A FRAMEWORK FOR LONG TERM ASSET MANAGEMENT PLAN USING ASSET PRIORITY INDEX AND CONDITION INDEX FOR THE NORTH CAROLINA FERRY SYSTEM

by

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ABSTRACT

BALAGEE SUBRAMANIAN. A Framework for Long-Term Asset Management plan using Asset Priority Index and Condition Index for the North Carolina Ferry System. (Under the guidance of DR. GLENDA MAYO and DR. JAKE SMITHWICK)

The North Carolina Department of Transportation (NCDOT) and the North Carolina Ferry System combined have many assets in place. This thesis primarily concerns the North Carolina Ferry System (NCFS). The NCFS has a sizable number of assets and a long-term asset management plan be put in place to help NCFS to make an informed decision regarding the acquisition, utilization, and disposal of their assets are indispensable. Previous research efforts have made an attempt to synthesize an asset inventory based on their condition index and apply them to a long-term asset management practices. This research focuses on the limitations of previous focuses and an attempt is made to find a better long-term asset management reporting practice. The concepts of Analytic Hierarchy Process, Asset Priority Index and Condition Index have been used here to develop a framework whereby the management at North Carolina Ferry Division (NCFD) can obtain a combined way to look at all assets, and can use the same to make strategic decisions regarding budget allocation, asset utilization, and disposal. These concepts have been applied to the 21 vessels currently under the NCFS.

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NCDOT	North Carolina Department of Transportation
NCFD	North Carolina Ferry Division
NCFO	National Census of Ferry Operators
FCI	Facility Condition Index
CI	Condition Index
AHP	Analytic Hierarchy Process
API	Asset Priority Index
ANP	Analytical Network Process
MAUT	Multi-Attribute Utility Theory
LCCA	Life Cycle Cost Analysis
FM	Facility Management
FCA	Facility Condition Assessment
NCES	National Centre for Educational Services
SWBS	Ship Work Breakdown Structure
WFS	Washington Ferry Service
FTA	Federal Transit Authority
KPI	Key Performance Indicator
DOI	Department of Interior
NPS	National Park Service
MCDM	Multi-Criteria Decision Making
CI	Consistency Index
BVP	Best Value Procurement

CHAPTER 1: INTRODUCTION

The North Carolina Ferry Division (NCFD) is a division of the North Carolina Department of Transportation (NCDOT) which has 21 ferries under its operation. The NCFS offers services that involve transporting passengers and their vehicles to a number of islands along the coast of North Carolina. The ferries started its operation in the mid-1920s and are the second largest ferry system in the United States. A survey by the National Census of Ferry Operators (NCFO) stated that the ferries in the United States carried over 115 million passengers and around 30 million vehicles in the year 2013 (Steve et al., 2016). Out of this, the NCFD transported around 800,000 vehicles and 1.8 million passengers (NCDOT). This implies the vital role of the ferries both in the country and in North Carolina. The ferries operated by the NCFD conduct more than 200 trips daily (Tsai et al., 2011). The 21 ferries operated by NCFS runs on seven regular routes. The NCFS also has an emergency route in case of coastal emergencies like hurricanes, storms and other complications. The NCFS has been ranked in the top 10 ferry systems in categories like annual service of passengers, a total number of terminals and the total number of vessels (Steve et al., 2016). All of the above implies the importance of this ferry system to the state of North Carolina and its integration with the community and the people. The NCFS not only serves the locals of NC but also provides services for the tourism industry.

1.1 Research Purpose

Even though the NCFS has an established network of systems in place to maintain their assets, many ferry operators have developed their own methods since there are no standardized or proven methods to maintain their fleet effectively and efficiently. Every ferry operation follows a different method to determine the condition and the remaining useful life of their asset. Previous research at UNC Charlotte adapted the condition assessment techniques used in buildings and applied them to the needs of the NC ferry division. The assets for the ferries were divided into respective systems based on their characteristics to create an asset hierarchy. Individual assets for each vessel were assessed for condition based on a scale of 1 to 5. The limitation in the existing method was the weight of the systems where all the systems were weighed equally. For example, the seating in the gallery was weighed equally to an engine. One of the objectives of this research is to solve this limitation. The method of Analytic Hierarchy Process (AHP) can be used to weigh the systems and use that to weight the condition index. Another objective of this research is to create a framework which can help the ferry industry to keep track of their assets which can help them to make decisions regarding acquisition, utilization, and disposal of assets. A variable known as Asset Priority Index is to be used here to prioritize the assets according to the goals of the organization. Both the condition index and the asset priority index can be plotted in a graph together to divide them into categories helping the ferry industry to get a better understanding of their assets. The resulting graphs and data can be used by any ferry industry to create their own personalized asset management plan.

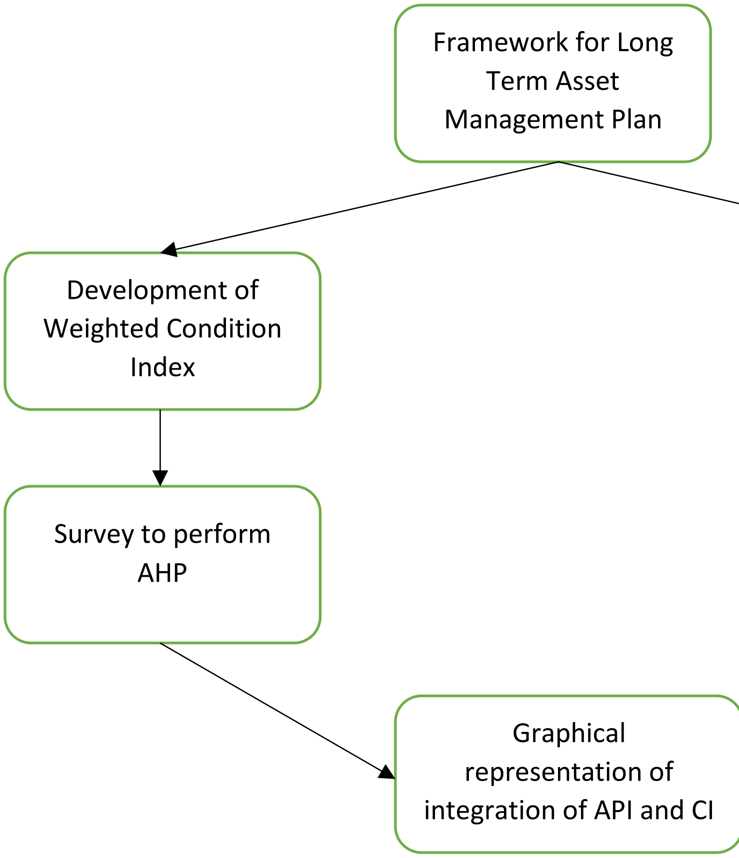


Figure 1: Objectives of Research

1.2 Problem Statement

The NCFS is currently working to develop a mature asset management plan, knowing that a system will be efficient when the assets are maintained and sustained in good condition. According to Stoller (2008), in the general scenario of a budget, there are rarely sufficient funds to perform operations that will help maintenance and the capital renewal occur when it is planned. This requires a framework which will provide information about the assets that require immediate attention. Even though there have been technological advances in this industry, several asset management challenges pose a generic problem. For example, some of the ferry industries do not collect and store sufficient data. With more data, better analysis like decay curves and machine learning could be performed. There is an added benefit of storing historical data. It helps in creating standardized measures for the ferry industry just like the building industry has. Particular to this research, the difficulty is to combine multiple attributes like Condition Index (CI), Asset Priority Index (API) together into an integrated graph which will be capable of portraying the information about the current situations of the assets.

1.3 Objectives and Scope

The objective of this research is to help solve the difficulties in a previous research and to create a framework that will help to divide the assets into categories which will help the ferry industry personnel to make informed decisions regarding their fleet. This objective is divided into steps to achieve it.

I. To devise a method to create a weighting method for the systems in the previously established asset hierarchy.

II. To determine the priority of the asset towards the goals of the organization. This is done by analyzing assets with respect to the API criteria and scoring them on a scale of 1 to 100.

III. To combine the weighted Condition Index and the Asset Priority Index and depict it in a visual representation which will help the people looking at it have a better understanding of the overall status of all assets.

To achieve the main objective, the subgoals mentioned above should be satisfied. The application of the combined metrics into a singular visual representation may be useful to any ferry operation by modifying it according to their own internal needs. The method chosen will depend on several categories. In this case, the data available on hand lead to the choosing of these aforementioned methods. Future research can use this framework to expand the understanding of useful life calculation for the ferry industry.

1.4 Research Approach

The idea behind the combined visualization framework came from multiple asset management plans being used in several other industries. An attempt is made to apply these measures in the marine and ferry industry. To obtain these results the research is to be conducted in the following steps.

I. Review of existing literature: Literature review was carried out for the two objectives of this research. First, to determine the weight of the systems in the asset hierarchy. Several methods were found out during the search. Some of them being the Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Multi-Attribute Utility Theory (MAUT) and Fuzzy Approach. Second to develop a framework for long-term asset management plan. The commonly used techniques in the literature review were Decay curves, Deterioration curves, Machine Learning, and other methods. The method suitable for the ferry industry was determined based on the internal needs of the ferry industry.

II. Development of Survey: After the determination of the suitable research approach, a survey will collect the required information users with the NCFS and other marine industry professionals. The survey is planned to be formulated in such a way that, both the objectives of the research are covered. Care is taken to avoid human inconsistencies by keeping the questions concise.

III. Analysis of Results: The results from the survey will be analyzed using and AHP Excel Template. The survey results will be separated into two based on the research objectives.

IV. Representation of Results: Based on the method chosen in the research approach, the results are to be represented graphically. The results are to be represented in such a way that even a lay-person looking at it will able to get a clear understanding of the standing of the assets.

More about the research methods are chosen and the method of analysis will be explained in detail in the research methodology section of this document.

1.5 Organization of Thesis

The remainder of this thesis is organized as follows,

I. Chapter 2 comprises of the literature review of the methodologies that are being used in this research. Some of the literature review to be covered in Chapter 2 are Condition Index, Analytic Hierarchy Process, Asset Priority Index, Level of Service and other related topics.

II. Chapter 3 comprises of the research methodology to explain in detail how this research has been carried out.

III. Chapter 4 and 5 will comprise the research results, analysis and conclusions.

IV. Chapter 6 will cover the conclusions and recommendations for future research.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The performance and the state of an asset is one of the most important factors in depicting its use to the organization. The goals of an asset are to directly or indirectly help in generating revenue or to support the other assets that generate revenue. One of the processes to determine whether the asset is fulfilling its objective is to perform a Life Cycle Cost Analysis (LCCA). LCCA is a process of evaluating the economic performance of a building or a particular asset over its entire lifetime (Stanford University, 2005). Another definition of LCCA states that it is the total cost of ownership which is further defined as a cradle to grave perspective (Lindqvist, 2012). The cradle to grave perspective in the asset management is one which needs to be avoided. This method means that an asset is not tended to at the proper timing and left to deteriorate and be replaced later. The methods to analyze life-cycle cost for the building has fairly been used before and has been standardized. But, the application of LCCA to the marine industry is new and a tough process to begin with due to the extensive nature and complexity of assets. Gupta (1983) states that LCCA has also been used to deal with problems like determining and increasing the remaining useful life of an asset. This corroborates to what is being attempted to be done here for the marine industry. Focusing on NCFS, this can help them to determine the categories under which their assets fall which can be used to develop a more structured budget. However, it has been found that methodologies, where costs have been part of the life cycle analysis, are not effective.

2.2 Asset Hierarchy and Condition Assessment

Facility Management (FM) relies on accurate data to make accurate decisions. One Important aspect of accurate data is the condition and performance of assets obtained through the Facility Condition Assessment (FCA) (Mayo, 2018). The Condition Index is an important attribute that can play a crucial role in managing and maintaining assets. Building performance and the condition assessment are one single entity and should not be separated as the condition of the building is the best way to measure its performance (Abbot, 2007).

