry. More specifically, for ferry services, there are no established standards for hierarchy.

An important consideration for the methodology was the costs to complete an inventory assessment. Owner costs will range in the building sector from +0.05 per square foot for a basic list, to +0.50 per square foot for a component level (Keady, 2013). A decision that should be made internally (and differs from owner to owner depending on the levels of need) is how deep into the hierarchy the inventory should track. The method used for this research included a complete assessment and view of all assets to be considered. Photos were taken of most of the components for each vessel. On average, the assessments took about 3 hours per ferry, depending on the class. This did not include time outside of the documentation period for research pertaining to specific components to fully comprehend and categorize items in the system. All components were documented to assist in the development of a hierarchy, but an owner may choose to only complete future condition assessment at higher levels. For example, some owners choose to track small replacement parts only for inventory purposes and not for asset management purposes.

To assist the NCFS with the decision regarding what to track, assets should only be tracked for strategic asset management purposes if the owner has an established planned use for that information – such as for preventative maintenance scheduling or for reporting overall condition. Kong et al. (2016) stated that through the utilization of an inventory database, there are techniques to then identify Life Cycle Costs (LCC) for both the assets as a component and for overall systems. Therefore, if the owner has no desire to schedule PM or track the total cost of ownership for a component, then tracking the asset only adds time and cost, but no benefit to an organization's mission. However, once inventory is collected, procedures should be in place to maintain the inventory and inventory condition since the manpower and cost are significantly greater to regather the information as opposed to maintaining the existing data. For this research, a list of all possible assets is included to enable further consideration later by NCFS if they chose to not track all components.

The process used to create the inventory included the complete collection of assets on the ferry vessel. The list of assets was then compared to the SWBS (Ship Work Breakdown Structure) and discussed with the NCFS employees to complete a determination of overall categories. This method was completely dependent upon the components collected as part of the inventory data for the NCFS but could easily be expanded for other ferry vessel owners.

## SECOND DELIVERABLE: CONDITION ASSESSMENTS

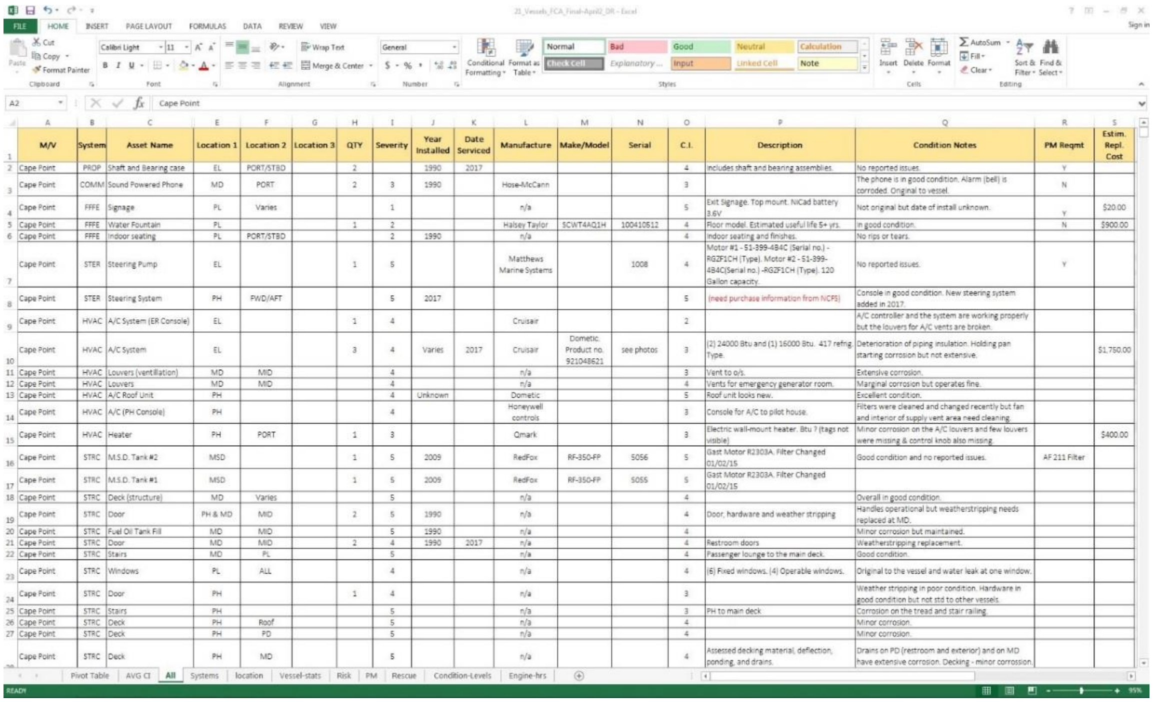
The second deliverable was to establish metrics for the condition assessments of ferry vessels and to identify the required data to summarize and represent the condition of each vessel in a single calculation – titled a Condition Index (CI). To determine the condition index rating for each system and for each ferry, the research team divided the data collection process into two parts. The first part required a needed form to collect data for each of the components and sub-components and to also allow for the necessary notes. There was no access to the internet therefore many of the tools which require connectivity were not an option for our data collection process. For this case, the researchers utilized a hard-copy form during the assessment process (Appendix A). The second part was to enter the data from the condition assessments forms into a database. Additional information from hand notes and interviews from the assessment were also added. To obtain the results as a Condition Index rating, the researchers entered category data for each asset into a field titled "systems" to track assets per the designed hierarchy.

The NCFS has 21 ferry vessels that are categorized by class as shown in Table 10. The summary provides the results of the established categorical data collection. Acquiring the CA data was a time-consuming and extensive task due to a number of assets and complexity of the assets. The Hatteras class is the smallest class with an average vessel length of 149' 9".

**Table 10: Summary of Data Collection per Class**

| Condition Assessment Year | Class | Number of Ferries | Number of Systems | Number of Assets |
|---|---|---|---|---|
| **2017 - 2018** | Sound | 05 | 10 | 538 |
| | River | 09 | 10 | 697 |
| | Hatteras | 07 | 10 | 538 |
| **Total** | | **21** | **10** | **1773** |

The resulting total of 1773 assets were assessed during the CA process which began in February of 2017 and was completed in January of 2018. Figure 11 provides an example the overall Excel data results and column headings. The desired preference to collect in Excel and with individual columns for the data content is due to the potential for the NCFS to upload the data into a Computerized Maintenance Management System (CMMS) in the future. Keady (2013) explains that efficiency asset management stems from data that is normalized and separated so that specific searches for assets by different attributes are possible. Many CMMS software programs offer a means to directly upload Excel spreadsheet data into their systems.



| | M/V | System | Asset Name | Location 1 | Location 2 | Location 3 | QTY | Severity | Year Installed | Date Serviced | Manufacture | Make/Model | Serial | C.I. | Description | Condition Notes | PM Reqmt | Estim. Repl. Cost |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | Cape Point | PROP | Shaft and Bearing case | EL | PORT/STBD | | 2 | | 1990 | 2017 | | | | 4 | Includes shaft and bearing assemblies. | No reported issues. | Y | |
| 3 | Cape Point | COMM | Sound Powered Phone | MD | PORT | | 2 | 3 | 1990 | | Hose-McCann | | | 3 | | The phone is in good condition. Alarm (bell) is corroded. Original to vessel. | N | |
| 4 | Cape Point | FFFE | Signage | PL | Varies | | | 1 | | | n/a | | | 5 | Exit Signage. Top mount. NiCad battery 3.6V | Not original but date of install unknown. | Y | $20.00 |
| 5 | Cape Point | FFFE | Water Fountain | PL | | | 1 | 2 | | | Halsey Taylor | SCWT4AQ1H | 100410512 | 4 | Floor model. Estimated useful life 5+ yrs. | In good condition. | N | $900.00 |
| 6 | Cape Point | FFFE | Indoor seating | PL | PORT/STBD | | | 2 | 1990 | | n/a | | | 4 | Indoor seating and finishes. | No rips or tears. | | |
| 7 | Cape Point | STER | Steering Pump | EL | | | 1 | 5 | | | Matthews Marine Systems | | 1008 | 4 | Motor #1 - 51-399-4B4C (Serial no.) - RGZF1CH (Type). Motor #2 - 51-399-4B4C(Serial no.) -RGZF1CH (Type). 120 Gallon capacity. | No reported issues. | Y | |
| 8 | Cape Point | STER | Steering System | PH | FWD/AFT | | | 5 | 2017 | | | | | 5 | (need purchase information from NCFS) | Console in good condition. New steering system added in 2017. | | |
| 9 | Cape Point | HVAC | A/C System (ER Console) | EL | | | 1 | 4 | | | Cruisair | | | 2 | | A/C controller and the system are working properly but the louvers for A/C vents are broken. | | |
| 10 | Cape Point | HVAC | A/C System | EL | | | 3 | 4 | Varies | 2017 | Cruisair | Dometic. Product no. 921048621 | see photos | 3 | (2) 24000 Btu and (1) 16000 Btu. 417 refrig. Type. | Deterioration of piping insulation. Holding pan starting corrosion but not extensive. | | $1,750.00 |
| 11 | Cape Point | HVAC | Louvers (ventillation) | MD | MID | | | 4 | | | n/a | | | 3 | Vent to o/s. | Extensive corrosion. | | |
| 12 | Cape Point | HVAC | Louvers | MD | MID | | | 4 | | | n/a | | | 4 | Vents for emergency generator room. | Marginal corrosion but operates fine. | | |
| 13 | Cape Point | HVAC | A/C Roof Unit | PH | | | | 4 | Unknown | | Dometic | | | 5 | Roof unit looks new. | Excellent condition. | | |
| 14 | Cape Point | HVAC | A/C (PH Console) | PH | | | | 4 | | | Honeywell controls | | | 3 | Console for A/C to pilot house. | Filters were cleaned and changed recently but fan and interior of supply vent area need cleaning. | | |
| 15 | Cape Point | HVAC | Heater | PH | PORT | | 1 | 3 | | | Qmark | | | 3 | Electric wall-mount heater. Btu ? (tags not visible) | Minor corrosion on the A/C louvers and few louvers were missing & control knob also missing. | | $400.00 |
| 16 | Cape Point | STRC | M.S.D. Tank #2 | MSD | | | 1 | 5 | 2009 | | RedFox | RF-350-FP | 5056 | 5 | Gast Motor R2303A. Filter Changed 01/02/15 | Good condition and no reported issues. | AF 211 Filter | |
| 17 | Cape Point | STRC | M.S.D. Tank #1 | MSD | | | 1 | 5 | 2009 | | RedFox | RF-350-FP | 5055 | 5 | Gast Motor R2303A. Filter Changed 01/02/15 | | | |
| 18 | Cape Point | STRC | Deck (structure) | MD | Varies | | | 5 | | | n/a | | | 4 | | Overall in good condition. | | |
| 19 | Cape Point | STRC | Door | PH & MD | MID | | 2 | 5 | 1990 | | n/a | | | 4 | Door, hardware and weather stripping | Handles operational but weatherstripping needs replaced at MD. | | |
| 20 | Cape Point | STRC | Fuel Oil Tank Fill | MD | MID | | | 5 | 1990 | | n/a | | | 4 | | Minor corrosion but maintained. | | |
| 21 | Cape Point | STRC | Door | MD | MID | | 2 | 4 | 1990 | 2017 | n/a | | | 4 | Restroom doors | Weatherstripping replacement. | | |
| 22 | Cape Point | STRC | Stairs | MD | PL | | | 5 | | | n/a | | | 4 | Passenger lounge to the main deck. | Good condition. | | |
| 23 | Cape Point | STRC | Windows | PL | ALL | | | 4 | | | n/a | | | 4 | (6) Fixed windows. (4) Operable windows. | Original to the vessel and water leak at one window. | | |
| 24 | Cape Point | STRC | Door | PH | | | 1 | 4 | | | n/a | | | 3 | | Weather stripping in poor condition. Hardware in good condition but not std to other vessels. | | |
| 25 | Cape Point | STRC | Stairs | PH | | | | 5 | | | n/a | | | 3 | PH to main deck | Corrosion on the tread and stair railing. | | |
| 26 | Cape Point | STRC | Deck | PH | Roof | | | 5 | | | n/a | | | 4 | | Minor corrosion. | | |
| 27 | Cape Point | STRC | Deck | PH | PD | | | 5 | | | n/a | | | 4 | | Minor corrosion. | | |
| | Cape Point | STRC | Deck | PH | MD | | | 5 | | | n/a | | | 4 | Assessed decking material, deflection, ponding, and drains. | Drains on PD (restroom and exterior) and on MD have extensive corrosion. Decking - minor corrossion. | | |

**Figure 11: Sample of Condition Assessment Data for 21 ferry vessels**

## THIRD DELIVERABLE: SUMMARY OF EXISTING APPLICATIONS

<u>The third deliverable</u> is to determine the primary factors which may have a significant impact on determining the remaining useful life of the vessel. The literature contains various studies which acknowledge the use of multiple variables in determining the useful life of an owner's assets. It is evident from the various methods used (e.g. Charleston, SC and the City of Eagan, MN) that the choice of appropriate variables has a significant impact on determining appropriate strategy and is dependent on the needs of the owner and the type of industry. Therefore, reviewing various methods from the literature served as a reference which resulted in the determination of four overall variables. The variables may now be considered for a new framework for the calculation of the remaining useful life of a ferry vessel:

1. Maintenance and Repair (M&R) costs: By knowing the M&R costs, assumptions can be made about the condition of the fleet. However, the M&R costs should not be used singularly because there are two ways to interpret annual spending. If the spending amount on the ferry vessel is higher than the optimum amount, then it means that the ferry vessel is not in a good condition and potentially indicating deterioration. In other words, "The cost of maintenance work increases as the condition deteriorates, and this is the primary reason for the decaying the built environment" (Abbott et al. 2007). However, if a component is replaced as a result of a maintenance need, the condition has then improved. Charleston County and City of Eagan are using this as one of the variables that should be used for determining remaining useful life. The metric is used often but caution should be taken with regards to its indication of condition.

2. Age: Age is one of the primary variables typically used for determining remaining useful life because based on the age of an overall asset, metrics are used to determine what percentage of the age has been consumed. However, this calculation requires that owners utilize an arbitrary (in some cases) number of years for an estimated life. Owners often use what manufactures specify to be an estimated year/date to replace an asset, but in the case of a ferry vessel that utilizes numerous assets, it is difficult to predict a useful life. For the basic calculation, it makes the process an easy one for calculating the remaining useful life. For instance, a manufacturer gives an estimated number of hours for an engine (in this case hours to define its life cycle) to work properly - based on the owner performing required maintenance. The Chicago Regional Transportation Authority has used the ratio of

age to useful life for establishing groups for different age categories of the assets. Charleston County and the City of Eagan has used this also as one of the variables to determine the remaining useful life for vehicles.

3. <u>Location points/Use conditions:</u> Washington State utilizes a location condition as part of their life cycle calculation (also refer to Table 9). Consideration for location due to two primary reasons. First, its use by another ferry operation and additionally due to the internal concerns of the NCFS stating that vessels on the Hatteras route are generally in worse condition upon arrival to the shipyard (as a result of extensive use and water conditions). The water and depth conditions affect the vessels, but at this point, that effect is to an unknown degree. An additional benefit in tracking asset condition is the possibility to review the work orders for specific issues of the different classes of vessels as well as their routes to identify trends for specific routes. This would require extensive historical data and to date, the NCFS has only tracked work orders in SAP for approximately 1.5 years and not for all 21 ferry vessels.

4. <u>Condition Assessment</u>: The CA has a significant impact because it showcases the actual condition of the system or vessel, and therefore, it is a prime factor in determining the estimated useful life. There are three ways that the CA data can benefit to the organization. First, based on the historical data of condition assessments, it is possible to eventually forecast the condition of the vessel. Second, budget planners can plan their budget according to the condition and severity of the assets. Third, asset managers can track the condition and also prioritize the maintenance work based on CA data. In the building industry, it is general practice to

incorporate the CA data in calculating the estimated useful life, however, there are limited sources who have published their use of CA data for calculating the estimated useful life for transportation vehicles. Charleston, South Carolina (Owen, 2012) has included Condition as one of the factors to determine the useful life for vehicles. Aside from the Washington State Ferry system, most organizations do not use CA as a consideration applied to ferry vessels to determine the remaining useful life.

# CHAPTER 4: PRESENTATION OF RESEARCH RESULTS

This chapter presents the results of the three deliverables outlined in Chapter 3. The first deliverable of the framework was to create an asset hierarchy based on the initial review of information from NCFS's past records as well as the first condition assessment (Swan Quarter ferry vessel). During the first months of condition assessment, a list of categories for documentation was created for the ferry assets (Figure 12). Equipment categories may eventually be refined for the needs of the NCFS. For example, the FTA (2016) specifies that sprinkler systems are to be classified as part of a separate category in fire protection. Other fixtures not associated with fire protection are part of Plumbing.

The Navy SWBS structure (1997) categories the entire sprinkler system in Auxiliary Systems. It also states that staircases are classified as part of the Interior, but any fire escapes on the outside of a building (for commercial construction) are classified as part of the Shell. In an effort to modify existing standards with consideration of the well-established standards within the building industry, this research categorized stairs and vessel escape hatches as a part of the Structural category due to the material and the maintenance tracking.

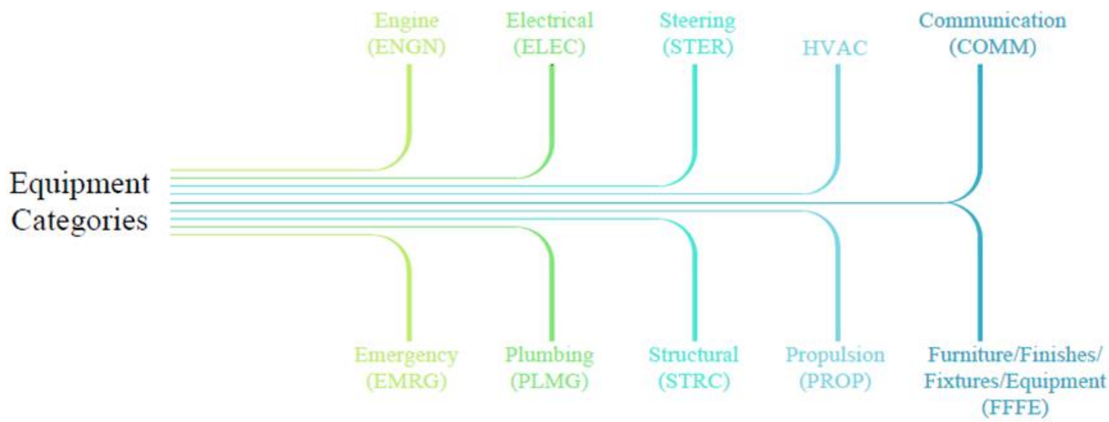



**Figure 12: Asset Hierarchy**

To assist the NCFS with a similar hierarchy, the researchers propose a resulting list of assets (Appendix B). Additionally, as shown in Figure 13 the first level represents the system name, the second level represents the generic asset name and the third level is showing the sub-assets. A similar structure is utilized in the SWBS breakdown and in the commercial building industry.

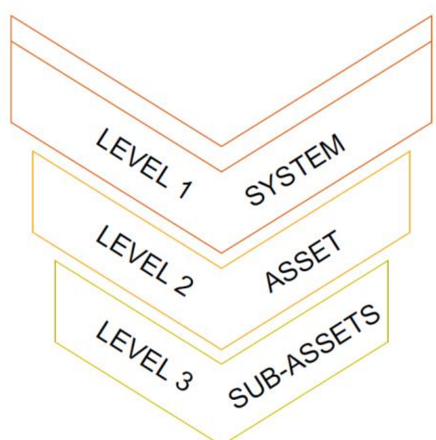



**Figure 13: Ferry Asset System Level Categories**

The complete asset list is provided in Appendix B and shows the use of the three resulting established levels. NCFS may also use the document as an asset inventory resource and as a checklist for their current maintenance needs. Ultimately, the final list can be modified if needed and imported into a computerized asset system to accommodate the current operations. The list includes all assets but as stated in the methodology, the NCFS will need to internally decide the levels at which they plan to track their assets. There are many components that require maintenance and the current list includes 225 first level items, providing insight as to the number of components a ferry owner must not only assess for condition but must also maintain. If each vessel has between 225 to 250 components, then the total number of assets in NCFS fleet includes over 5000 pieces of equipment which must be purchased, managed, tracked and maintained.

The second deliverable was to develop a method for conducting the condition assessments and to complete the assessments for 21 vessels. The research team has followed the steps outlined by FTA (2018) and as shown in Figure 4. To ensure consistency within the DOT asset management needs, the FTA (2016) five-point scale (Figure 14) was adopted for use as the assigned rating scale whereby an assignment of five was used for an asset that is in excellent condition and a rating of one was assigned to assets in poor condition and to those that require refurbishment or the need to be replaced.

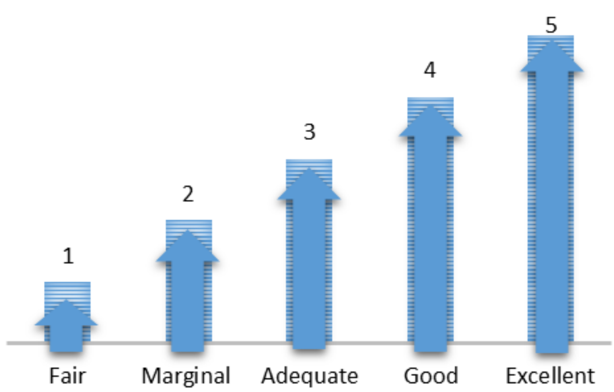



**Figure 14: Five Point Scale (FTA, 2016)**

The condition assessment was conducted over a period of 12 months and collected data to measure and evaluate the condition of each vessel. This process included a visit to each vessel and data was collected with a visual inspection and manually data entry in a form created for this purpose (Appendix A). Once data was collected, the manual entries were entered into a database with the capability to export to Excel. Once the data was exported into Excel, the spreadsheet was used for tasks, such as sorting, grouping, automating, and ultimately used to prepare the summary reports. After analyzing the condition assessment data, there are three overarching reporting metrics presented.