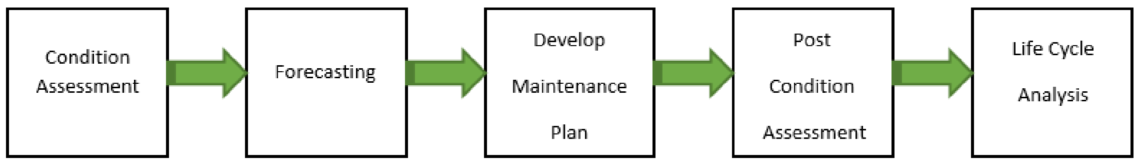


Figure 2: Main functions of an Asset Management System (Ahluwalia, 2008)

Based on the figure above and research from a study conducted by Ahluwalia (2008), it is known that the condition assessment process is one of the imperative functions of Asset management. The National Centre for Education Services (NCES) also states that condition assessment is important to find out the level of preventive maintenance required for the assets in a facility/building. Abbot (2007) states that condition assessment is one of the best methods to evaluate a building, he also states that it has rarely been used and has been undervalued for many years. FM is one that engages with a range of disciplines and services also the development, organization, and management particularly the buildings and their systems, fittings and furnishing (Kamaruzzaman, 2010). All the assets in a building cannot be categorized under one asset inventory. If done so that'll make it difficult to track the assets. Under further deliberation on the statement by Kamaruzzaman, it is clear that an asset hierarchy is required under an asset inventory. Based on studies conducted by Uzarski and Burley in 1997 and Elhakeem in 2007 a facility or building can be divided into components or systems into a desired number of levels. This division of the assets based on their characteristics is known as asset hierarchy. The division of assets and the hierarchy level depends upon the type of organization/facility/building. Elkaheem (2007) describes the benefits on asset hierarchy as (1) Simplifies the process; (2) Helps in calculation preference among systems to help in allocating funds; (3) Easier to maintain assets by assessing systems as a whole. An essential step in an FCA is that a building/facility must be broken down into components and sub-components to create a hierarchy (Mayo, 2018). The U.S. Navy and the University of Michigan together developed a Ship Work Breakdown Structure (SWBS). This is an early example of a hierarchy in the marine industry. This was intended for shipbuilding for the naval ships. The Washington Ferry Service (WFS) tried to implement the idea of SWBS into their asset inventory. The NCFS works their assets through SAP which do not have hierarchical options. The effort is being currently made to add more levels in the hierarchy. Breaking down the assets and categorizing them into a hierarchical structure will help rank the deficiencies in repair.

2.2.1 Condition Assessment: Data Collection and Measure

There are many forms of collecting the condition data for the assets. The most similar one for the ferry industry is the method used by the Federal Transit Authority (FTA). FTA has forms with required details about the asset. The previous part of this research (Raja, 2018) for the NCFS had followed a similar method to collect the condition data. These forms had the following categories, (1) Asset name; (2) Location; (3) Year Installed; (4) Manufacture; (5) Condition Index; (7) Description; (8) Condition notes. These forms also required to attach a photo of the current condition of the asset. This photo should be updated at regular intervals or if any work is done on it whichever comes first. Ahluwalia (2008) and Straub (2002) mention in their studies the importance and effectiveness of recording images in visual inspections. The scores of the condition assessment by Raja (2018) were on a scale of one to five. One being in poor condition and five being in excellent condition. The rating scales used in this previous part of this research is validated by a number of other research suggestions.

(1) The Asset Management plan for an Inland Ferry Fleet in Canada used a condition index on a scale of one to five (Opus International Consultants, 2012).

(2) A Bridge Management System (BMS) developed by Gattuli (2005) and Chiaramonte (2005) used a condition index rating on a scale of one to five.

(3) Abbot et al., 2007 for Buildings and Owen (2012) for Transportation vehicles conducted condition assessment on a scale of one to five.

(4) VDOT (2016) for Highway and Thompson (2013) for Transportation Assets performed condition assessments on a scale of 1 to 100.

2.3 Weighting the Systems in the Asset Hierarchy

One of the limitations to the initial part of this research conducted by Raja (2018) was the relative importance of the systems under the asset hierarchy. Systems cannot have the same priority and are practically not possible. For example, the main system comprising of assets related to engine, propulsion & steering cannot be given the same priority that is being given to the furnishings on the vessel. The literature review under this sub-heading is an attempt to solve this limitation. “The concept of priority is quintessential and how priorities are derived influences the choice one makes. Priorities should be unique and not one of many possibilities" (Saaty, 2002). Some of the tools used to weigh criteria and make decisions involving multiple criteria are

(1) Multiple-Attribute Utility Theory (MAUT).

(2) Multiple-Attribute Value Theory (MAVT).

(3) Analytic Network Process (ANP).

(4) Fuzzy Approach.

(5) Analytic Hierarchy Process (AHP).

Out of these methods, the Analytic Hierarchy Process (AHP) is being used in this research mainly due to its simplicity. According to a study conducted by Lai and Hopkins (1995), there is no notable difference between Multiple-Attribute Utility Theory (MAUT) and Analytic Hierarchy Process (AHP). The AHP is a technique that is adaptable and can be applied to any hierarchy to derive performance measures (Rangone, 1996). Even though performance is not being measured in this research, the AHP can be applied to the asset hierarchy. The AHP process has been used in a number of different scopes within the transportation industry to resolve issues. (C Ugboma et al, 2006). The AHP was a technique developed by Thomas L. Saaty in the 1970s. It is used in various fields in the process of Multi-Criteria Decision Making (MCDM). The level at the top of the hierarchy is defined as the goal and it branches out to form criteria. The criteria will be interrelated and of importance to the goal. The criteria are further branched to form sub-criteria. At the last level, the decision alternatives are present. These level are evaluated in pairs to determine their relative importance towards achieving the goal (Albayrakoglu, 2006).

According to Saaty (1986) and Forman & Gass (2001), the AHP is fundamentally based on four theorems,

(1) Reciprocality: It is defined as the ability within the process to perform paired reciprocal pairwise comparisons among the elements.

(2) Homogeneity: It is defined as the need for comparing elements of a similar type based on a common property.

(3) Dependence: It is defined as the need for the elements at each level to be dependent on an element at a higher level in the hierarchy. The elements at the same level should be independent of each other.

(4) Expectations: This is defined as the necessity to add all the criteria and sub-criteria that are an integral part in achieving the objective/goal at the top level.

Zahedi (1986) states that the AHP technique comprises four steps,

(1) Developing a hierarchy by disintegrating the decision problem into analogous elements. These elements should be categorized under criteria and decision alternatives.

(2) Collecting the data required to perform a pairwise comparison.

(3) Determining the relative weights of the decision elements using the eigenvalue approximation method.

(4) Accumulating the results from the previous step to calculate the ratings for the decision alternatives elements.

I.N. Lagoudis et al states that the AHP method should contain decision making elements that can be collated but should not be exactly the same. These elements should be attained from the common goal and not from the weights or priority. It is not essential to add the last level of decision alternatives within the hierarchy. The last level of decision alternatives can be removed or ignored if the aim is to only determine the weights/priority for the criteria. Such methods have been adopted in transport, passenger shipping and supply chain management research involving AHP by Bagchi et al., 1987; Bagchi, 1989; Brooks, 1990; D'este, 1992; Johansson et al., 1993; Hopkins et al., 1993; Menon et al., 1998; I.N. Lagoudis et al., 2011. This kind of AHP technique without the last hierarchy level will be used in this research validated by the above-mentioned research. Once all the criteria are defined and placed in a hierarchical level, the pairwise comparison will be performed. The input of the user should be based on a predefined scale. R.W. Saaty (1987) developed a fundamental scale which is modified as used widely. The scale is from 1 to 9 along with a verbal explanation to differentiate the numbers. The following Table 1 depicts the fundamental scale created by R.W Saaty in 1987.

Table 1: The Fundamental Scale of AHP. (R.W. Saaty, 1987)

Intensity of importance on an absolute scale	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment strongly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is strongly favored and its dominance demonstrated in practice
9	Extreme Importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals	If activity i has one of the above numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining n numerical values to span the matrix.

During the process of evaluating/scoring the pairwise comparisons, the respondent should be attentive and be consistent with the answers throughout the process. "Consistency is the degree to which the perceived relationship between elements in the pairwise comparison is maintained" (Ugboma et al., 2006). These inconsistencies may occur due to several reasons like when the respondents were not provided with enough introductory information to perform the pairwise. Another reason is when the respondents lack the judgment required to answer the question. For all these and many other reasons, a valuable aspect of inconsistency is attributed to a good thing. "The AHP allows inconsistency because in making judgments people are more likely to be cardinally inconsistent than cardinally consistent because they cannot estimate precisely measurement values even from a known scale and worse when they deal with intangibles and ordinally intransitive" (T.L. Saaty, 2001). To get a consistent result, the evaluation process must fulfill two conditions,

(1) Transitivity

(2) Proportionality.

According to Godel's second incompleteness theorem, in most of the cases, it is nonviable to gratify the proportionality condition when a restricted scale is used. This is the reason the AHP techniques by T.L. Saaty (1988) allows for a 10 percent inconsistency. Saaty (2001) suggests that the transitivity condition should at least be fulfilled to reduce inconsistency.

2.3.1 Analytic Hierarchy Process Data Collection

There are a number of ways to collect the data needed to develop the pairwise comparisons. One of the main methods is to create a survey to collect the information. The respondents of this survey are based on the type of the criteria that is chosen. In the study conducted by Ugboma et al (2006) AHP was used to weigh criteria in selecting a port in Uganda. The author states that a survey was created with detailed instructions posted on the introductory page of the survey and wherever necessary. He also states that an attempt was made to make the respondents familiar with the pairwise comparison process to make it easier for them to answer. This was done so that there was a minimum inconsistency index in the survey results. The authors also followed up on survey results which were found to be inconsistent by contacting the respondents based on the study by Selly and Forman (2002). In a research led by I.N. Lagoudis et al. (2011), a similar AHP was performed to rank the Key Performance Indicators (KPI) in the Greek ferry system. "The impact on the entire Greek community and especially on the Aegean islands close to the accident site or the ones connected to the specific itinerary was enormous. It shook the perception that the islanders had shaped about the safety of traveling by ship over the previous decades" (I.N. Lagoudis et al., 2011). This kind of an incident can change the results of the survey dramatically. A follow up recommended by Selly and Forman (2002) is one of the methods to handle situations like this. Even though this research does not encompass the kind of state the Greeks had, precautions will be made to make sure that these inconsistencies will be dealt with.

2.4 Long-Term Asset Management Plan

Industries of various field particular ferry/marine industry, have a requirement to maintain the assets under their disposition. “Although the primary focus of the research was to 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” (Raja, 2018). The above statement is what’s being attempted to be achieved in this research. In a study conducted by Ahluwalia (2008) she has listed five steps to successfully manage a group of assets. These five steps modified and rearranged can serve the needs of the ferry industry (Ahluwalia, 2008).

(1) Assessment of the current condition of the assets.

(2) Prognosis of future decline in the condition of assets.

(3) Prioritize the assets based on the constraints of the budget.

(4) Choosing the repair and maintenance action plan.

(5) Update the condition assessment of the asset.

The second step of predicting the future condition is a challenge during the exertion of maintenance strategies while estimating the remaining useful life (Le Son et al., 2013). Timely maintenance is a crucial part is increasing the life of the asset. In the case of the ferry/marine industry as stated by Peter Lauridsen “Boats can continue to operate indefinitely if well maintained.” According to Woodward (1997), the need for maintenance increases as the age of the vessel increases. To understand when to maintain an asset, the three phases of an asset mentioned in a study by Rao (2015) can be used. He states that the asset has phases known as

(1) Start-up Cycle.

(2) Wealth Cycle.

(3) Break-down Cycle.

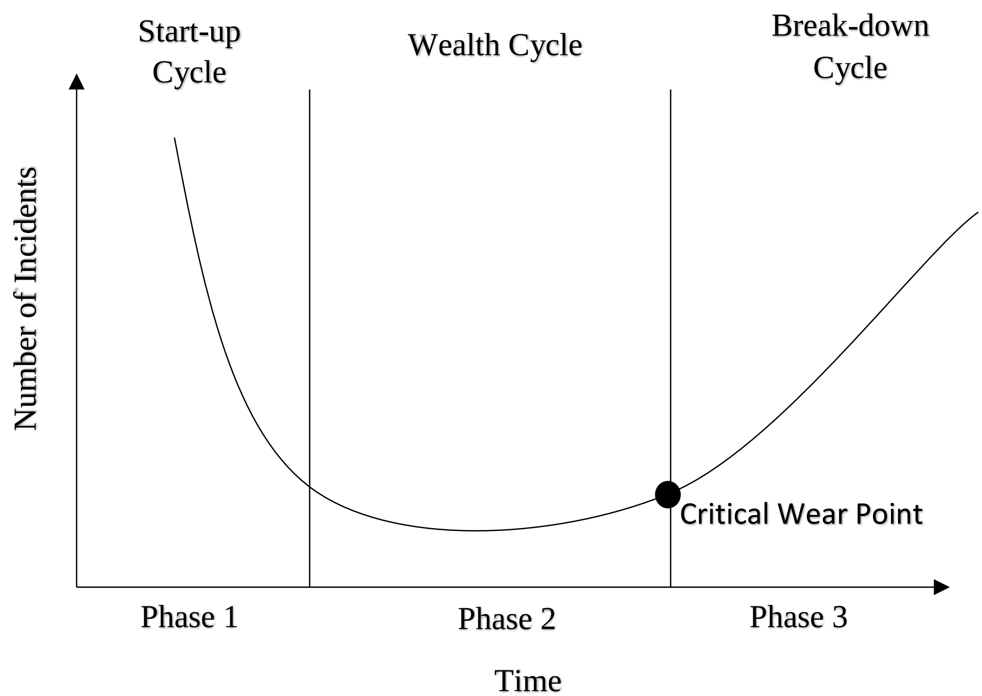


Figure 3: Maintenance Bucket Curve (Rao, 2015)

One of the main steps in the research by Ahluwalia (2008) is prioritizing the assets that need immediate attention. One of the tools that can be used to prioritize is known as the Asset Priority Index. This was founded by the Department of Interior to help them develop a clear link to their organizational goal.