I. <u>The lowest condition assessment rating based on CI</u>: Each ferry has 10 systems which include an average of 85 assets. One advantage of utilizing system categories is the capability to review condition based on that particular category. After assigning the CI for each asset, the results in the last row represent the total averages and a final CI for that vessel. The results are presented in Figure 15. Based on the results, the Southport ferry has the lowest condition index of 3.75. This particular ferry has consumed 22 years of the 30-year anticipated replacement time (or a consumed 74% of its useful life). For the Southport ferry, Propulsion and HVAC systems have lowest CI of 2.00 and 2.50 respectively indicating that the systems are at the highest level of concern for budgeting and maintenance planning.

Ferry Vessel

| System | Cape Point | Carteret | Cedar Island | Chicamacamico | Croatoan | Fort Fisher | Frisco | Gov. Daniel Russell | Gov. James B Hunt JR. | Hatteras | Kinnakeet | Lupton | Neuse | Ocracoke | Roanoke | Sea Level | Silver Lake | SouthPort | Standford White | Swan Quarter | Thomas A Baum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Communication | 3.50 | 4.17 | 3.50 | 5.00 | 4.25 | 4.50 | 5.00 | 3.67 | 5.00 | 4.50 | 4.33 | 3.00 | 3.00 | 4.00 | 4.20 | 4.33 | 3.50 | 3.67 | 5.00 | 4.71 | 4.00 |
| Electrical | 4.33 | 4.26 | 4.65 | 3.64 | 4.13 | 4.53 | 4.56 | 4.42 | 4.33 | 4.19 | 4.31 | 4.79 | 4.25 | 4.19 | 4.05 | 5.00 | 4.55 | 4.38 | 3.94 | 4.57 | 3.86 |
| Emergency | 4.50 | 4.38 | 4.82 | 4.17 | 4.40 | 4.33 | 4.21 | 4.33 | 4.83 | 4.60 | 4.73 | 4.64 | 3.82 | 4.50 | 4.60 | 4.85 | 5.00 | 4.25 | 4.13 | 4.75 | 4.29 |
| Engine | 4.50 | 4.14 | 4.50 | 2.50 | 4.50 | 4.60 | 4.00 | 4.60 | 4.00 | 4.00 | 4.00 | 4.57 | 4.25 | 4.00 | 4.33 | 5.00 | 5.00 | 4.00 | 3.50 | 4.86 | 3.33 |
| FFFE | 4.33 | 3.69 | 3.56 | 3.60 | 4.29 | 4.00 | 4.11 | 3.83 | 3.75 | 3.63 | 4.00 | 4.00 | 3.33 | 3.80 | 3.50 | 4.60 | 4.38 | 3.00 | 3.33 | 4.60 | 3.40 |
| HVAC | 3.29 | 3.00 | 3.10 | 3.17 | 3.63 | 3.20 | 4.13 | 3.50 | 4.00 | 3.83 | 4.00 | 4.20 | 2.57 | 3.67 | 4.00 | 4.67 | 3.20 | 2.50 | 3.00 | 4.64 | 3.43 |
| Plumbing | 4.00 | 4.50 | 4.00 | 3.55 | 4.14 | 4.40 | 4.22 | 4.50 | 3.00 | 4.29 | 4.36 | 4.29 | 4.57 | 4.60 | 4.00 | 4.63 | 4.17 | 4.83 | 3.33 | 4.20 | 3.80 |
| Propulsion | 4.00 | 4.00 | 4.00 | 4.50 | 4.50 | 4.50 | 4.00 | 4.00 | 3.33 | 5.00 | 5.00 | 5.00 | 4.50 | 4.00 | 4.50 | 5.00 | 4.00 | 2.00 | 4.00 | 4.00 | 4.00 |
| Steering | 4.50 | 4.00 | 3.50 | 5.00 | 5.00 | 5.00 | 4.50 | 4.00 | 4.00 | 4.00 | 4.67 | 5.00 | 5.00 | 4.33 | 5.00 | 5.00 | 4.50 | 5.00 | 4.00 | 5.00 | 3.50 |
| Structure | 3.95 | 4.03 | 4.63 | 3.32 | 4.31 | 3.89 | 4.05 | 4.06 | 4.50 | 4.53 | 4.45 | 4.25 | 3.86 | 3.77 | 3.73 | 4.14 | 4.73 | 3.83 | 3.60 | 4.30 | 4.14 |
| Average CI | 4.09 | 4.02 | 4.03 | 3.84 | 4.31 | 4.29 | 4.28 | 4.09 | 4.08 | 4.26 | 4.39 | 4.37 | 3.92 | 4.09 | 4.19 | 4.72 | 4.30 | 3.75 | 3.78 | 4.56 | 3.78 |

CI

2.00 5.00

**Figure 15: Condition Index Rating System Wise**

II. <u>The lowest condition assessment rating for a **system**</u>: An additional area of analysis included the data for 10 systems (Figure 15). The results showcase the identified the systems for future review for potential purchasing decisions and the potential for the systems requiring higher levels of budgetary needs. As shown in the Figure 16, HVAC and FFFE have the lowest condition index rating 3.56 and 3.84 respectively. FFFE is typically not a concern for Coast Guard inspections and is understandably not a high priority for planned maintenance periods.

**Table 11: Analysis of Various Ferry Systems**

| Year | System | Brief Description | Total Number of Assets |
|---|---|---|---|
| 2017 and 2018 | COMM | Communication | 64 |
| | ELEC | Electric/Electrical | 464 |
| | EMRG | Emergency | 232 |
| | ENGN | Engine | 91 |
| | FFFE | Fixtures, Furniture, Flooring, and Equipment | 147 |
| | HVAC | Heating, Ventilation and AC | 174 |
| | PLMG | Plumbing | 153 |
| | PROP | Propulsion | 33 |
| | STER | Steering | 32 |
| | STRC | Structure | 383 |
| **Total** | **10 Systems** | | **1773** |

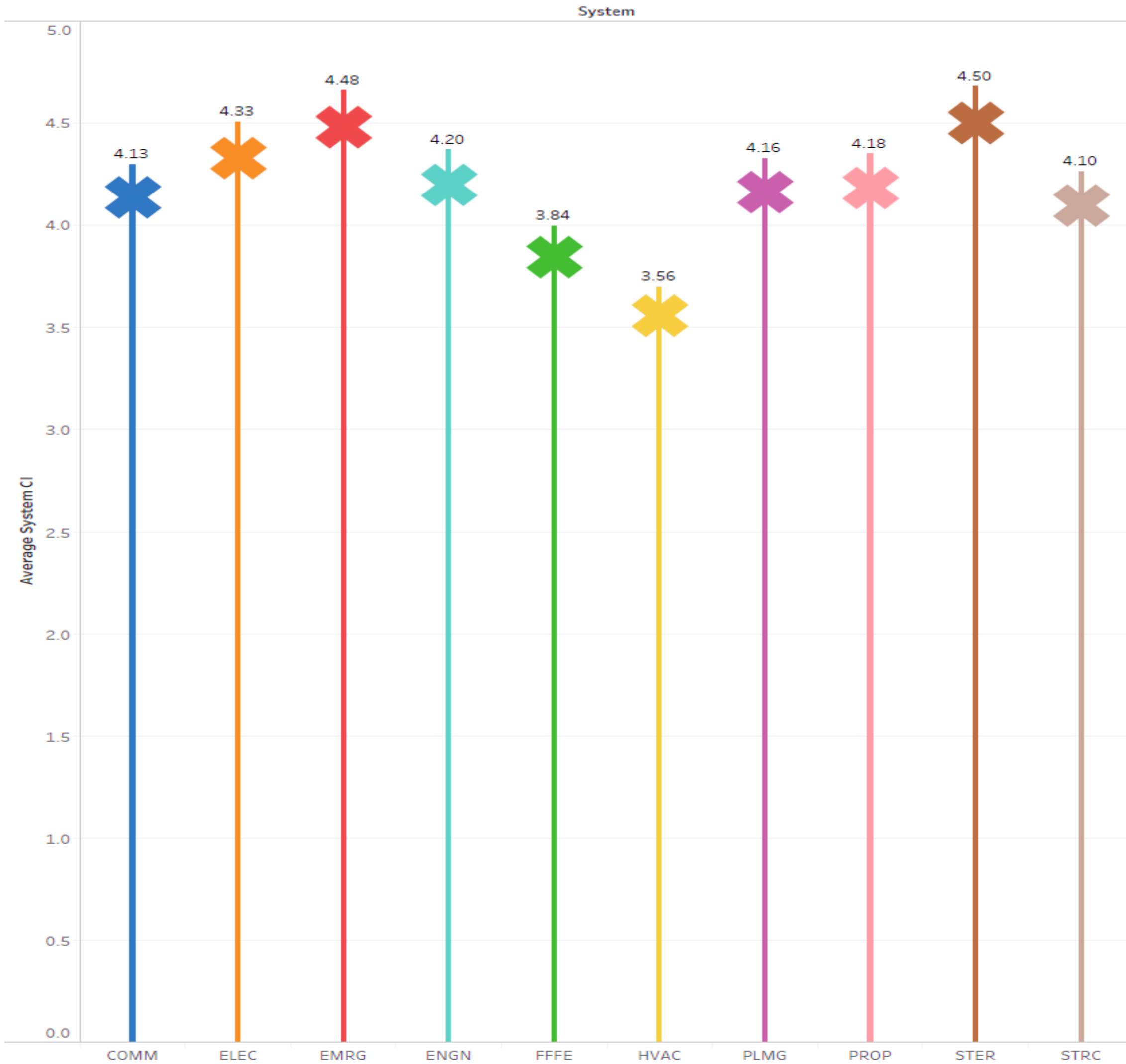



**Figure 16: Average System CI**

III. <u>The comparison between age and condition assessment rating</u>: This section assists with the understanding about whether age or M&R cost can represent a good indication for the condition of the vessel. As shown in Figure 17, the data was used to compare age and M&R costs with the condition index rating. It is evident that age does not provide a good metric for the condition of the vessel. For instance, the Sea Level has only consumed 7 years and this vessel has a 4.63 condition rating, however, the Gov. James B. Hunt Jr. has consumed 34 years, but it has a 4.23

condition rating, a considerably high rating for its age. There is not a large difference between condition index ratings but there is a large difference between numbers of years has consumed. Again, it should be noted that there is an acceptable threshold for the Coast Guard for many of the assets and there is never situation where certain ferry vessel components drop below marginal condition.

The NCFS provided data for the M&R cost values for funds spent within the July 2016 till June 2017 time period. After comparing M&R cost and CI, it can be summarized that M&R cost do not represent the condition of the vessel. As an example, NCFS has spent $1,138,893 on the Croatoan which is 15 years old and has a 4.28 CI and conversely, they have spent only $127,095 on Floyd J. Lupton which is 18 years old and has a 4.27 CI. It is important to note that M&R cost figures include all maintenance costs and is currently not tracked/assigned based on a specific system. Therefore, it is not possible to compare the dollar value used for the assets/component/purpose.

In essence, any single variable is not a good indicator for condition (e.g. assigning a number for an overall vessel) and likewise, an individual variable is not optimum for determining the useful life. Thus, the four presented variables are recommended for consideration for the framework for the calculation the remaining useful life.

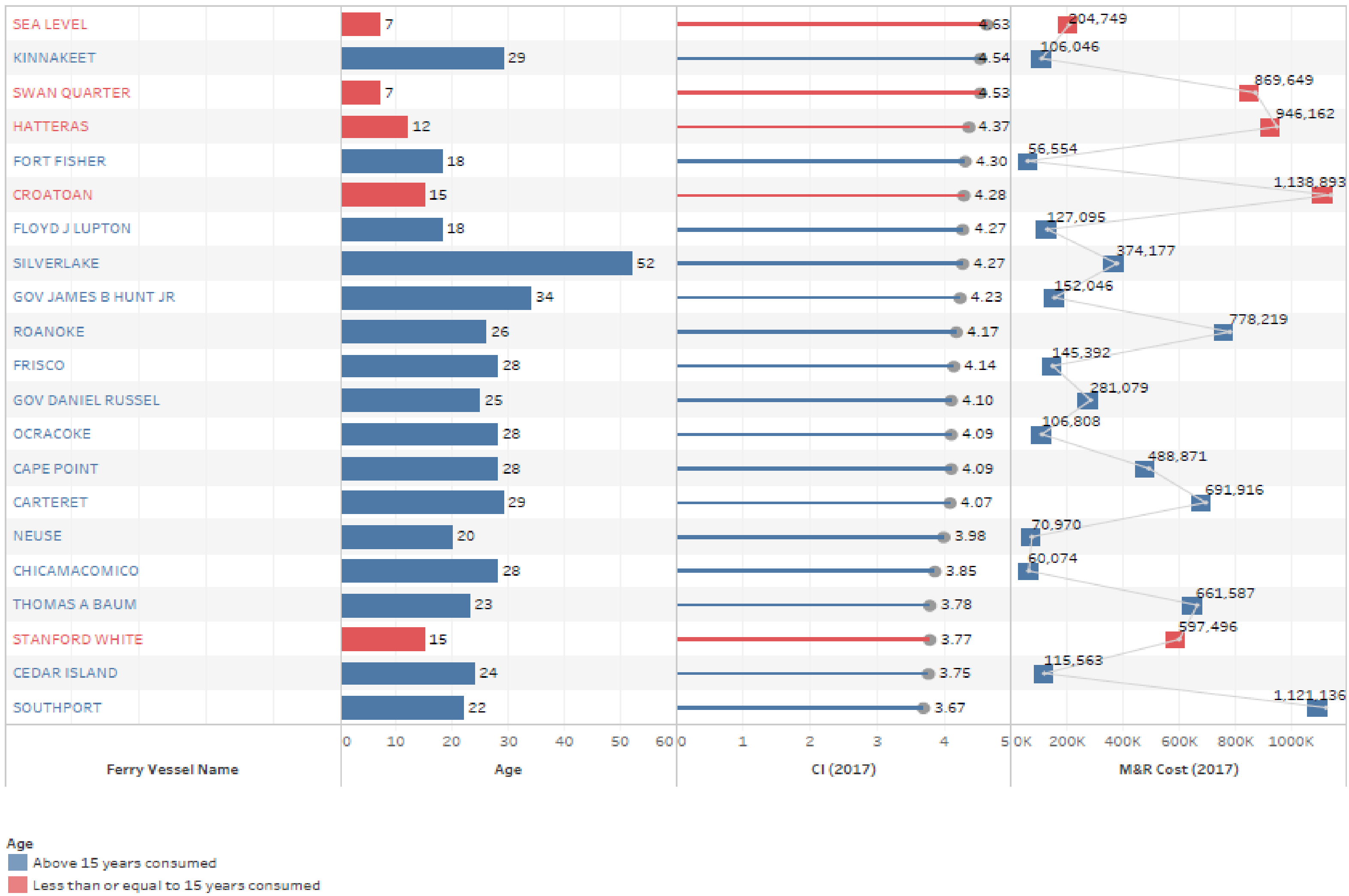



**Figure 17: Showing CI with Age**

As a result of the third deliverable, this section represents the effort to develop the considerations for a future framework for the calculation of the remaining useful life. Utilizing the reference of Charleston, South Carolina's point scale system, the factor method, the life cycle model developed by WSF, and the city of Eagan's replacement process system, the recommendation is to use a 5-point scale system (1 being poor and 5 being excellent) to provide a common ranking system for each of the variables for consideration:

The overall proposed calculation will combine the discussed variables as follows:

**EUL (designated as the Adjusted Replacement Year)**

**= Original Replace Year + Condition Adjustment**

**+ Service Adjustment**

**Service Adjustment = Average of (M&R Points + Age Points + Location Points**)

Items 1-3 as explained below are combined into a "Service Adjustment" calculation.

I. <u>Maintenance and Repair Points</u>: 1 to 5 points are assigned based on the total M&R percentage calculation. A 1 is assigned to a vessel which has spent 100% of the M&R costs and 5 is assigned to a vessel which has an excellent condition and has no M&R percentage on the initial cost (Table 12). M&R Percentage formula is useful to convert the M&R cost into percentage.

$$\text{M\&R Percentage} = \frac{\text{M\&R cost x 100}}{\text{Initial Cost or purchase cost}}$$

For example, the NCFS has spent $1,121,136.06 for maintaining the Southport vessel and the initial cost (purchase cost) for Southport is $4,686,700.00. By using

M&R percentage formula, the NCFS has spent 24% of its maintenance cost on initial cost and would be assigned (Table 12) 4 points.

**Table 12: Points scale system for M&R cost and Ratio of Age to Useful Life**

| Percentage Range | Points |
|---|---|
| 80% ≤ 100% | 1 |
| 60% < 80% | 2 |
| 40% < 60% | 3 |
| 20% < 40% | 4 |
| 0% < 20% | 5 |

II. Age Points: The Chicago Regional Transportation Authority has used the ratio of age to useful life (mentioned in Chapter 2) to assign groups for different aged assets. Similarly, the age to useful life ratio is appropriate to use to obtain the points to apply to the useful life consumed. The previously mentioned scale (Table 12) is used for this variable also. A 1 point is assigned to a vessel if the ferry has consumed 100% or more than that and 5 point is assigned to the vessel if the ferry has consumed 20% or lower than that. For example, the Southport at 74% of its useful life would be assigned (Table 12) two points.

III. Location Points: This variable is dependent on the depth and salinity condition because it affects the vessel's hull, a critical asset. For example, the ferries require channels roughly 80 feet wide and eight feet deep to travel safely along the Outer Banks (Reide, 2017). The natural depth of Pamlico Sound is about four feet, which may indicate more frequent issues with the hull because of the low depth. Additionally, the salinity of the waterways may also affect each vessel. Some routes are near inlets where salinity may be as high as 35 parts per thousand (ppt). The Swan Quarter ferry travels in salinity of 5-15 ppt (depending on river flow) to 30 ppt near Hatteras. Others, are typically in waters between 5-15 ppt, depending on precipitation and river flow (Reide, 2017). By documenting the hull maintenance requirements (corrections for corrosion and dents) the conditions may indicate possible structural longevity and future manpower requirements in terms of time and repair costs for specific vessels based on their primary route. There are five different locations (Table 13) that have different depths and salinity content. For example, the Southport ferry (at the SouthPort terminal location) if utilizing the assigned ranking determined by NCFS, would be assigned three points.

**Table 13: Assigned Points based on Location (Ranking was determined by NCFS)**

| **Locations** | **Ranking** | **Location points based on water condition (depth and salinity)** |
|---|---|---|
| Hatteras | 01 | 01 |
| Cedar Island – Swan Quarter – Ocracoke | 02 | 02 |
| Southport | 03 | 03 |
| Cherry Branch – Pamlico River | 04 | 04 |
| Currituck | 05 | 05 |

IV. Condition Assessment/Adjustment: For this variable, the scale is already mentioned in Chapter 4 (Figure 14). However, there are some changes with the condition assessment data. The researchers have assigned weightage percentages (Table 14) to all the systems based on the ranking given by NCFS's quality assurance professionals.

**Table 14: Ranking and Weightage as per criticality of the system**

| Systems | Ranking | Weighted Percentage |
|---|---|---|
| **Emergency** | 01 | 14.0% |
| **Structure** | | 14.0% |
| **Engine** | 02 | 11.5% |
| **Propulsion** | | 11.5% |
| **Electric** | 03 | 9.5% |
| **Steering** | | 9.5% |
| **Communication** | 04 | 8.5% |
| **Plumbing** | | 8.5% |
| **HVAC** | 05 | 7.5% |
| **FFFE** | 06 | 5.5% |
| **Total** | | 100.0% |

It is important to assign the weightage based on the severity of the system to the ferry vessel. For instance, issues determined by the United States Coast Guard (USCG) hold priority in terms of funding and importance and therefore is assigned the maximum weight for those categories. Likewise, FFFE (Furniture, Finishes, Fixture, and Equipment) has lower severity than any other systems since furniture has less of an impact on day-to-day operations and therefore is assigned the minimum weight factor. Percentage of a system formula is useful to convert the assessed CI into percentage.

$$\text{Percentage of a system} = \frac{\text{Assessed CI Rating}}{\text{Maximum CI Rating}} \text{ X Weighted Percentage assigned to a system}$$

Where, maximum possible CI rating is 5 (for this study, 5-point scale system is used). The percentage scale (Table 15) is based on the condition percentage. Similar to the WSF, the longest EUL was determined based on the NCFS's historical data. Since there have only been two surplused vessels, both 52 years, the longest EUL was set at 20 additional years and the condition index was equally divided based on this determination.

**Table 15: Condition Adjustment based on the percentage scale**

| Percentage Scale | Condition | Condition Adjustment (yrs) |
|---|---|---|
| 0% < 20% | Poor | 0 |
| 20% < 40% | Marginal | 5 |
| 40% < 60% | Adequate | 10 |
| 60% < 80% | Good | 15 |
| 80% ≤ 100% | Excellent | 20 |

For instance, the Southport vessel's HVAC system has actual condition rating of 2.50 and would be weighted more heavily than other components. However, in the application of weighted percentages, the overall percentage of the Southport vessel would be 76% and would be categorized as a vessel in good condition (Table 15). Therefore, the condition adjustment of 15 years would be added as the adjustment in useful life.