2.5 Introduction to Asset Priority Index

Founded by the Department of Interior (DOI) for managing their owned and leased real estate assets, API is a tool that helps managers or other professional to determine a priority/ relative importance of assets under their disposal. The API can be combined along with other metrics to assess condition, utilization, maintenance and other. According to DOI, API gives the ability to management/managers to make informed decisions regarding timely maintenance, disposal of assets and other related stuff regarding the mission of the organization. Some of the other organizations that use API are NASA, U.S. Navy, U.S. Air Force and other government and private organizations. The API can also be referred to as a balanced scorecard approach that will help in making precise decisions. According to the U.S. Wildlife Service, the calculation of API involves six steps,

(1) Defining categories under Mission Dependency.

(2) Defining criteria for scoring step 1.

(3) Defining categories under Asset Substitutability.

(4) Define criteria for scoring step 3.

(5) Determine and Interpret the API score.

(6) Internal Controls for API scores.

Before starting these steps the mission of the organization for which the API is being calculated should be defined clearly. The score will solely depend on this mission goal. For instance, the mission goals for various organizations are listed below.

Department of Interior:

Resource Protection.

Management of Resource Use.

Provision of Recreational facilities.

To serve the communities.

U.S. Fish and Wildlife Service:

To manage the constructed property which will help and not hinder in the major organization goal (i.e.) conserving, protecting and enhancing fish, wildlife, plants, and their habitats.

Integrating life cycle cost into decision making to make sure assets with the highest priority gets maintained in a reliable and cost-effective manner.

National Park Service:

Natural Resource Preservation.

Cultural Resource Preservation.

Visitor Use.

Park Operations.

Asset Substitutability.

As stated by NPS, the API can be an important tool to,

(1) Allocate resources.

(2) Optimize the use of assets like building, land, etc.

(3) Decide which assets need to be disposed.

The method that the National Park Service utilized will be the basis of the framework for this research. Following is the literature of the procedure the National Park Service has adopted as their asset management plan.

2.5.1 National Park Service (NPS) Asset Management

In the past, NPS maintained their assets by converging on the whole portfolio of the park, without taking into consideration the backlogs and the importance to their mission. Then they came up with a method to combine Facility Condition Index (FCI) with another metric to prioritize assets which will help them to identify critical assets. As defined by the NPS, "The API is a balanced scorecard approach that allows park managers and decision makers to compare the relative importance of facilities relative to one another to create an overall asset management strategy". The NPS has more than 70,000 facilities under its care with a current replacement value of $150 billion and on top of everything they have more than 84 million acres of land in the country. The NPS has previously stated that among these parks, there are a number of parks that are going through budget cuts. Hence, the decision to use API combined with other metrics had been taken to prioritize their needs. Their objective is to use API as a measure that will prove to be data-driven which will help to reduce the allocation of resources to one type of facility when other homologous facilities exist. The API was scored on a 100 point scale based on their criteria:

(1) Natural Resource Preservation: The assets that directly helps the NPS's goal of national resource preservation fall under this criteria.

(2) Cultural Resource Preservation: The assets that directly or indirectly contribute to the culture or history fall under this criteria.

(3) Visitor Use: Assets that help in assisting in "Visitor accessibility, understanding, and enjoyment". Usually quantified by a number of visitors using the asset.

(4) Park Operations: Any asset that helps in the everyday operations of the park, in managing the park, contracts, security, safety, and emergency.

(5) Asset Substitutability: Assets which can be substituted but still can fulfill all the requirements of the asset that is being replaced are placed under this criteria.

Once the criteria are decided they needed to be weighed in regard to the mission goals and core priorities of NPS. The criteria chosen should be distinct and interdependent from each other. Every asset should be evaluated with each criterion in all the levels (low to high) to establish a score that best defines the asset. All of the staff at the NPS came together during the development of the API as it is a collaborative process which will impact all the divisions within their organization. API as the only metric did not help the NPS to achieve its goals. As stated by Douglas W. Kincaid, "Ultimately, NPS combined three analytical tools to do the job: facility condition index (FCI), asset priority index (API), and critical systems identification. ". The decision to add other metrics like API came after they performed their Facility Condition Index (FCI). The results of their condition assessment showed that their facilities had an immense resource requirement to solve the current deficiencies which were not attributed to one type but spread across a wide variety of asset types. This created a need for prioritization. Douglas W. Kincaid stated that one of the shortfalls with an example stating that the FCI of a building can be higher than a utility system but a low-cost component which may not be considered important can be critical to the operation of the utility line. To control these shortfalls, the NPS combined the two metrics (FCI and API). As a result of this integration, the NPS was able to focus on allocating resources on the assets that have high priorities to make intelligent and targeted investment decisions. One more metric that the NPS used was the critical systems identification. This was used because of the wide variety of types they had under their inventory. This metric will not be used in this research due to the similarity in the assets in the inventory. The NPS achieved a cogent and sturdy technique of evaluating their portfolio and differentiating the various kinds of individual facilities. One of the challenges faced by the NPS was to make the FCI standard across all their facilities. In an attempt to standardize it they created categories to place assets of the same type together. This proved to be successful to their objective. A similar categorization of asset types was already performed in the previous part of this research to group assets with similar attributes. The categorization performed by NPS resulted in 31 different asset types. Even among these types are not considered homogenous because it seemed unreasonable to compare the road condition and a fortification. The asset management plan that the NPS adopted has changed them from “reactive to strategic data-driven management of assets” (Kincaid, 2013). After scoring and validating API, a graphical representation of the results are required to understand the situation of the assets. This can be represented in a number of ways. The graphs represented in the past are,

(1) National Park Service (NPS):

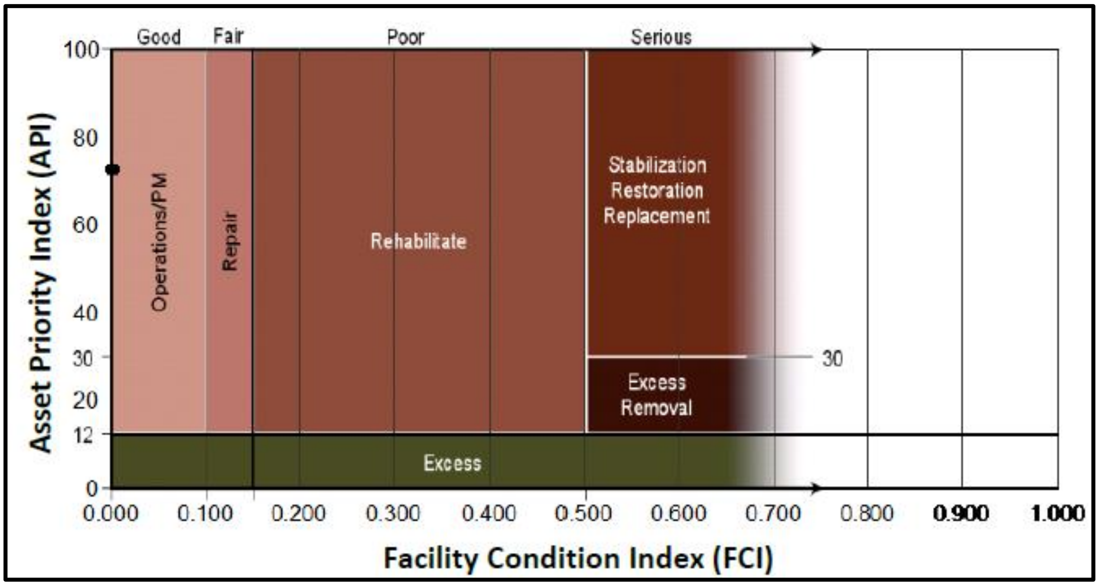


Figure 4: Asset priority index (API) vs Condition index (CI) (NPS)

(2) Department of Interior (DOI):

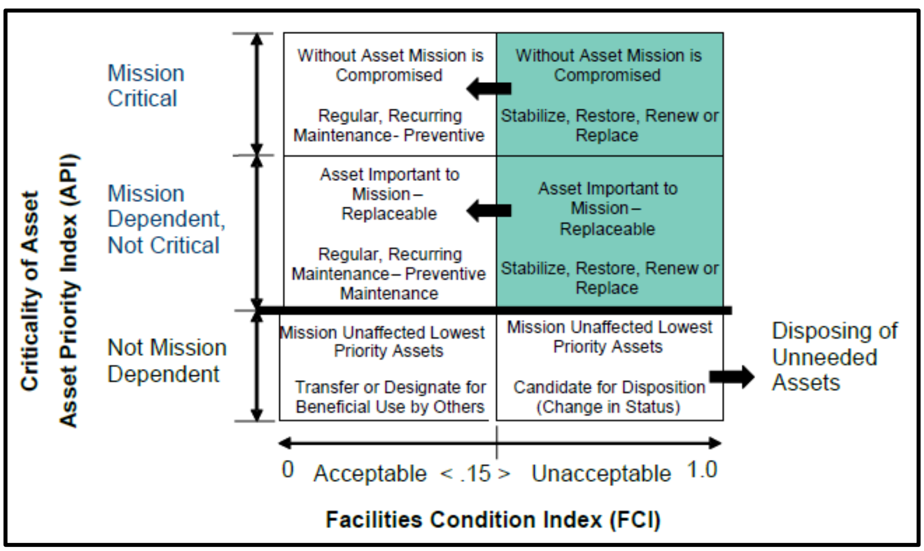


Figure 5: Asset priority index (API) vs Condition index (CI) (DOI)

This research will try to apply such graphs into the NCDOT Ferry division asset management plan to help them classify their assets based on their condition and importance.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

As stated in the objectives and scope chapter of this thesis, this research comprises of three parts.

(1) Determining weight for the systems in the asset hierarchy using Analytic Hierarchy Process (AHP).

(2) Establish a priority rating for the assets in the inventory using the Asset Priority Index (API) metric.

(3) Integrate the weighted condition index and the Asset Priority Index into a visual aid (e.g.: Graphs, Scatterplots, Bar charts, etc.) to help NCFD understand the current situation of their assets and to provide them a guide to make sound decisions investment decisions.

The methodology for each of the objective will be discussed separately.

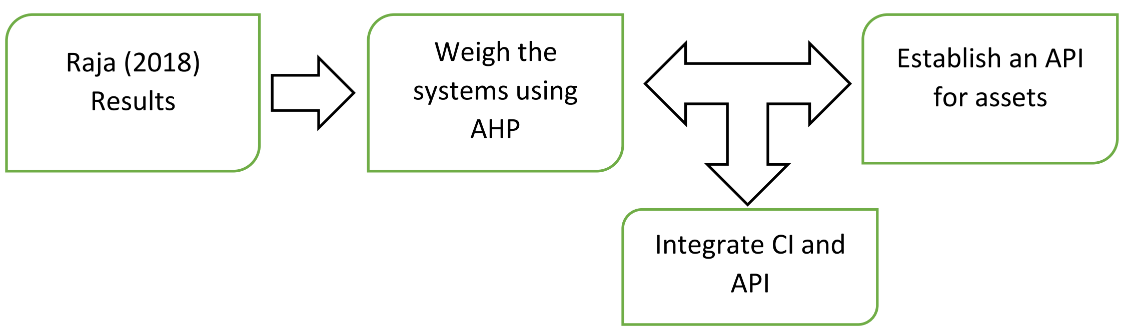


Figure 6: Three parts of the Research

3.2 Weighing the Systems Using AHP

In the previous research conducted by Raja (2018), an asset hierarchy was established for the assets in the NCFD inventory. A homologous set of systems were created to categorize the assets. Since all the vessels have similar components, a homologous set of categories will be sufficient to make the condition index consistent throughout. One of the limitations is that the systems were given equal importance which will alter the final condition index of the vessel as two different systems cannot have the same importance. For example, an engine component cannot be treated equally to an HVAC component. To differentiate the importance within the systems the Analytical Hierarchy Process (AHP) was used. Developed by Saaty in the 1970s AHP is a method used to help managers make decisions where multiple criteria are involved. The criteria are ranked and assigned a priority percentage which helps Multi-Criteria Decision Making (MCDM). This research will stop at ranking the criteria as validated by previous literature. The NCFD has 10 systems under their asset inventory namely,

(1) Engine.
(2) Propulsion.
(3) Steering.
(4) Electrical.
(5) Plumbing.
(6) HVAC.
(7) Communication.
(8) Emergency.
(9) FFFE
(10) Structure

As explained by Klaus (2014), there is a concept known as magical number. This number is 7±2. This number states that the number of criteria should be between 5 and 9 for the most reliable results. Klaus (2014) states that there are three reasons behind it.