Based on the literature review and by referencing various organizations' methods, these mentioned four variables are acknowledged into a framework for the calculation of remaining useful life. These variables would complement as an additional feature to support better recording of asset condition. However, this framework has some limitations:

I. There is a possibility of calculating one variable multiple times. For instance, Location variable is determined as an individual variable, however, the location is already accounted for in part due to the condition assessment data.

II. The proposed framework requires future research and validation for the following:

a. Industry study for overall use of the developed hierarchy should be validated by industry professionals. Additional research should include components that may be applicable for larger ferry vessels and the inclusion of newer technologies and power systems now considered for the ferry industry.

b. Further analysis using historical data and industry consent to refine and validate the calculation for determining the EUL.

*Note: An example of the proposed calculation is shown in Appendix E*

Each of the variables presented as part of this research require further scrutiny. The variables were proposed as considerations due to their historical uses with other transportation and construction industries but may not be optimum for the ferry industry.

# CHAPTER 5: CONCLUSIONS AND FUTURE RESEARCH

## CONCLUSIONS

Ferry vessels are essential for the development of coastal communities and ultimately, to provide a multi-model transportation system that would help to create strong public transportation in the United States. Many shipyards are facing asset management issues and are a challenge to manage, particularly in the light of constrained budgets which complicate decisions about long-term capital budget. Such decisions are highly dependent on an accurate condition assessment process. The main goals to develop an asset inventory and hierarchy for ferry vessels will assist ferry operations with incremental steps toward asset maturity. Additionally, a method for determining long-term budgetary decisions using condition data vs. financial data will support early decision making for operations that do not have extensive financial

Ferry vessels are complex in nature due to the large number of diverse, interrelated components and systems involved. There is a high level of subjectivity involved with developing the condition assessment and the proposed methodology allows for specific feedback at the component level to be averaged into a final CI rating. Components can be assessed by crew on an incremental basis with minimal effort. The development of the asset hierarchy assists to form a structured method of conducting the condition assessments.

Based on the objective of the study, the main contribution is the analysis of condition assessment data for a sample of 21 ferry vessels of NCFS. Based on the analysis, the condition data may be included in the capital planning process and assist to formalize inspection frequency and prioritize inspection tasks, especially at the system level where more frequent inspections are evident as a result of the lower CI scores. This study has contributed to industry knowledge by:

I. Providing a proposed asset hierarchy and a resulting asset inventory that may be uploaded to a CMMS system.
II. Recommended list of items to track in CMMS (columns in spreadsheet) to provide a historical database for future analysis and decision making.
III. Recommending considerations for higher (more mature) levels of asset management for ferry operations.

Recommendations to NCFS:

I. Incorporate the condition assessment data into the CMMS (Computer Maintenance Management System) software or asset management software to manage and track the condition of the assets.
II. Analyze the condition assessment data to prioritize the budget for maintenance and repair. For instance, HVAC system and its assets rank lower in condition index rating. This is supported by interviews stating how often systems must be replaced. Consider tracking types of mechanical units for tracking longevity of specific manufacturers.
III. Standardize the asset hierarchy in order to improve the sharing of important maintenance data/information not only among departments but within organization and provide a means to analyze historical data.

IV. To eliminate the manual hand-written condition assessment forms, NCFS should consider the collection process (electronically while in the shipyard) if advertising for a CMMS system.

V. NCFS should develop a condition assessment schedule to ensure continuity and provide a means to update the provided results as opposed to conducting a new assessment. Additionally, consider a phased assessment to review while the vessel is underway and additionally while the vessel is in dry-dock based on the noted advantages of each.

## RECOMMENDATIONS FOR FUTURE RESEARCH

There are multiple variable options that can be incorporated into the calculation of remaining useful life presented in Chapter 3 (third deliverable). Future research may begin the exploration of variables that could affect the remaining useful life specifically for the ferry industry. The presented research completed the literature review for how different agencies are using different variables to estimate the useful life; but this also opens new opportunities for a more analytical study of the potential variables. The following issues need further study:

- Providing a proposed asset hierarchy and asset inventory for ferry vessels to be further developed for the industry.
- The consideration of multiple input variables, combined with the condition assessment to determine a more dependable estimated useful life.

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# APPENDIX A. CONDITION ASSESSMENT FORM

## Condition Assessment

M/V: Cape Point FC Date: 04/23/2017

| | | | |
|---|---|---|---|
| System: | ELEC | | |
| Asset Name: | Radar | | |
| Location: | PH | Roof | |
| Risk Lvl: | | | |
| Asset ID: | | | |


Asset Metadata:

Year Installed:
Date Serviced:

Manufacturer/Make/Model/Serial#

| | | | |
|---|---|---|---|
| Furuno | | | 5173-5285 |

Description:

Type - RSB-0070
Antena and structure support

| C.I. | Description |
|---|---|
| 05 | Excellent |

PM Requirement:

Condition:

Corroded clamps.

University of North Carolina Charlotte

APPENDIX B. GENERAL ASSET LIST

| Systems (Level 1) | Assets (Level 2) | Sub-assets (Level 3) |
|---|---|---|
| **Communication** | Emergency Phone | Sound powered telephones |
| | Marine Radar VHF | |
| | Beacons and Sounders | |
| | PA Speakers | |
| **Electrical** | Electrical Panel | Motor Controllers |
| | | Breaker |
| | | Emergency Switchboard |
| | | Unit Gauge Panel |
| | Thruster Controls | |
| | Power | Outlets |
| | | Shore Power Plug |
| | | Batteries |
| | Lighting | Interior Lighting |
| | | Outside Deck Lighting |
| | | Navigation Lights |
| | | Navigation Light Control Panel |
| | | Search light |
| | | Flood light |
| | | Compass light |
| | | Overhead fluorescent Fixture |
| | | Light Masts |
| | | Pilot house lights-red-white |
| | Generator | Generator |
| | | Transmission |
| | | Emergency Generator |
| | Wiring | Junction box |
| | | Electrical distribution cabling |
| | | Console wiring |
| | Boat Winch Hoisting | |
| | Transformer | |
| | Signaling | Fog signal |
| | | Fog Nozzle |
| | Pilot House Controls | Wind meter |
| | | Public address systems |
| | | Transducer |
| | | Fathometer |
| | | Loran GPS |
| | | Windshield wipers |
| | | Wiper blades |
| | | Radios |

| Systems (Level 1) | Assets (Level 2) | Sub-assets (Level 3) |
|---|---|---|
| | | Radio Antennas |
| | | Radars |
| | | Radars Antennas |
| | | Compasses |
| | | Weather Station |
| | | Horns |
| | Structured Cabling | Pilot House cabling |
| | Misc. | Hand dryer |
| | | Speakers |
| | | Vending Machines |
| | | TV |
| | | Cameras |
| | Arm Assembly | |
| | Alternator | |
| **Emergency** | Emergency Shut-off | Fuel |
| | | Emergency ventilation shutdown controls |
| | | Engine Room Vents |
| | Fire System | Fire Protection System Controller |
| | | Fire Extinguishers |
| | | Fire detector |
| | | Fire Suppression System Actuator |
| | | Co2 Releases |
| | | Co2 Cylinders |
| | | Emergency Generator Room Pilot Cylinder |
| | | Louver/Fire Damper Operator |
| | | Fire Pull Station |
| | | Fire Bell/ General Alarm |
| | | External Fire pump (piping, valves, fittings, hose) |
| | Sprinkler | Sprinkler Pump Start Switch |
| | | Sprinkler Heads |
| | | Sprinkler Pump |
| | IBA | |
| | Fire Accessories | Fire hydrant rocker lug |
| | Through-bulkhead firestop | Firestop packing |
| | | Cable box |
| | Life-Saving Equipment | AED (automatic external defibrillator) |
| | | First Aid Kit |
| | | life ring |
| | Davit | Davit Structure |
| | | Davit hook |
| | | Davit controller |
| | Rescue | Life Jackets (PFD) |

| Systems (Level 1) | Assets (Level 2) | Sub-assets (Level 3) |
|---|---|---|
| | | Life raft |
| | | Life ring |
| | | Rescue vessel mount |
| | | Rescue Fence |
| | | Debarkation Ladder |
| | | Rescue vessels (boats) |
| | Outboard | Evinrude |
| **Engine** | Caterpillar | CAT 3408 440 HP |
| | | CAT 3412 475 HP |
| | | CAT 3412 542 HP |
| | | CAT 3508 805 HP |
| | | CAT 3508 805 HP |
| | | CAT D398 825 HP |
| | | CAT 18 |
| | General Motor | GM 12V-71 350 HP |
| | | GM 6-71N 165 HP |
| | | GM EMD-710 |
| | MTU Diesel Engine | MTU 1140 |
| | Fuel Fill valve/Connector | |
| | Fuel Tank | Fuel Day Tank |
| | | Hydraulic Tank/ Hydraulic oil Tank |
| | Lube Oil Tank | |
| | Engine Filters | Fuel Filter |
| | | Oil Filter |
| | Fuel/Water Separator | |
| | Air Compressor | |
| **FFFE** | Seating | Passenger Interior Seating |
| | | Passenger Exterior Seating |
| | | Captain Chairs |
| | | Bunks for Crew and Captains |
| | | Galley Seating |
| | Interior Finishes | Wall panels |
| | | Cabinets |
| | Service Items | Paper towel dispenser |
| | | Microwave |
| | | Refrigerator |

| Systems (Level 1) | Assets (Level 2) | Sub-assets (Level 3) |
| --- | --- | --- |
| | | Water Cooler |
| | | Soap dispenser |
| | Fixtures | Plan Table |
| | Signage | Vessel |
| | | Representative School |
| | | Safety signage |
| | | Hailing Port |
| | | Hatch Labels |
| | | Valve Placard |
| | | Exit Sign |
| **HVAC** | Cooling | Air Handling Unit (AHU) |
| | | A/C filters |
| | | Thermostats/controller |
| | | Coils |
| | | Condenser |
| | | Air Conditioning Unit |
| | Heating | Thermostats/controller |
| | | Unit heater |
| | Ventilation | Outside Air Inlet to Pilot House |
| | | Captain Stateroom Toilet Exhaust Hood |
| | | Passenger Deck Toilet Exhaust Hood |
| | | Front Void Exhaust Air Vent |
| | | Supply Louver |
| | | Exhaust Louver |
| | | Blower |
| | | Exhaust fans |
| **Plumbing** | Bilge | Bilge Suction Pump |
| | | Bilge overboard valve |
| | Sea Chest | Sea Chest compartment |
| | | Sprinkler sea chest valve |
| | | Shaft cooling sea chest valve |
| | | Sea Chest vent |