(1) Human brain has a limited processing power (George A. Miller, 1956) (Saaty and Ozdemir, 2003).

(2) The number of pairwise comparisons will increase with the increase of the criteria. For example, 9 criteria will need 36 pairwise comparisons. This will lead to a lot of inconsistencies and will eventually exceed the stipulated index value.

(3) The limited scale of 1 to 9 is a limitation as criteria increases. If a system has 10 criteria the maximum possible weight will be less than 50%, which cannot be true according to the respondent's judgment.

For the reasons stated above, the criteria within the asset hierarchy have been reduced to get a reliable weight. The following changes have been made to the list of system,

(1) Main System: Comprises of assets related to Engine, Propulsion, and Steering.

(2) Auxiliary System: Comprises of assets related to Electrical, Plumbing, and HVAC.

(3) Life-Saving System: Comprises of assets related to Communication and Emergency.

(4) FFFE: Comprises of Furniture, Fixtures, and miscellaneous Equipment.

(5) Structure: Comprises of the assets that make up the exterior structure of the ferry, including assets like hull fittings, hatches, stairs, doors and windows.

This has reduced the number of criteria to 5 within the range of the magical number of 7±2. Once the systems were categorized, a survey was performed to determine the weight/priority of the systems to the main goal. It was advised that the survey should be answered with the goal in mind and without considering the overall condition of the systems under their perception.

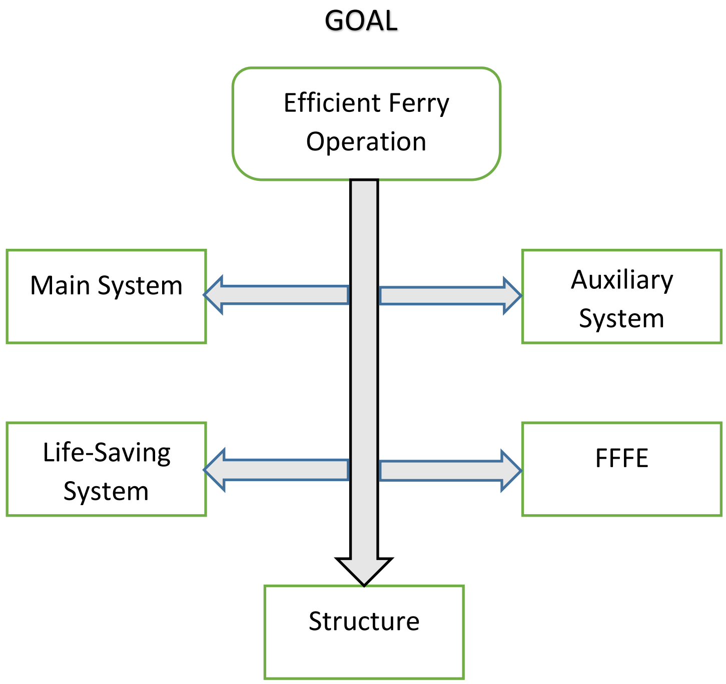


Figure 7: AHP Goals and Criteria Hierarchy

In the survey, the respondents were asked to the rate the importance of each system relative to another based on Table 2 and Figure 8.

Table 2: AHP Scoring Scale

	Numeric Value	Definition
Increasing Importance	1	Equally Important
	2	Intermediate Value
	3	Moderately Important
	4	Intermediate Value
	5	Strong Importance
	6	Intermediate Value
	7	Very Strong Importance
	8	Intermediate Value
	9	Extremely Important

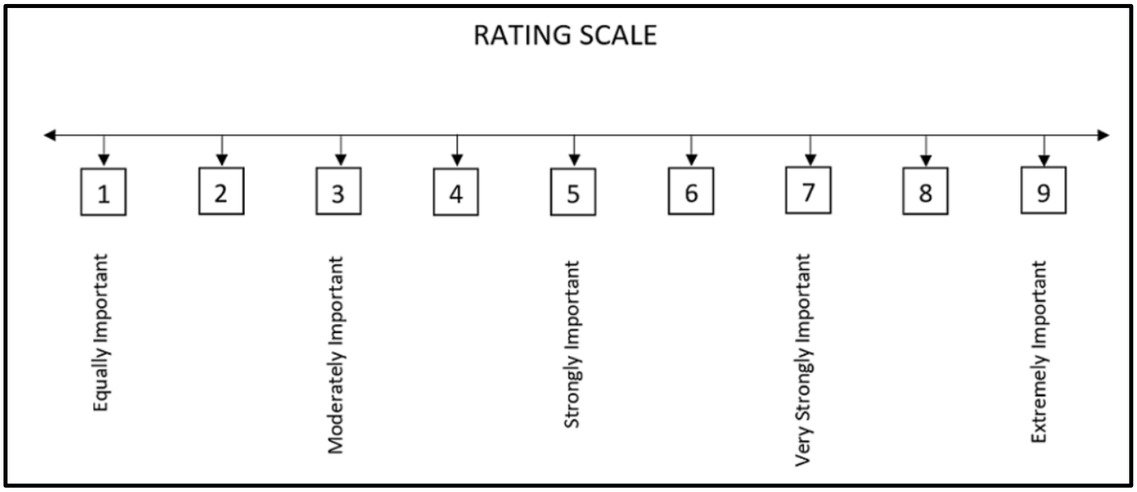
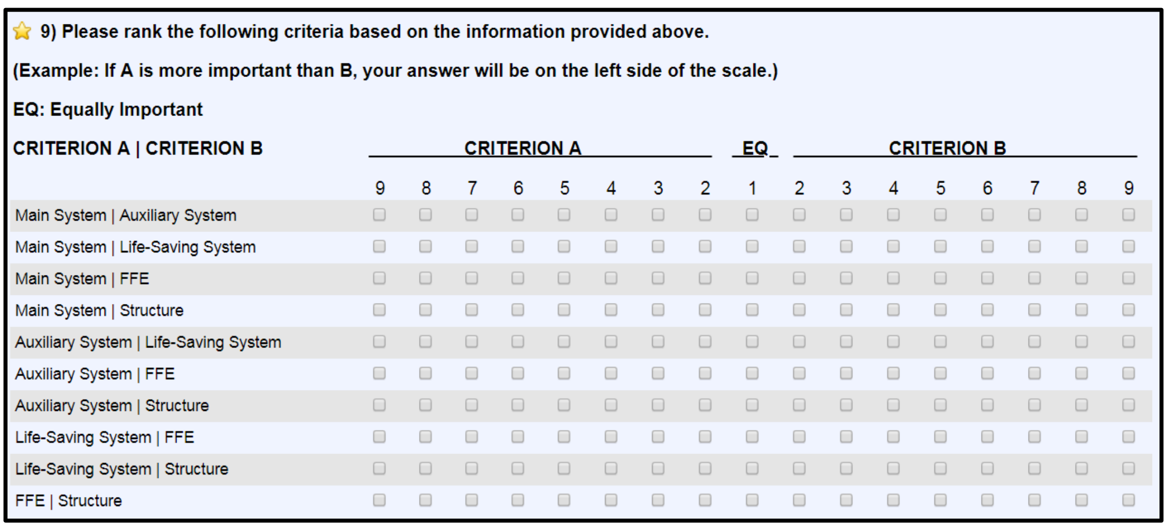


Figure 8: AHP Rating scale

Figure 9 depicts the question on the survey,



9) Please rank the following criteria based on the information provided above.

(Example: If A is more important than B, your answer will be on the left side of the scale.)

EQ: Equally Important

CRITERION A | CRITERION B	CRITERION A								EQ	CRITERION B							
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Main System | Auxiliary System																	
Main System | Life-Saving System																	
Main System | FFE																	
Main System | Structure																	
Auxiliary System | Life-Saving System																	
Auxiliary System | FFE																	
Auxiliary System | Structure																	
Life-Saving System | FFE																	
Life-Saving System | Structure																	
FFE | Structure																	

Figure 9: Survey for Criteria Weight

Once the survey results were collected it was analyzed for inconsistencies. The inconsistencies in the model was confirmed by contacting the respondents in order to reassess the inputs. To evaluate the results, an AHP Excel template developed by Klaus D. Goepel in 2014 was used. Once the results were inputted in the excel sheet, it calculated the Consistency Index (CI). If the CI was more than 10%, it provided a result containing the most meaningful answer based on the other inputs. With this as a reference an attempt was made to contact the respondents to make necessary corrections. After the CI reached 10% or lower, the template created pairwise comparison charts and provided a ranking percentage. An example input and output are depicted in Figure 10, 11 and 12.

		Criteria		more important ?	Scale	
i	j	A	B	- A or B	(1-9)	
1	2	Main System	Auxiallary System	A	2	
1	3		Life Saving System	B	5	3
1	4		FFFE	A	8	
1	5		Structure	A	3	
1	6					
1	7					
1	8					
2	3	Auxiallary System	Life Saving System	B	6	
2	4		FFFE	A	7	
2	5		Structure	A	2	
2	6					
2	7					
2	8					
3	4	Life Saving System	FFFE	A	9	1
3	5		Structure	A	6	
3	6					
3	7					
3	8					
4	5	FFFE	Structure	B	9	2

Figure 10: Input tab (Klaus, 2014)

Decision Matrix A					participant 1
	System	Auxiallary System	Life Saving System	FFFE	Structure
	1	2	3	4	5
1	1	2	0.2	8	3
2	1	1	0.166667	7	2
3	5	6	1	9	6
4	0	0.142857	0.111111	1	0.111
5	0	0.5	0.166667	9	1

Figure 11: Pairwise Comparison (Klaus, 2014)

	Criterion	Comment	Weights	Rk
1	Main System	Engine, Propulsion and Steering	19.1%	2
2	Auxillary System	Electrical, Plumbing and HVAC	12.5%	3
3	Life Saving System	Communication and Emergency	55.9%	1
4	FFFE		2.5%	5
5	Structure		9.9%	4

Figure 12: Ranking results (Klaus, 2014)

3.3 Establishing Asset Priority Index (API)

The API for the NCFD is based on the asset management plan employed by the National Park Service (NPS) in which the metrics Condition Index (CI) and API were combined. To establish the API, the most important part is defining the criteria. But, before defining the criteria, the goals of the organization should be checked and revised. This is because the criteria should be based on the goal of the organization. In the case of the NCFD, their goals are (only regarding the vessels),

(1) To preserve and maintain the vessel to provide uninterrupted service to the community and other.

(2) To serve the community and others by satisfying and fulfilling customer needs in order to increase the usage of ferries.

The next step is to define the scoring criteria. The criteria has to be based on the goals stated above. Figure 13 depicts the criteria defined based on the goals of the NCFD.

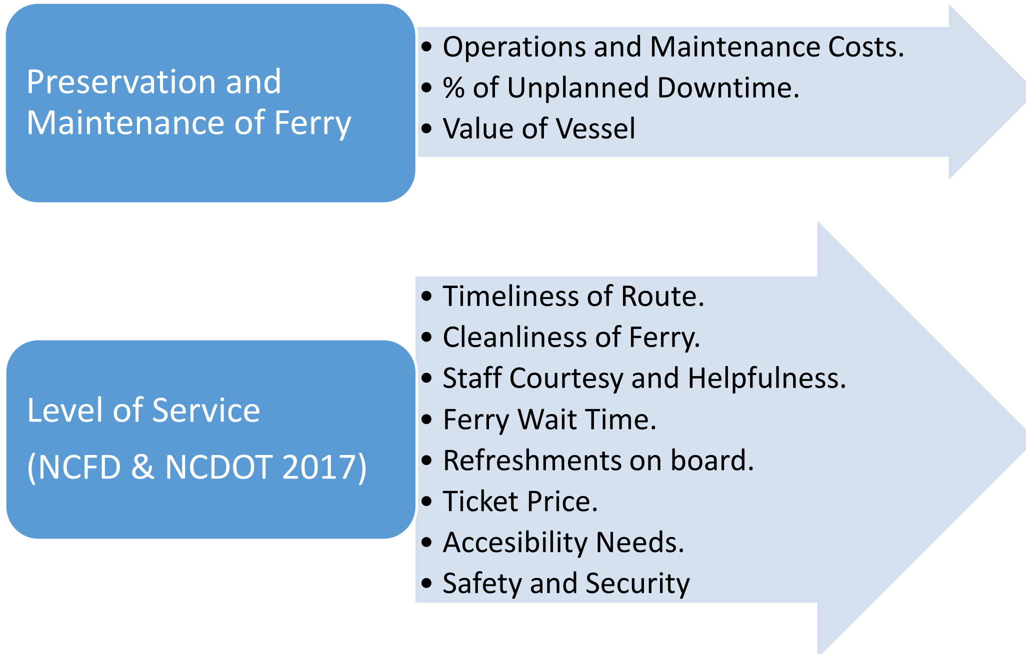


Figure 13: Hierarchy of Goals and Criteria for API

The next step is to weigh the criteria. The following are the weights of the criteria,

- Operations & Maintenance Costs: 30%
- Unplanned Downtime: 20%
- Value of Vessel: 20%
- Level Of Service (Survey by researchers): 10%
- Level of Service (NCDOT Customer Survey 2017): 10%
- Accessibility: 10%

The following Table 3 depicts the scale that will be used to define the criteria. The scale below is susceptible to be reversed based on the nature of the criteria. For instance, the unplanned downtime criteria will have a higher score if downtime is less. But in case of Level of service criterion will have a lower score if the level of service is less.

Table 3: API Scoring Scale

Level	Description	Score
Low	An asset that would be directly capable of compromising the mission goals and their criteria.	1
Medium	Assets that are needed for fulfilling the mission but their status is moderate	2
High	Criteria that have a high value of the corresponding description.	3

To score the assets with a valid API, a survey was conducted collecting information required. For some of the criteria NCFD provided the researchers with data in the form of spreadsheets which was used to score the assets.

3.4 Integrating the API and CI Metrics

The National Park Service (NPS) under their asset management plan has combined their API score and the CI rating together to better understand prioritization based on the current condition of the assets. This research aimed to adopt a similar strategy to develop a graphical/visual aid to showcase the information about the assets condition and their importance to the organization together. After the first and second objectives had been achieved, the integration of the both was done. An example portrayal of the results are as follows,

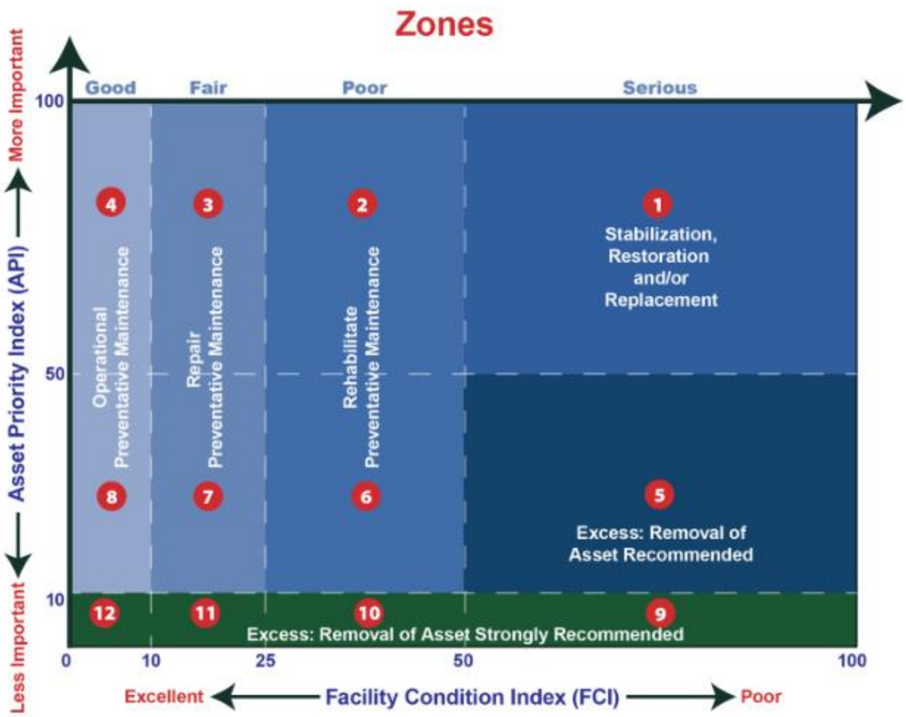


Figure 14: Relationship between API and FCI (Sterling, 2018)

The above graph was used by a consulting firm (received by the researchers through an internal memo) who performed a similar analysis on their dry facilities. The above graph will be modified and used in this research for the purpose of similarity. This will help them to compare graphs and analyze their entire portfolio together. The following graph in Figure 15 and 16 is the aim to be achieved after the analysis of the results.

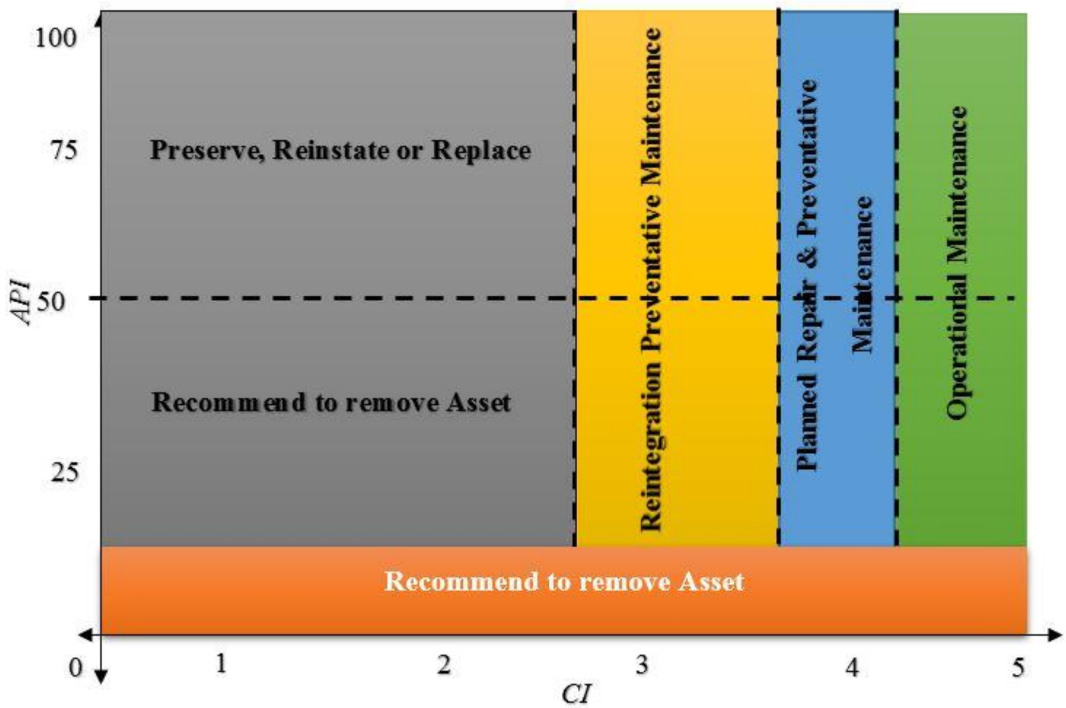


Figure 15: Adaptation of Sterling API vs CI graph.

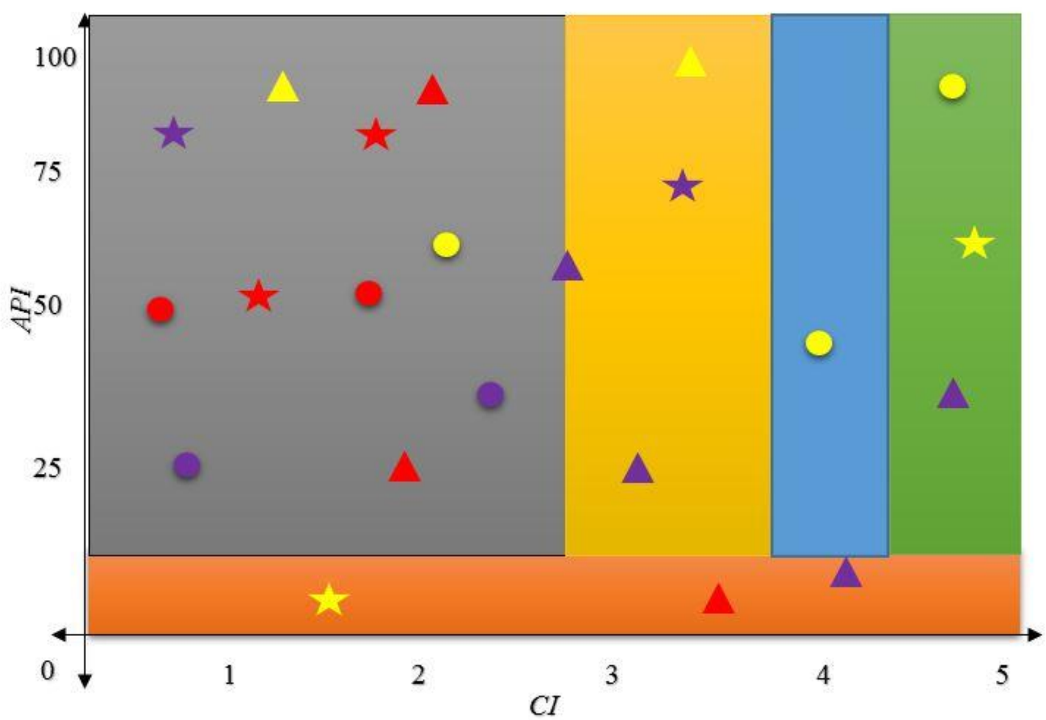


Figure 16: Graph with sample data color-coded with backlog.

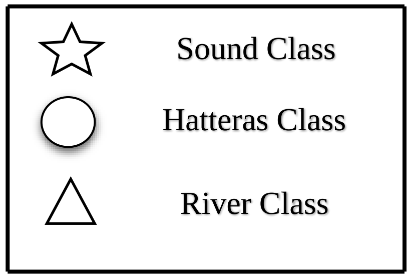


Figure 17: Legend

Backlog Color Code

Yellow: Low Backlog

Purple: Moderate Backlog

Red: High Backlog

Figure 18: Legend for Backlog

The backlog have also been color coded as shown above. After analyzing the results, such a graph will be plotted using which then decision makers at the NCFD can use to make informed investment decisions regarding the asset acquisition, maintenance and disposal.

CHAPTER 4: DATA COLLECTION AND ANALYSIS

4.1 Data Collection

As mentioned in Chapter 3, a survey was formulated and sent out to collect data which helped in developing the Asset Priority Index (API) and the Weight for the systems in the asset hierarchy using Analytic Hierarchy Process (AHP). The following were the information collected from the survey,

(1) Perception of the value of each class of vessels that serves to fulfill the needs of the North Carolina Ferry Division (NCFD).

(2) The Level of Service of each vessel based on Timeliness, Cleanliness, Wait time, Refreshments and adequate seating. This data comes from the stakeholders at the North Carolina Ferry Division (NCFD).

(3) Perception of the Unplanned Downtime for each vessel.

(4) Perception of the ability of the vessels to serve customers with accessibility needs.

(5) Relative importance between the five criteria within the existing asset hierarchy.

Additionally, the survey data from the NCDOT Customer Service 2017 was also used in this research to determine the Level of Service from the customer's point of view. This data involved data from criteria like,

(1) Timeliness of Ferry.

(2) Cleanliness of Ferry.

(3) Staffing on Ferry.

(4) Courtesy and Helpfulness of Staff.

(5) Ferry Wait time.

(6) Refreshments on Board.

(7) Ticket Price.

(8) Safety and Security on Board.

4.2 Data Analysis

4.2.1 Data for Weighing the Systems

The data from the survey gives the results of the relative importance of the each system from five respondents. These survey data was used as inputs in the AHP Excel Template developed by Klaus in 2014. This AHP template is discussed in the previous chapter. The initial inputs of the AHP are shown in Table 4, 5, 6, 7, and 8.

(1) Respondent 1:

Table 4: Respondent 1 AHP inputs.