| Systems (Level 1) | Assets (Level 2) | Sub-assets (Level 3) |
|---|---|---|
| | | Gate Valve |
| | | Sea Chest Strainers |
| | Potable Water | Water Pump |
| | | Sink |
| | | Sink Drain |
| | | Water Fountain |
| | | Water Hose Reel |
| | | Bladder Tanks |
| | | Fresh Water Tank |
| | | Hot Water Heater |
| | Waste Water/Restrooms | Water Closet |
| | | Wash Basin |
| | | Urinal |
| **Propulsion** | Propeller shaft | |
| | Propeller | |
| | Engine Control System | |
| | Engine Control Unit | |
| | Reduction Gear Cooling Pump | |
| | Drive Shaft | |
| | Bow/stern thrusters | |
| | Cutlass bearing | |
| | Shaft Taches | |
| **Steering** | Hydraulic Power Steering Unit | Steerage Hydraulic pumps |
| | | Hydraulic |
| | | Rudder Quad. Void |
| | Steering Room | Aft Steering Room |
| | | Steering Rams |
| **Structure** | Hull | |
| | Thru-hull fittings | Sea Chest |
| | | Sea valves |
| | | Keel/grid cooler grounds |
| | | Transducers |

| Systems (Level 1) | Assets (Level 2) | Sub-assets (Level 3) |
|---|---|---|
| | | Shaft Packing |
| | | Rudder packing |
| | | Shaft Bearings |
| | Bulkheads | |
| | Stair | |
| | Ladder | |
| | Forward void (rope locker) port | |
| | Forward void (rope locker) starboard | |
| | Deck hatch | Engine Room 24" Escape |
| | Railing | Stanchions |
| | | Handrails |
| | Decking | |
| | Bow Doors | |
| | Doors | Door Frame |
| | | Weather Tight |
| | | Watertight |
| | Windows | Fixed |
| | | Operable |
| | Capac Anodes | |
| | Anchor | |
| | Anchor chain | |
| | Navigation/Communication Mast | |
| | IBA Launch skids | Horizontal |
| | | Linear |
| | Fuel oil tank fill center | |
| | Potable water tank fill forward | |
| | Mast Structure | |
| | Forepeak Void | |

APPENDIX C. SAMPLE FORM A-10

| |
|---|
| Inspection Date: |
| Inspector Name: |
| Facility Name: |
| Address/Location: |

| ID | Component | Asset Quantity | Unit of Measure | Percent of Asset Quantity by Condition | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | 5 Excellent | 4 Good | 3 Adequate | 2 Marginal | 1 Poor |
| A. | Roof | | | | | | | |
| B. | Shell | | | | | | | |
| C. | Interior | | | | | | | |
| D. | Conveyance | | | | | | | |
| E. | Plumbing | | | | | | | |
| F. | HVAC | | | | | | | |
| G. | Fire Protection | | | | | | | |
| H. | Electrical | | | | | | | |
| I. | Equipment | | | | | | | |
| J. | Site | | | | | | | |

**Figure 18. Form for Administrative/Maintenance Facility Condition Assessment Form**

APPENDIX D. SAMPLE REPORT

## TABLE OF CONTENTS

**Section 1: Metadata**

| | | | |
|---|---|---|---|
| **Vessel** | CARTERET | | SAP Vessel 061 |
| **Date of Assessment** | Nov -03 | **2018** | |
| | **Meta Data** | | |
| **Built** | 1989 | **Shipyard** | Halter Marine |
| **Class** | Sound | | |
| **Route** | Cedar Island - Ocracoke | | |
| **University Affiliation** | UNC-Chapel Hill | | |
| | **Service** | | |
| **County** | Carteret - Hyde | **District** | 2 |
| **Vehicle Capacity** | 49 | **Crew** | 7 |
| **Passengers** | 300 | | |
| **Length** | 220' -6" | | |
| **Breadth** | 50'-0" | | |
| **Depth** | 12'-6" | | |
| **Draft** | 6'-6" | | |
| **Gross Ton** | 771 | | |
| | **Life Cycle Information** | | |
| **Original Cost** | **$2,656,567.00** | | |
| **Age** | 29 | | |
| **Replacement YR (@30)** | 2019 | | |

## Introduction

This report contains the results of the Condition Assessment for Carteret ferry vessel. This ferry class is sound which includes double ender vessels. This particular ferry vessel has three levels.

I. Pilot House Level (Top)
II. Passenger Level
III. Main Deck Level

This ferry was built in 1989 by Halter Marine shipyard. This ferry can carry up to 49 vehicles and 300 passengers. The original price to build for this ferry is **$2,656,567.00** and the NCFS has spent **$691,916.15** from 1st July 2016 till 30th June 2017 for maintaining the ferry vessel.

It is important to note that this study does not include any ultrasound measures of hull thickness or any type of structural testing analysis. This study is based on the visual inspection and 5 point scale (Figure 1) system was used for Condition Assessment.

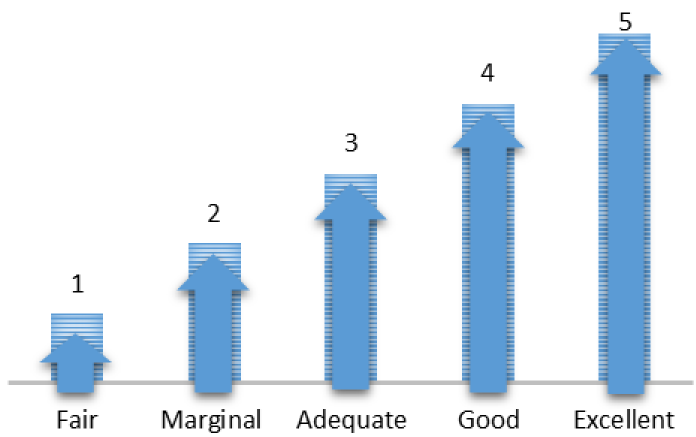



**Figure 1: Condition Assessment Scale**

The result of the condition assessment inspection is mentioned in Table 1. In addition, in Figure 2 representing the system which has lower condition index. Table 2 is explaining few of the deficiencies with few assets.

Vessel condition surveys should be conducted on a regular basis to establish a historical dataset to foresee trends and to provide a planning mechanism for budgeting and expected expenditures. The condition assessment for each vessel in the year 2017, provides the initial foundation (as the first condition assessment set for the NCFS fleet) upon which additional data may be added from other historical sources which were not available prior to this report:

## Carteret Condition Survey

### Summary

Condition surveys were completed over a 1-year and therefore not all vessels were assessed while in the shipyard. The Carteret assessment took place while it was on the route on November 03rd, 2017.

Each system is rated below to provide a sub-categorization indicating a priority for future planning for this vessel. Overall, the condition of the Carteret is good, but the location plays an instrumental role in the degradation of parts. The hull and structural components return with more corrosion due to the route it serves.

Engines are new (completed after the condition assessment process) and a majority of the condition issues on the vessel are due to corrosion. Based on the collected condition data, HVAC system needs most of the attention maintenance wise because this system has got lowest condition index rating of 3.00 and second lowest condition index rating is 3.69 which is calculated for FFFE system.

**The summary condition index (CI) for the Carteret vessel is a: …………..... <u>4.02</u>**

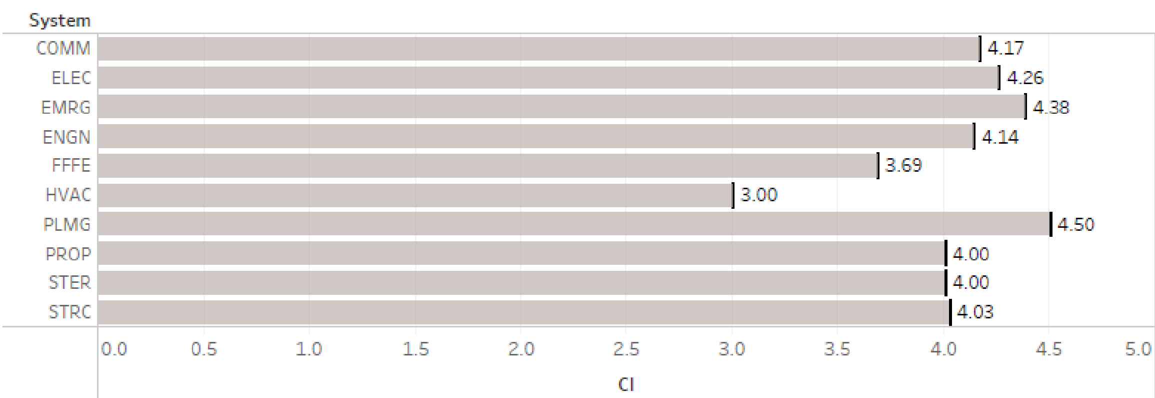



**Figure 2: System-wise condition index rating.**

## Condition Assessment Data:

Table 1 presenting as an example of the condition of each asset by assigning condition index rating with other required data for tracking the asset.

**Table 1: Condition Assessment Data**

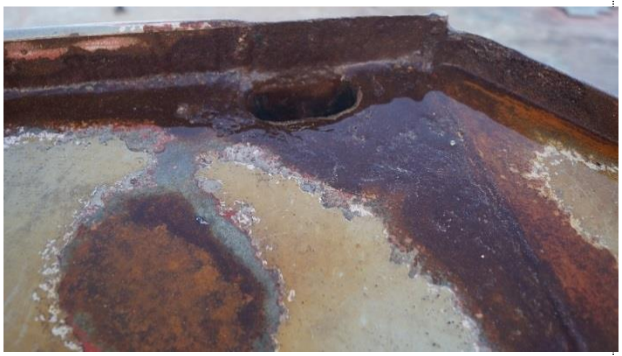
| System | Asset Name | Location | | Year Installed | Manufacture | CI | Description | Condition Notes |
|---|---|---|---|---|---|---|---|---|
| **STRC** | IBA Launch | PH | PORT | 1989 | n/a | 5 | Parallel launch type with the single manual actuator to release 5 IBAs simultaneously. | Rubber pads removed from launch skids at dry dock (for maintenance). The structure is in excellent condition. |
| **STRC** | Stairs | PH | STBD | 1989 | n/a | 4 | Stairs from Pilot House to Passenger Lounge | Normal corrosion on treads. |
| **STRC** | Door | PH | PORT | 1989 | n/a | 4 | Door(s) from PH to PH interior. Assessment includes weather stripping and lock. | Weather stripping is in good condition. |
| **STRC** | Door | PH | Crew Area | 1989 | n/a | 4 | Door for crew & galley area (Interior). FSD1 | In good condition. Replace rope (holding door) with a doorstop. |
| **STRC** | Door | PH | Crew Area | 1989 | n/a | 4 | Door for Restroom for galley area. | In good condition. |

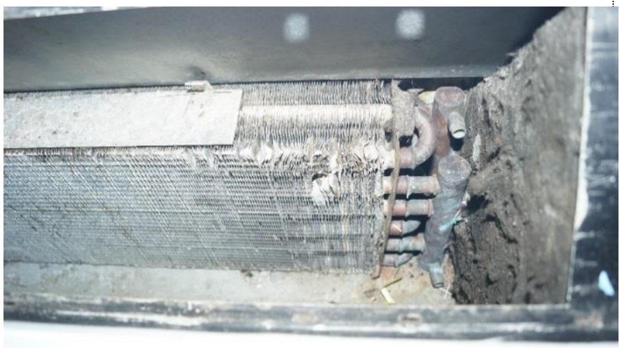
**<u>Summary of Deficiencies:</u>**

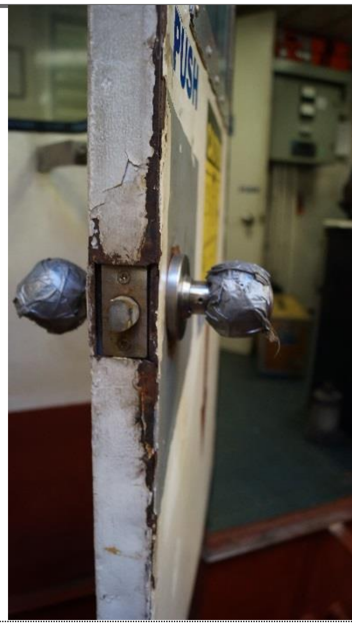
Table 2 presenting the few of the deficiencies is having with few assets with its photographs.