Criterion A	**Criterion B**	**Original Results**	
Main System	Auxiliary System	A	1
Main System	Life Saving System	A	2
Main System	FFFE	A	2
Main System	Structure	A	6
Auxiliary System	Life Saving System	B	5
Auxiliary System	FFFE	B	2
Auxiliary System	Structure	B	7
Life Saving System	FFFE	A	3
Life Saving System	Structure	B	8
FFFE	Structure	B	8
Consistency Index		66%	

(2) Respondent 2:

Table 5: Respondent 2 AHP inputs.

Criterion A	Criterion B	Original Results	
Main System	Auxiliary System	A	5
Main System	Life Saving System	A	1
Main System	FFFE	A	3
Main System	Structure	A	4
Auxiliary System	Life Saving System	A	1
Auxiliary System	FFFE	A	1
Auxiliary System	Structure	B	4
Life Saving System	FFFE	A	3
Life Saving System	Structure	A	5
FFFE	Structure	A	3
Consistency Index		14%	

(3) Respondent 3:

Table 6: Respondent 3 AHP inputs.

Criterion A	Criterion B	Original Results	
Main System	Auxiliary System	A	8
Main System	Life Saving System	A	1
Main System	FFFE	A	1
Main System	Structure	A	1
Auxiliary System	Life Saving System	A	1
Auxiliary System	FFFE	A	1
Auxiliary System	Structure	A	1
Life Saving System	FFFE	A	1
Life Saving System	Structure	A	1
FFFE	Structure	A	1
Consistency Index		14%	

(4) Respondent 4:

Table 7: Respondent 4 AHP inputs.

Criterion A	Criterion B	Original Results	
Main System	Auxiliary System	A	1
Main System	Life Saving System	B	9
Main System	FFFE	A	1
Main System	Structure	B	9
Auxiliary System	Life Saving System	B	9
Auxiliary System	FFFE	A	1
Auxiliary System	Structure	B	9
Life Saving System	FFFE	A	1
Life Saving System	Structure	A	1
FFFE	Structure	B	9
Consistency Index		12%	

(5) Respondent 5:

Table 8: Respondent 5 AHP inputs.

Criterion A	Criterion B	Original Results	
Main System	Auxiliary System	A	1
Main System	Life Saving System	A	1
Main System	FFFE	A	6
Main System	Structure	A	1
Auxiliary System	Life Saving System	B	5
Auxiliary System	FFFE	A	5
Auxiliary System	Structure	A	1
Life Saving System	FFFE	A	7
Life Saving System	Structure	A	4
FFFE	Structure	B	4
Consistency Index		9%	

The template has the ability to show the inputs that are inconsistent. The following tables 9,10,11,12 and 13 depict the proposed changes in the AHP model by the template.

(1) Respondent 1:

Table 9: Respondent 1 Proposed Changes

		Criteria		more important ?	Scale		
i	j	A	B	- A or B	(1-9)		
1	2	Main System	Auxiallary System	A	1	2	A4
1	3		Life Saving System	A	2		
1	4		FFFE	A	2		
1	5		Structure	A	6	1	B1
1	6						
1	7						
1	8						
2	3	Auxiallary System	Life Saving System	B	5		
2	4		FFFE	B	2		
2	5		Structure	B	7		
2	6						
2	7						
2	8						
3	4	Life Saving System	FFFE	A	3		
3	5		Structure	B	8	3	B2
3	6						
3	7						
3	8						
4	5	FFFE	Structure	B	8		
4	6						

(2) Respondent 2:

Table 10: Respondent 2 Proposed Changes

		Criteria		more important ?	Scale		
i	j	A	B	A or B	(1-9)		
1	2	Main System	Auxiallary System	A	5		
1	3		Life Saving System	A	1		
1	4		FFFE	A	3		
1	5		Structure	A	4		
1	6						
1	7						
1	8						
2	3	Auxiallary System	Life Saving System	A	1	2	B3
2	4		FFFE	A	1		
2	5		Structure	B	4	1	B1
2	6						
2	7						
2	8						
3	4	Life Saving System	FFFE	A	3		
3	5		Structure	A	5		
3	6						
3	7						
3	8						
4	5	FFFE	Structure	A	3	3	A1
4	6						

(3) Respondent 3:

Table 11: Respondent 3 Proposed Changes

		Criteria		more important ?	Scale		
i	j	A	B	A or B	(1-9)		
1	2	Main System	Auxiallary System	A	8	1	A2
1	3		Life Saving System	A	1	2	A2
1	4		FFFE	A	1	2	A2
1	5		Structure	A	1	2	A2
1	6						
1	7						
1	8						
2	3	Auxiallary System	Life Saving System	A	1	2	B2
2	4		FFFE	A	1	2	B2
2	5		Structure	A	1	2	B2
2	6						
2	7						
2	8						
3	4	Life Saving System	FFFE	A	1		
3	5		Structure	A	1		
3	6						
3	7						
3	8						
4	5	FFFE	Structure	A	1		
4	6						

(4) Respondent 4:

Table 12: Respondent 4 Proposed Changes

		Criteria		more important ?	Scale		
i	j	A	B	A or B	(1-9)		
1	2	Main System	Auxiallary System	A	1		
1	3		Life Saving System	B	9		
1	4		FFFE	A	1	2	B2
1	5		Structure	B	9		
1	6						
1	7						
1	8						
2	3	Auxiallary System	Life Saving System	B	9		
2	4		FFFE	A	1	2	B2
2	5		Structure	B	9		
2	6						
2	7						
2	8						
3	4	Life Saving System	FFFE	A	1	1	A4
3	5		Structure	A	1	2	B2
3	6						
3	7						
3	8						
4	5	FFFE	Structure	B	9		
4	6						

(5) Respondent 5:

Table 13: Respondent 5 Proposed Changes

		Criteria		more important ?	Scale
i	j	A	B	A or B	(1-9)
1	2	Main System	Auxiallary System	A	1
1	3		Life Saving System	A	1
1	4		FFFE	A	6
1	5		Structure	A	1
1	6				
1	7				
1	8				
2	3	Auxiallary System	Life Saving System	B	5
2	4		FFFE	A	5
2	5		Structure	A	1
2	6				
2	7				
2	8				
3	4	Life Saving System	FFFE	A	7
3	5		Structure	A	4
3	6				
3	7				
3	8				
4	5	FFFE	Structure	B	4
4	6				

As stated by Klaus in his paper about this template. The differing intensity of red cells are an indication of inconsistent inputs. These inconsistent inputs are marked in order. This means that the input marked as 1 is the most inconsistent input among the other inputs. The green value next to the red cells are the probable answer to reduce the inconsistency based on the other consistent inputs. “Participants might slightly modify the highlighted judgements in the direction of the ideal judgement, in order to improve consistency” (Goepel, 2013). Based on this, for this research the inputs have been adjusted to reduce the Consistency Index to 10% or lesser. Care has been taken to make the least number of changes to avoid changing the nature of the data. The following tables 14, 15, 16, 17, and 18 compares the original and updated inputs and consistency index (The highlighted rows are the changes made from the original),

(1) Respondent 1:

Table 14: Respondent 1 Updated AHP Model

Criterion A	Criterion B	Original Results		Updated Results	
Main System	Auxiliary System	A	1	A	3
Main System	Life Saving System	A	2	A	2
Main System	FFFE	A	2	A	2
Main System	Structure	A	6	B	1
Auxiliary System	Life Saving System	B	5	B	5
Auxiliary System	FFFE	B	2	B	2
Auxiliary System	Structure	B	7	B	7
Life Saving System	FFFE	A	3	A	3
Life Saving System	Structure	B	8	B	3
FFFE	Structure	B	8	B	8
Consistency Index		66%		7%	

(2) Respondent 2

Table 15: Respondent 2 Updated AHP Model

Criterion A	Criterion B	Original Results		Updated Results	
Main System	Auxiliary System	A	5	A	5
Main System	Life Saving System	A	1	A	1
Main System	FFFE	A	3	A	3
Main System	Structure	A	4	A	4
Auxiliary System	Life Saving System	A	1	A	1
Auxiliary System	FFFE	A	1	A	1
Auxiliary System	Structure	B	4	B	1
Life Saving System	FFFE	A	3	A	3
Life Saving System	Structure	A	5	A	5
FFFE	Structure	A	3	A	3
Consistency Index		14%		7%	

(3) Respondent 3:

Table 16: Respondent 3 Updated AHP Model

Criterion A	Criterion B	Original Results		Updated Results	
Main System	Auxiliary System	A	8	A	2
Main System	Life Saving System	A	1	A	1
Main System	FFFE	A	1	A	1
Main System	Structure	A	1	A	1
Auxiliary System	Life Saving System	A	1	A	1
Auxiliary System	FFFE	A	1	A	1
Auxiliary System	Structure	A	1	A	1
Life Saving System	FFFE	A	1	A	1
Life Saving System	Structure	A	1	A	1
FFFE	Structure	A	1	A	1
Consistency Index		14%		1%	

(4) Respondent 4:

Table 17: Respondent 4 Updated AHP Model

Criterion A	Criterion B	Original Results		Updated Results	
Main System	Auxiliary System	A	1	A	1
Main System	Life Saving System	B	9	B	9
Main System	FFFE	A	1	A	1
Main System	Structure	B	9	B	9
Auxiliary System	Life Saving System	B	9	B	9
Auxiliary System	FFFE	A	1	A	1
Auxiliary System	Structure	B	9	B	9
Life Saving System	FFFE	A	1	A	4
Life Saving System	Structure	A	1	A	1
FFFE	Structure	B	9	B	9
Consistency Index		12%		2%	

(5) Respondent 5:

Table 18: Respondent 5 Updated AHP Model

Criterion A	Criterion B	Original Results		Updated Results
Main System	Auxiliary System	A	1	No Changes
Main System	Life Saving System	A	1	
Main System	FFFE	A	6	
Main System	Structure	A	1	
Auxiliary System	Life Saving System	B	5	
Auxiliary System	FFFE	A	5	
Auxiliary System	Structure	A	1	
Life Saving System	FFFE	A	7	
Life Saving System	Structure	A	4	
FFFE	Structure	B	4	
Consistency Index		9%		9%

After the changes were made to the AHP model, the individual rankings and the consolidated rankings were derived. Table 19 shows the individual ranking results for each respondent.

Table 19: Individual Respondent Ranking

System	**R1**	**R2**	**R3**	**R4**	**R5**
Main System	25%	38%	23%	5%	22%
Auxiliary System	5%	12%	17%	5%	16%
Life Saving System	18%	29%	20%	39%	42%
FFFE	8%	13%	20%	6%	4%
Structure	43%	7%	20%	45%	16%

Table 20 provides the ranking results by consolidating all the individual results shown above,

Table 20: Consolidated Ranking List

	Criterion	Comment	Weights	Rk
1	Main System	Engine, Propulsion and Steering	21.9%	3
2	Auxiallary System	Electrical, Plumbing and HVAC	11.2%	4
3	Life Saving System	Communication and Emergency	32.2%	1
4	FFFE		10.1%	5
5	Structure		24.6%	2

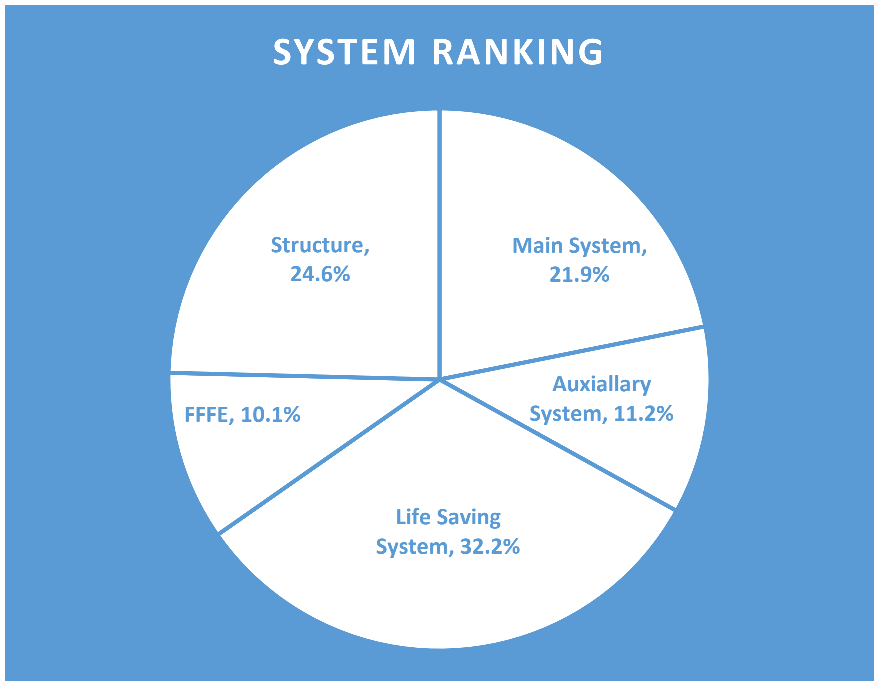


Figure 19: Consolidated Ranking

The following table depicts the weights for all the 10 systems by assuming that the systems grouped within a system will have an equal weight.

Table 21: Distribution of Weights to all systems.

Sr.No	System	Weight	Sr.No	System	Weight
1	Communication	16.10%	**6**	HVAC	3.73%
2	Electrical	3.73%	**7**	Plumbing	3.73%
3	Emergency	16.10%	**8**	Propulsion	7.30%
4	Engine	7.30%	**9**	Steering	7.30%
5	FFFE	10.10%	**10**	Structure	24.60%

4.2.3 Data for Asset Priority Index (API)

The data used for calculating the API comes from three sources,

(1) The survey conducted by the researchers on behalf of the NCFD. This data contains criteria like,

i) Value of Vessel.

ii) Level of Service (NCFD stakeholder's perspective).

iii) % of Unplanned Downtime.

iv) Accessibility facilities on vessels.

(2) The maintenance costs for one fiscal year provided by the NCFD. This data consists of,

i) Cost of maintenance and related operations for each vessel.

ii) Respective codes to distinguish the repairs into the existing systems.

(3) The customer service survey conducted by NCDOT in 2017. This data consists of criteria like,

i) Timeliness of Ferry.

ii) Cleanliness of Ferry.

iii) Staffing on Ferry.

iv) Courtesy and Helpfulness of Staff.

v) Ferry Wait time.

vi) Refreshments on board.

vii) Ticket Price.

viii) Safety and Security on board.

All of the aforementioned data are of qualitative type except the maintenance cost. To calculate the API these qualitative data must be converted into a quantitative type. For this purpose, for each of the answer type a number value has been assigned and the results are converted into quantitative. The following are the scale used for the available data.

1) Scale for the survey conducted by the researchers:

Table 22: Scale for survey conducted by researchers.

Criteria	Scale for the Different Types of Answers		
	Low	Moderate	Maximum
Value of Vessel	1	2	3
Level of Service	1	2	3
Unplanned Downtime	3	2	1
Accessibility	0 (Not present)	-	1 (Present)

2) Scale for the maintenance costs data:

The costs have been used directly in the calculation of the API since it is already a quantifiable value.

3) Scale for NCDOT 2017 Customer Service Survey:

Table 23: Scale for NCDOT 2017 Customer Service Survey

Criteria	Scale for the Different Types of Answers		
	Exceeds Expectations	Meets Expectations	Does Not Meet Expectations
Timeliness of Ferry	3	2	1
Cleanliness of Ferry	3	2	1
Staffing on Ferry	3	2	1

Table 24: Continuation of Table 23.

Criteria	Scale for the Different Types of Answers		
	Exceeds Expectations	Meets Expectations	Does Not Meet Expectations
Courtesy and Helpfulness of Staff	3	2	1
Ferry Wait Time	3	2	1
Refreshments on Board	3	2	1
Ticket price	3	2	1
Safety and Security on Board	3	2	1

Using these scales, all of the data is converted into quantitative data. Using these values the API for each vessel was calculated. The original and the analyzed survey results are attached in the Appendix A Chapter.

CHAPTER 5: RESULTS

5.1 Calculation of Asset Priority Index

To calculate the Asset Priority Index (API), a procedure known as the Best Value Procurement (BVP) method is used. BVP is primarily a method used by owners to select contractors based on criteria other than the bid price. These criteria include past performance, qualifications and others which cannot be defined by a certain value. This method is adopted here because the criteria to calculate the API consists of one constant value ($) and other intangible values. To perform BVP, each criterion should have a best value. The Best Value is defined as the value that is the most advantageous to that criteria. For Example, if bid price is the criteria the best value will be the minimum of bid price among all the respondents. Contrary to that if experience is the criteria, the maximum in that criteria will be the best value. In this case, choosing the best value differs because they are different ways a best value for a vessel can be defined. In the NCFD, the vessels are organized by their 3 different classes namely, Hatteras, River and Sound. The three methods to define the best value are,

1) Overall Method

   This method is where the best value of each criteria is chosen from the entire fleet as a reference. The best value is chosen from all the three classes of vessels combined.

2) Cost by Class Method

   In this method, the best value for the maintenance cost criteria will be chosen based on the class in which the vessel is grouped. The best value for the remaining criteria will be chosen based on the overall method.

3) Everything by Class Method

In this method, all the criteria best value will be defined by class. This means that each class of vessel will have its own best value.

The following tables 25, 26, and 27 are the best values for the three methods mentioned above,

Table 25: Best values for Overall Method

Criteria	Function	Best Value
Operation & Maintenance Costs	Minimum	$ 56,553.81
Unplanned Downtime	Maximum	2.40
Value of Vessel	Maximum	2.60
Level of Service (This research)	Maximum	3.00
Level of Service (NCDOT)	Maximum	2.22
Accessibility	Maximum	3.00

Table 26: Best Values for Cost by Class Method.

Criteria	Function	Best Value		
		Hatteras	River	Sound
Operation & Maintenance Costs	Minimum	$ 60,074.00	$ 56,553.81	$115,563.31
Unplanned Downtime	Maximum	2.40		
Value of Vessel	Maximum	2.60		
Level of Service (This research)	Maximum	3.00		
Level of Service (NCDOT)	Maximum	2.22		
Accessibility	Maximum	3.00		

Table 27: Best Values for Everything by Class Method

Criteria	Function	Best Value		
		Hatteras	River	Sound
Operation & Maintenance Costs	Minimum	$ 60,074.00	$ 56,553.81	$ 115,563.31
Unplanned Downtime	Maximum	2.20	2.40	2.20
Value of Vessel	Maximum	1.40	2.00	2.60
Level of Service (This research)	Maximum	2.00	3.00	2.80
Level of Service (NCDOT)	Maximum	2.19	2.22	2.10
Accessibility	Maximum	1.20	2.40	3.00

Once the best values have been defined, the weights of the criteria were defined. In this research for the NCFD, the weights have been defined in such a way that it matches the existing weightage they have for the API of their dry facilities. The weightage is mentioned below,

Table 28: Asset Priority Index (API) Criteria Weighting

Criteria	Weight
Operation & Maintenance Costs	30%
Unplanned Downtime	20%
Value of Vessel	20%
Level of Service (This research)	10%
Level of Service (NCDOT)	10%
Accessibility	10%

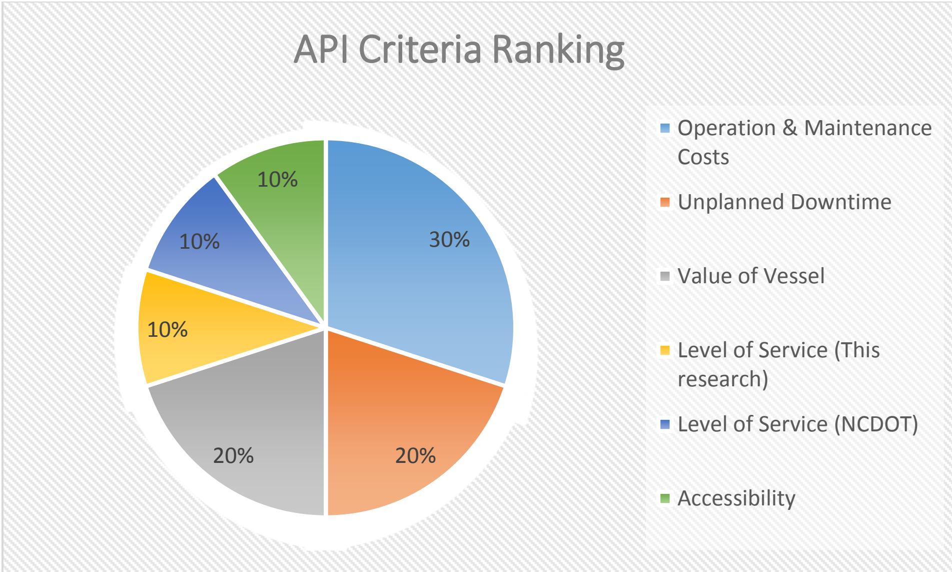


Figure 20: API Criteria Ranking

The formula used in the BVP method here are,

1) For Tangible/Constant Values:

$$\left(\frac{Best\ Value}{Criteria\ Value\ of\ Vessel}\right) X\ Weight\ (\%)$$

Equation 1: Formula for Tangible/Constant Values

2) For Intangible Values:

$$\left(\frac{Criteria\ Value\ of\ Vessel}{Best\ Value}\right) X\ Weight\ (\%)$$

Equation 2: Formula for Intangible Values

Using these above formulae, weights and best values, the API was calculated for the three different methods. Following tables 29, 30, and 31 depict the APIs for all the three methods.

Table 29: API Scores by Overall Method.

Class	Vessel	API Scores	API Scores
Hatteras	Thomas A Baum	48%	58%
	Roanoke	47%	
	Frisco	60%	
	Chicamacomico	77%	
	Cape Point	50%	
	Ocracoke	58%	
	Kinnakeet	65%	
River	Gov. Daniel Russel	68%	70%
	Gov. James B Hunt Jr	72%	
	Southport	63%	
	Neuse	82%	
	Floyd J Lupton	72%	
	Fort Fisher	92%	
	Stanford White	61%	
	Croatoan	61%	
	Hatteras	59%	
Sound	Silver Lake	69%	72%
	Swan Quarter	69%	
	Sea Level	75%	
	Cedar Island	81%	
	Carteret	67%	

Table 30: API Scores using Cost by Class Method.

Class	Vessel	API Scores	API Scores
Hatteras	Thomas A Baum	48%	59%
	Roanoke	47%	
	Frisco	61%	
	Chicamacomico	78%	
	Cape Point	50%	
	Ocracoke	59%	
	Kinnakeet	66%	
River	Gov. Daniel Russel	68%	70%
	Gov. James B Hunt Jr	72%	
	Southport	63%	
	Neuse	82%	
	Floyd J Lupton	72%	
	Fort Fisher	92%	
	Stanford White	61%	
	Croatoan	61%	
	Hatteras	59%	
Sound	Silver Lake	73%	79%
	Swan Quarter	71%	
	Sea Level	84%	
	Cedar Island	96%	
	Carteret	70%	

Table 31: API scores using Everything by Class Method

Class	Vessel	API Scores	API Scores
Hatteras	Thomas A Baum	64%	77%
	Roanoke	67%	
	Frisco	81%	
	Chicamacomico	98%	
	Cape Point	70%	
	Ocracoke	76%	
	Kinnakeet	86%	
River	Gov. Daniel Russel	75%	76%
	Gov. James B Hunt Jr	78%	
	Southport	70%	
	Neuse	89%	
	Floyd J Lupton	78%	
	Fort Fisher	98%	
	Stanford White	67%	
	Croatoan	68%	
	Hatteras	65%	
Sound	Silver Lake	75%	80%
	Swan Quarter	72%	
	Sea Level	85%	
	Cedar Island	98%	
	Carteret	71%	

Based on the business and decision-making model of the NCFD, one of the three methods may be chosen. If decisions are made based on the class of vessels, then everything by class method will be more suitable and produce a better serving model.

5.2 Updating Condition Index Based On the AHP Results

As mentioned previously, this research is an extension to a previous research conducted by Raja (2018). His research focused on developing a condition assessment for all the assets under an asset hierarchy with different systems. He considered that all the systems were of equal importance. That is where this research helps in defining the weights using the method of AHP. The following are the Original Condition Index, the weight of systems and the new Weighted Condition Index for all the 21 vessels.