**Table 2: Summary of Deficiencies of few assets**

| Component | System | Rating | Description |
|---|---|---|---|
|  | HVAC (Heating, Ventilating, and Air Conditioning) | 03 (Adequate) | Ceiling mounted Air Conditioning unit – A/C system requires air filter but there is no air filter in pilot house's A/C unit. |
|  | FFFE (Finishes, Fixtures, Furnishes, & Equipment) | 01 (Fair) | Tissue dispenser – Found broken in rest-room. |
|  | STRC (Structure) | 02 (Marginal) | Decking – Extensive corrosion found at the Pilot House Level |

| Component | System | Rating | Description |
|---|---|---|---|
|  | STRC (Structure) | 02 (Marginal) | Decking – Extensive corrosion found near to the water drain at the Pilot House Level |
|  | HVAC (Heating, Ventilating, and Air Conditioning) | 03 (Adequate) | Floor Mounted Air Conditioner (at passenger level)– There was no filter and the dust is on the filter panel which decreases the cooling efficiency of the A/C. |
|  | FFFE (Finishes, Fixtures, Furnishes, & Equipment) | 03 (Adequate) | Indoor seating (chair) – Tear in chair's upholstery at the passenger indoor seating lounge. |

| Component | System | Rating | Description |
|---|---|---|---|
|  | HVAC (Heating, Ventilating, and Air Conditioning) | 02 (Marginal) | Floor Mounted Air Conditioner (at passenger level) – No filters and the parts of the A/C has dust on it. |
|  | HVAC (Heating, Ventilating, and Air Conditioning) | 01 (Fair) | Air conditioning controlling system (at passenger level) – The controller system get burned due to a short circuit. This controller does not work. |
|  | FFFE (Finishes, Fixtures, Furnishes, & Equipment) | 03 (Adequate) | Passenger Indoor Seating – Tear in couch leather at the passenger lounge. |
|  | STRC (Structure) | 01 (Fair) | Hull Structure (Metal Frame) – A metal piece is broken which gives the support to the hull. |

| Component | System | Rating | Description |
|---|---|---|---|
|  | FFFE (Finishes, Fixtures, Furnishes, & Equipment) | 02 (Marginal) | Door Accessories (knob) – Existing door accessories are no longer operate properly. |
|  | EMRG (Emergency) | 02 (Marginal) | Cable Tray (at the engine level) – The metal cable tray is corroded and this tray is not holding cables properly. |
|  | STRC (Structure) | 02 (Marginal) | Hull Structure (outer area) - Due to the salinity of the water and weather affect there are several holes found in the hull area because of an extensive corrosion. |

# APPENDIX E. SAMPLE RESULT

The mentioned results are based on the four variables and its anticipated points which are stated in the Chapter.4 research results (third deliverable) of this document. These variables are applied on the NCFS's 21 ferry vessels. This results representing how to use those points into RUL formula.

Figure 1 represents the result of M&R points. Figure 2 represents the result of Age points. Figure 3 represents the result of Location points. Figure 4 represents the result of CA points. Figure 5 represents the final outcome of these variables. Figure 6 showing the Excel sheet with combining all variables in one sheet.

| Vessel | Class | Initial Cost | Maintenance Cost (1 July 2016 thru 30 June 2017) | Percentage of maintenance cost on Initial cost | M&R Points |
|---|---|---|---|---|---|
| THOMAS A BAUM | Hatteras | $2,389,695.00 | $661,587.24 | 27.69 | 4.00 |
| ROANOKE | Hatteras | $1,929,065.00 | $778,219.19 | 40.34 | 3.00 |
| FRISCO | Hatteras | $1,769,000.00 | $145,392.47 | 8.22 | 5.00 |
| CHICAMACOMICO | Hatteras | $1,769,000.00 | $60,074.00 | 3.40 | 5.00 |
| CAPE POINT | Hatteras | $1,769,000.00 | $488,871.15 | 27.64 | 4.00 |
| OCRACOKE | Hatteras | $1,949,391.00 | $106,807.98 | 5.48 | 5.00 |
| KINNAKEET | Hatteras | $1,878,000.00 | $106,045.59 | 5.65 | 5.00 |
| GOV DANIEL RUSSEL | River | $3,484,000.00 | $281,078.81 | 8.07 | 5.00 |
| GOV JAMES B HUNT JR | River | $1,396,796.00 | $152,046.33 | 10.89 | 5.00 |
| SOUTHPORT | River | $4,686,700.00 | $1,121,136.06 | 23.92 | 4.00 |
| NEUSE | River | $5,375,000.00 | $70,970.20 | 1.32 | 5.00 |
| FLOYD J LUPTON | River | $5,400,000.00 | $127,094.65 | 2.35 | 5.00 |
| FORT FISHER | River | $5,400,000.00 | $56,553.81 | 1.05 | 5.00 |
| STANFORD WHITE | River | $3,840,000.00 | $597,495.56 | 15.56 | 5.00 |
| CROATOAN | River | $5,349,000.00 | $1,138,892.95 | 21.29 | 4.00 |
| HATTERAS | River | $5,950,000.00 | $946,162.35 | 15.90 | 5.00 |
| SILVERLAKE | Sound | $515,000.00 | $374,177.30 | 72.66 | 2.00 |
| SWAN QUARTER | Sound | $15,000,000.00 | $869,649.21 | 5.80 | 5.00 |
| SEA LEVEL | Sound | $15,000,000.00 | $204,749.40 | 1.36 | 5.00 |
| CEDAR ISLAND | Sound | $5,083,987.00 | $115,563.31 | 2.27 | 5.00 |
| CARTERET | Sound | $2,656,567.00 | $691,916.15 | 26.05 | 3.00 |

**Figure 1: Calculation of M&R Points**

| 3 | Vessel | Built Year | Replace Year | Remaining Life (yrs) | Life consumed (yrs) | Replace LC | Useful Life Consumed (%) | Age Points (yrs) |
|---|---|---|---|---|---|---|---|---|
| 4 | THOMAS A BAUM | 1995 | 2025 | 7 | 23 | 30 | 76.67 | 2.00 |
| 5 | ROANOKE | 1992 | 2022 | 4 | 26 | 30 | 86.67 | 2.00 |
| 6 | FRISCO | 1990 | 2020 | 2 | 28 | 30 | 93.33 | 2.00 |
| 7 | CHICAMACOMICO | 1990 | 2020 | 2 | 28 | 30 | 93.33 | 2.00 |
| 8 | CAPE POINT | 1990 | 2020 | 2 | 28 | 30 | 93.33 | 2.00 |
| 9 | OCRACOKE | 1990 | 2020 | 2 | 28 | 30 | 93.33 | 2.00 |
| 10 | KINNAKEET | 1989 | 2019 | 1 | 29 | 30 | 96.67 | 2.00 |
| 11 | GOV DANIEL RUSSEL | 1993 | 2023 | 5 | 25 | 30 | 83.33 | 2.00 |
| 12 | GOV JAMES B HUNT JR | 1984 | 2014 | -4 | 34 | 30 | 100.00 | 1.00 |
| 13 | SOUTHPORT | 1996 | 2026 | 8 | 22 | 30 | 73.33 | 3.00 |
| 14 | NEUSE | 1998 | 2028 | 10 | 20 | 30 | 66.67 | 3.00 |
| 15 | FLOYD J LUPTON | 2000 | 2030 | 12 | 18 | 30 | 60.00 | 3.00 |
| 16 | FORT FISHER | 2000 | 2030 | 12 | 18 | 30 | 60.00 | 3.00 |
| 17 | STANFORD WHITE | 2003 | 2033 | 15 | 15 | 30 | 50.00 | 4.00 |
| 18 | CROATOAN | 2003 | 2033 | 15 | 15 | 30 | 50.00 | 4.00 |
| 19 | HATTERAS | 2006 | 2036 | 18 | 12 | 30 | 40.00 | 4.00 |
| 20 | SILVERLAKE | 1965/1995 | 2025 | 7 | 23 | 30 | 76.67 | 2.00 |
| 21 | SWAN QUARTER | 2011 | 2041 | 23 | 7 | 30 | 23.33 | 5.00 |
| 22 | SEA LEVEL | 2011 | 2041 | 23 | 7 | 30 | 23.33 | 5.00 |
| 23 | CEDAR ISLAND | 1994 | 2024 | 6 | 24 | 30 | 80.00 | 2.00 |
| 24 | CARTERET | 1989 | 2019 | 1 | 29 | 30 | 96.67 | 2.00 |

**Figure 2: Age Points**

| | Vessel | Location | Location Points (yrs) |
|---|---|---|---|
| 3 | | | |
| 4 | THOMAS A BAUM | CB | 4.00 |
| 5 | ROANOKE | HT | 1.00 |
| 6 | FRISCO | HT | 1.00 |
| 7 | CHICAMACOMICO | HT | 1.00 |
| 8 | CAPE POINT | HT | 1.00 |
| 9 | OCRACOKE | HT | 1.00 |
| 10 | KINNAKEET | HT | 1.00 |
| 11 | GOV DANIEL RUSSEL | BV | 5.00 |
| 12 | GOV JAMES B HUNT JR | CT | 5.00 |
| 13 | SOUTHPORT | SP | 3.00 |
| 14 | NEUSE | CB | 4.00 |
| 15 | FLOYD J LUPTON | HT | 1.00 |
| 16 | FORT FISHER | SP | 3.00 |
| 17 | STANFORD WHITE | HT | 1.00 |
| 18 | CROATOAN | HT | 1.00 |
| 19 | HATTERAS | HT | 1.00 |
| 20 | SILVERLAKE | CI | 2.00 |
| 21 | SWAN QUARTER | SQ | 2.00 |
| 22 | SEA LEVEL | OC | 2.00 |
| 23 | CEDAR ISLAND | OC | 2.00 |
| 24 | CARTERET | OC | 2.00 |

**Figure 3: Location Points**

| Vessel | Condition Index Rating | Weighted Percentages | Service Adjustment (yrs) | Condition Adjustment (yrs) | Added Useful Life (yrs) | Adjusted Replacement Year |
|---|---|---|---|---|---|---|
| THOMAS A BAUM | 3.78 | 76.61% | 3.00 | 15 | 18 | 2043 |
| ROANOKE | 4.19 | 84.00% | 2.00 | 20 | 22 | 2044 |
| FRISCO | 4.28 | 85.13% | 3.00 | 20 | 23 | 2043 |
| CHICAMACOMICO | 3.84 | 76.71% | 3.00 | 15 | 18 | 2038 |
| CAPE POINT | 4.09 | 82.43% | 2.00 | 20 | 22 | 2042 |
| OCRACOKE | 4.09 | 82.05% | 3.00 | 20 | 23 | 2043 |
| KINNAKEET | 4.39 | 88.65% | 3.00 | 20 | 23 | 2042 |
| GOV DANIEL RUSSEL | 4.09 | 82.63% | 4.00 | 20 | 24 | 2047 |
| GOV JAMES B HUNT JR | 4.08 | 82.56% | 4.00 | 20 | 24 | 2038 |
| SOUTHPORT | 3.75 | 75.76% | 3.00 | 15 | 18 | 2044 |
| NEUSE | 3.92 | 79.59% | 4.00 | 15 | 19 | 2047 |
| FLOYD J LUPTON | 4.37 | 88.60% | 3.00 | 20 | 23 | 2053 |
| FORT FISHER | 4.29 | 86.38% | 4.00 | 20 | 24 | 2054 |
| STANFORD WHITE | 3.78 | 76.29% | 3.00 | 15 | 18 | 2051 |
| CROATOAN | 4.31 | 86.85% | 3.00 | 20 | 23 | 2056 |
| HATTERAS | 4.26 | 86.50% | 3.00 | 20 | 23 | 2059 |
| SILVERLAKE | 4.3 | 87.79% | 2.00 | 20 | 22 | 2047 |
| SWAN QUARTER | 4.56 | 91.27% | 4.00 | 20 | 24 | 2065 |
| SEA LEVEL | 4.72 | 98.80% | 4.00 | 20 | 24 | 2065 |
| CEDAR ISLAND | 4.03 | 82.79% | 3.00 | 20 | 23 | 2047 |
| CARTERET | 4.02 | 81.26% | 2.00 | 20 | 22 | 2041 |

**Figure 4: CA Percentages**

| Vessel | Service Adjustment (yrs) | Condition Adjustment (yrs) | Added Useful Life (yrs) | Adjusted Replacement Year |
|---|---|---|---|---|
| THOMAS A BAUM | 3.00 | 15 | 18 | 2043 |
| ROANOKE | 2.00 | 20 | 22 | 2044 |
| FRISCO | 3.00 | 20 | 23 | 2043 |
| CHICAMACOMICO | 3.00 | 15 | 18 | 2038 |
| CAPE POINT | 2.00 | 20 | 22 | 2042 |
| OCRACOKE | 3.00 | 20 | 23 | 2043 |
| KINNAKEET | 3.00 | 20 | 23 | 2042 |
| GOV DANIEL RUSSEL | 4.00 | 20 | 24 | 2047 |
| GOV JAMES B HUNT JR | 4.00 | 20 | 24 | 2038 |
| SOUTHPORT | 3.00 | 15 | 18 | 2044 |
| NEUSE | 4.00 | 15 | 19 | 2047 |
| FLOYD J LUPTON | 3.00 | 20 | 23 | 2053 |
| FORT FISHER | 4.00 | 20 | 24 | 2054 |
| STANFORD WHITE | 3.00 | 15 | 18 | 2051 |
| CROATOAN | 3.00 | 20 | 23 | 2056 |
| HATTERAS | 3.00 | 20 | 23 | 2059 |
| SILVERLAKE | 2.00 | 20 | 22 | 2047 |
| SWAN QUARTER | 4.00 | 20 | 24 | 2065 |
| SEA LEVEL | 4.00 | 20 | 24 | 2065 |
| CEDAR ISLAND | 3.00 | 20 | 23 | 2047 |
| CARTERET | 2.00 | 20 | 22 | 2041 |

**Figure 5: Final Result as Adjusted Replacement Years**

| Vessel | Remaining Useful Life | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Class | Initial Cost | Maintenance Cost (1 July 2016 thru 30 June 2017) | Percentage of maintenance cost on Initial cost | M&R Points | Built Year | Replace Year | Remaining Life (yrs) | Life consumed (yrs) | Replace LC | Useful Life Consumed (%) | Age Points (yrs) | Location | Location Points (yrs) | Condition Index Rating | Weighted Percentages | Service Adjustment (yrs) | Condition Adjustment (yrs) | Added Useful Life (yrs) | Adjusted Replacement Year |
| THOMAS A BAUM | Hatteras | $2,389,695.00 | $661,587.24 | 27.69 | 4.00 | 1995 | 2025 | 7 | 23 | 30 | 76.67 | 2.00 | CB | 4.00 | 3.78 | 76.61% | 3.00 | 15 | 18 | 2043 |
| ROANOKE | Hatteras | $1,929,065.00 | $778,219.19 | 40.34 | 3.00 | 1992 | 2022 | 4 | 26 | 30 | 86.67 | 2.00 | HT | 1.00 | 4.19 | 84.00% | 2.00 | 20 | 22 | 2044 |
| FRISCO | Hatteras | $1,769,000.00 | $145,392.47 | 8.22 | 5.00 | 1990 | 2020 | 2 | 28 | 30 | 93.33 | 2.00 | HT | 1.00 | 4.28 | 85.13% | 3.00 | 20 | 23 | 2043 |
| CHICAMACOMICO | Hatteras | $1,769,000.00 | $60,074.00 | 3.40 | 5.00 | 1990 | 2020 | 2 | 28 | 30 | 93.33 | 2.00 | HT | 1.00 | 3.84 | 76.71% | 3.00 | 15 | 18 | 2038 |
| CAPE POINT | Hatteras | $1,769,000.00 | $488,871.15 | 27.64 | 4.00 | 1990 | 2020 | 2 | 28 | 30 | 93.33 | 2.00 | HT | 1.00 | 4.09 | 82.43% | 2.00 | 20 | 22 | 2042 |
| OCRACOKE | Hatteras | $1,949,391.00 | $106,807.98 | 5.48 | 5.00 | 1990 | 2020 | 2 | 28 | 30 | 93.33 | 2.00 | HT | 1.00 | 4.09 | 82.05% | 3.00 | 20 | 23 | 2043 |
| KINNAKEET | Hatteras | $1,878,000.00 | $106,045.59 | 5.65 | 5.00 | 1989 | 2019 | 1 | 29 | 30 | 96.67 | 2.00 | HT | 1.00 | 4.39 | 88.65% | 3.00 | 20 | 23 | 2042 |
| GOV DANIEL RUSSEL | River | $3,484,000.00 | $281,078.81 | 8.07 | 5.00 | 1993 | 2023 | 5 | 25 | 30 | 83.33 | 2.00 | BV | 5.00 | 4.09 | 82.63% | 4.00 | 20 | 24 | 2047 |
| GOV JAMES B HUNT JR | River | $1,396,796.00 | $152,046.33 | 10.89 | 5.00 | 1984 | 2014 | -4 | 34 | 30 | 100.00 | 1.00 | CT | 5.00 | 4.08 | 82.56% | 4.00 | 20 | 24 | 2038 |
| SOUTHPORT | River | $4,686,700.00 | $1,121,136.06 | 23.92 | 4.00 | 1996 | 2026 | 8 | 22 | 30 | 73.33 | 3.00 | SP | 3.00 | 3.75 | 75.76% | 3.00 | 15 | 18 | 2044 |
| NEUSE | River | $5,375,000.00 | $70,970.20 | 1.32 | 5.00 | 1998 | 2028 | 10 | 20 | 30 | 66.67 | 3.00 | CB | 4.00 | 3.92 | 79.59% | 4.00 | 15 | 19 | 2047 |
| FLOYD J LUPTON | River | $5,400,000.00 | $127,094.65 | 2.35 | 5.00 | 2000 | 2030 | 12 | 18 | 30 | 60.00 | 3.00 | HT | 1.00 | 4.37 | 88.60% | 3.00 | 20 | 23 | 2053 |
| FORT FISHER | River | $5,400,000.00 | $56,553.81 | 1.05 | 5.00 | 2000 | 2030 | 12 | 18 | 30 | 60.00 | 3.00 | SP | 3.00 | 4.29 | 86.38% | 4.00 | 20 | 24 | 2054 |
| STANFORD WHITE | River | $3,840,000.00 | $597,495.56 | 15.56 | 5.00 | 2003 | 2033 | 15 | 15 | 30 | 50.00 | 4.00 | HT | 1.00 | 3.78 | 76.29% | 3.00 | 15 | 18 | 2051 |
| CROATOAN | River | $5,349,000.00 | $1,138,892.95 | 21.29 | 4.00 | 2003 | 2033 | 15 | 15 | 30 | 50.00 | 4.00 | HT | 1.00 | 4.31 | 86.85% | 3.00 | 20 | 23 | 2056 |
| HATTERAS | River | $5,950,000.00 | $946,162.35 | 15.90 | 5.00 | 2006 | 2036 | 18 | 12 | 30 | 40.00 | 4.00 | HT | 1.00 | 4.26 | 86.50% | 3.00 | 20 | 23 | 2059 |
| SILVERLAKE | Sound | $515,000.00 | $374,177.30 | 72.66 | 2.00 | 1965/1995 | 2025 | 7 | 23 | 30 | 76.67 | 2.00 | CI | 2.00 | 4.3 | 87.79% | 2.00 | 20 | 22 | 2047 |
| SWAN QUARTER | Sound | $15,000,000.00 | $869,649.21 | 5.80 | 5.00 | 2011 | 2041 | 23 | 7 | 30 | 23.33 | 5.00 | SQ | 2.00 | 4.56 | 91.27% | 4.00 | 20 | 24 | 2065 |
| SEA LEVEL | Sound | $15,000,000.00 | $204,749.40 | 1.36 | 5.00 | 2011 | 2041 | 23 | 7 | 30 | 23.33 | 5.00 | OC | 2.00 | 4.72 | 98.80% | 4.00 | 20 | 24 | 2065 |
| CEDAR ISLAND | Sound | $5,083,987.00 | $115,563.31 | 2.27 | 5.00 | 1994 | 2024 | 6 | 24 | 30 | 80.00 | 2.00 | OC | 2.00 | 4.03 | 82.79% | 3.00 | 20 | 23 | 2047 |
| CARTERET | Sound | $2,656,567.00 | $691,916.15 | 26.05 | 3.00 | 1989 | 2019 | 1 | 29 | 30 | 96.67 | 2.00 | OC | 2.00 | 4.02 | 81.26% | 2.00 | 20 | 22 | 2041 |

**Figure 6: Sample result of all the variables combined**