Table 32: Updated Condition Index for Cape Point

CAPE POINT						
S.No	**System**	**CI**	**Average CI**	**Weight**	**Weighted CI**	**Final CI**
1	Communication	3.50	4.09	16.10%	0.5635	4.08
2	Electrical	4.33		3.73%	0.16165333	
3	Emergency	4.50		16.10%	0.7245	
4	Engine	4.50		7.30%	0.3285	
5	FFFE	4.33		10.10%	0.43733	
6	HVAC	3.29		3.73%	0.12282667	
7	Plumbing	4.00		3.73%	0.14933333	
8	Propulsion	4.00		7.30%	0.292	
9	Steering	4.50		7.30%	0.3285	
10	Structure	3.95		24.60%	0.9717	

Table 33: Updated Condition Index for Carteret

CARTERET						
S.No	**System**	**CI**	**Average CI**	**Weight**	**Weighted CI**	**Final CI**
1	Communication	4.17	4.02	16.10%	0.67137	4.07
2	Electrical	4.26		3.73%	0.15904	
3	Emergency	4.38		16.10%	0.70518	
4	Engine	4.14		7.30%	0.30222	
5	FFFE	3.69		10.10%	0.37269	
6	HVAC	3.00		3.73%	0.112	
7	Plumbing	4.50		3.73%	0.168	
8	Propulsion	4.00		7.30%	0.292	
9	Steering	4.00		7.30%	0.292	
10	Structure	4.03		24.60%	0.99138	

Table 34: Updated Condition Index for Cedar Island

CEDAR ISLAND						
S.No	**System**	**CI**	**Average CI**	**Weight**	**Weighted CI**	**Final CI**
1	Communication	3.50	4.03	16.10%	0.5635	4.15
2	Electrical	4.65		3.73%	0.1736	
3	Emergency	4.82		16.10%	0.77602	
4	Engine	4.50		7.30%	0.3285	
5	FFFE	3.56		10.10%	0.35956	
6	HVAC	3.10		3.73%	0.11573333	
7	Plumbing	4.00		3.73%	0.14933333	
8	Propulsion	4.00		7.30%	0.292	
9	Steering	3.50		7.30%	0.2555	
10	Structure	4.63		24.60%	1.13898	

Table 35: Updated Condition Index for Chicamacomico

CHICAMACOMICO						
S.No	**System**	**CI**	**Average CI**	**Weight**	**Weighted CI**	**Final CI**
1	Communication	5.00	3.85	16.10%	0.805	3.92
2	Electrical	3.64		3.73%	0.13589333	
3	Emergency	4.17		16.10%	0.67137	
4	Engine	2.50		7.30%	0.1825	
5	FFFE	3.60		10.10%	0.3636	
6	HVAC	3.17		3.73%	0.11834667	
7	Plumbing	3.55		3.73%	0.13253333	
8	Propulsion	4.50		7.30%	0.3285	
9	Steering	5.00		7.30%	0.365	
10	Structure	3.32		24.60%	0.81672	

Table 36: Updated Condition Index for Croatoan

CROATOAN						
S.No	**System**	**CI**	**Average CI**	**Weight**	**Weighted CI**	**Final CI**
1	Communication	4.25	4.32	16.10%	0.68425	4.35
2	Electrical	4.13		3.73%	0.15418667	
3	Emergency	4.40		16.10%	0.7084	
4	Engine	4.50		7.30%	0.3285	
5	FFFE	4.29		10.10%	0.43329	
6	HVAC	3.63		3.73%	0.13552	
7	Plumbing	4.14		3.73%	0.15456	
8	Propulsion	4.50		7.30%	0.3285	
9	Steering	5.00		7.30%	0.365	
10	Structure	4.31		24.60%	1.06026	

Table 37: Updated Condition Index for Fort Fisher

FORT FISHER						
S.No	**System**	**CI**	**Average CI**	**Weight**	**Weighted CI**	**Final CI**
1	Communication	4.50	4.30	16.10%	0.7245	4.26
2	Electrical	4.53		3.73%	0.16912	
3	Emergency	4.33		16.10%	0.69713	
4	Engine	4.60		7.30%	0.3358	
5	FFFE	4.00		10.10%	0.404	
6	HVAC	3.20		3.73%	0.11946667	
7	Plumbing	4.40		3.73%	0.16426667	
8	Propulsion	4.50		7.30%	0.3285	
9	Steering	5.00		7.30%	0.365	
10	Structure	3.89		24.60%	0.95694	

Table 38: Updated Condition Index for Frisco

FRISCO						
S.No	**System**	**CI**	**Average CI**	**Weight**	**Weighted CI**	**Final CI**
1	Communication	5.00	4.28	16.10%	0.805	4.29
2	Electrical	4.56		3.73%	0.17024	
3	Emergency	4.21		16.10%	0.67781	
4	Engine	4.00		7.30%	0.292	
5	FFFE	4.11		10.10%	0.41511	
6	HVAC	4.13		3.73%	0.15418667	
7	Plumbing	4.22		3.73%	0.15754667	
8	Propulsion	4.00		7.30%	0.292	
9	Steering	4.50		7.30%	0.3285	
10	Structure	4.05		24.60%	0.9963	

Table 39: Updated Condition Index for Gov. Daniel Russel

GOV. DANIEL RUSSEL						
S.No	**System**	**CI**	**Average CI**	**Weight**	**Weighted CI**	**Final CI**
1	Communication	3.67	4.09	16.10%	0.59087	4.06
2	Electrical	4.42		3.73%	0.16501333	
3	Emergency	4.33		16.10%	0.69713	
4	Engine	4.60		7.30%	0.3358	
5	FFFE	3.83		10.10%	0.38683	
6	HVAC	3.50		3.73%	0.13066667	
7	Plumbing	4.50		3.73%	0.168	
8	Propulsion	4.00		7.30%	0.292	
9	Steering	4.00		7.30%	0.292	
10	Structure	4.06		24.60%	0.99876	

Table 40: Updated Condition Index for Gov. James B Hunt Jr.

GOV. JAMES B. HUNT JR						
S.No	**System**	**CI**	**Average CI**	**Weight**	**Weighted CI**	**Final CI**
1	Communication	5.00	4.07	16.10%	0.805	4.32
2	Electrical	4.33		3.73%	0.16165333	
3	Emergency	4.83		16.10%	0.77763	
4	Engine	4.00		7.30%	0.292	
5	FFFE	3.75		10.10%	0.37875	
6	HVAC	4.00		3.73%	0.14933333	
7	Plumbing	3.00		3.73%	0.112	
8	Propulsion	3.33		7.30%	0.24309	
9	Steering	4.00		7.30%	0.292	
10	Structure	4.50		24.60%	1.107	

Table 41: Updated Condition Index for Hatteras

HATTERAS						
S.No	**System**	**CI**	**Average CI**	**Weight**	**Weighted CI**	**Final CI**
1	Communication	4.50	4.26	16.10%	0.7245	4.35
2	Electrical	4.19		3.73%	0.15642667	
3	Emergency	4.60		16.10%	0.7406	
4	Engine	4.00		7.30%	0.292	
5	FFFE	3.63		10.10%	0.36663	
6	HVAC	3.83		3.73%	0.14298667	
7	Plumbing	4.29		3.73%	0.16016	
8	Propulsion	5.00		7.30%	0.365	
9	Steering	4.00		7.30%	0.292	
10	Structure	4.53		24.60%	1.11438	

Table 42: Updated Condition Index for Kinnakeet

KINNAKEET						
S.No	**System**	**CI**	**Average CI**	**Weight**	**Weighted CI**	**Final CI**
1	Communication	4.33	4.39	16.10%	0.69713	4.43
2	Electrical	4.31		3.73%	0.16090667	
3	Emergency	4.73		16.10%	0.76153	
4	Engine	4.00		7.30%	0.292	
5	FFFE	4.00		10.10%	0.404	
6	HVAC	4.00		3.73%	0.14933333	
7	Plumbing	4.36		3.73%	0.16277333	
8	Propulsion	5.00		7.30%	0.365	
9	Steering	4.67		7.30%	0.34091	
10	Structure	4.45		24.60%	1.0947	

Table 43: Updated Condition Index for Floyd J. Lupton

FLOYD J. LUPTON						
S.No	**System**	**CI**	**Average CI**	**Weight**	**Weighted CI**	**Final CI**
1	Communication	3.00	4.37	16.10%	0.483	4.24
2	Electrical	4.79		3.73%	0.17882667	
3	Emergency	4.64		16.10%	0.74704	
4	Engine	4.57		7.30%	0.33361	
5	FFFE	4.00		10.10%	0.404	
6	HVAC	4.20		3.73%	0.1568	
7	Plumbing	4.29		3.73%	0.16016	
8	Propulsion	5.00		7.30%	0.365	
9	Steering	5.00		7.30%	0.365	
10	Structure	4.25		24.60%	1.0455	

Table 44: Updated Condition Index for Neuse

NEUSE						
S.No	**System**	**CI**	**Average CI**	**Weight**	**Weighted CI**	**Final CI**
1	Communication	3.00	3.92	16.10%	0.483	3.81
2	Electrical	4.25		3.73%	0.15866667	
3	Emergency	3.82		16.10%	0.61502	
4	Engine	4.25		7.30%	0.31025	
5	FFFE	3.33		10.10%	0.33633	
6	HVAC	2.57		3.73%	0.09594667	
7	Plumbing	4.57		3.73%	0.17061333	
8	Propulsion	4.50		7.30%	0.3285	
9	Steering	5.00		7.30%	0.365	
10	Structure	3.86		24.60%	0.94956	

Table 45: Updated Condition Index for Ocracoke

OCRACOKE						
S.No	**System**	**CI**	**Average CI**	**Weight**	**Weighted CI**	**Final CI**
1	Communication	4.00	4.09	16.10%	0.644	4.04
2	Electrical	4.19		3.73%	0.15642667	
3	Emergency	4.50		16.10%	0.7245	
4	Engine	4.00		7.30%	0.292	
5	FFFE	3.80		10.10%	0.3838	
6	HVAC	3.67		3.73%	0.13701333	
7	Plumbing	4.60		3.73%	0.17173333	
8	Propulsion	4.00		7.30%	0.292	
9	Steering	4.33		7.30%	0.31609	
10	Structure	3.77		24.60%	0.92742	

Table 46: Updated Condition Index for Roanoke

ROANOKE						
S.No	**System**	**CI**	**Average CI**	**Weight**	**Weighted CI**	**Final CI**
1	Communication	4.20	4.19	16.10%	0.6762	4.15
2	Electrical	4.05		3.73%	0.1512	
3	Emergency	4.60		16.10%	0.7406	
4	Engine	4.33		7.30%	0.31609	
5	FFFE	3.50		10.10%	0.3535	
6	HVAC	4.00		3.73%	0.14933333	
7	Plumbing	4.00		3.73%	0.14933333	
8	Propulsion	4.50		7.30%	0.3285	
9	Steering	5.00		7.30%	0.365	
10	Structure	3.73		24.60%	0.91758	

Table 47: Updated Condition Index for Sea Level

SEA LEVEL						
S.No	**System**	**CI**	**Average CI**	**Weight**	**Weighted CI**	**Final CI**
1	Communication	4.33	4.72	16.10%	0.69713	4.59
2	Electrical	5.00		3.73%	0.18666667	
3	Emergency	4.85		16.10%	0.78085	
4	Engine	5.00		7.30%	0.365	
5	FFFE	4.60		10.10%	0.4646	
6	HVAC	4.67		3.73%	0.17434667	
7	Plumbing	4.63		3.73%	0.17285333	
8	Propulsion	5.00		7.30%	0.365	
9	Steering	5.00		7.30%	0.365	
10	Structure	4.14		24.60%	1.01844	

Table 48: Updated Condition Index for Silver Lake

SILVER LAKE						
S.No	**System**	**CI**	**Average CI**	**Weight**	**Weighted CI**	**Final CI**
1	Communication	3.50	4.30	16.10%	0.5635	4.40
2	Electrical	4.55		3.73%	0.16986667	
3	Emergency	5.00		16.10%	0.805	
4	Engine	5.00		7.30%	0.365	
5	FFFE	4.38		10.10%	0.44238	
6	HVAC	3.20		3.73%	0.11946667	
7	Plumbing	4.17		3.73%	0.15568	
8	Propulsion	4.00		7.30%	0.292	
9	Steering	4.50		7.30%	0.3285	
10	Structure	4.73		24.60%	1.16358	

Table 49: Updated Condition Index for Southport

SOUTHPORT						
S.No	**System**	**CI**	**Average CI**	**Weight**	**Weighted CI**	**Final CI**
1	Communication	3.67	3.75	16.10%	0.59087	3.76
2	Electrical	4.38		3.73%	0.16352	
3	Emergency	4.25		16.10%	0.68425	
4	Engine	4.00		7.30%	0.292	
5	FFFE	3.00		10.10%	0.303	
6	HVAC	2.50		3.73%	0.09333333	
7	Plumbing	4.83		3.73%	0.18032	
8	Propulsion	2.00		7.30%	0.146	
9	Steering	5.00		7.30%	0.365	
10	Structure	3.83		24.60%	0.94218	

Table 50: Updated Condition Index for Stanford White

STANFORD WHITE						
S.No	**System**	**CI**	**Average CI**	**Weight**	**Weighted CI**	**Final CI**
1	Communication	5.00	3.78	16.10%	0.805	3.91
2	Electrical	3.94		3.73%	0.14709333	
3	Emergency	4.13		16.10%	0.66493	
4	Engine	3.50		7.30%	0.2555	
5	FFFE	3.33		10.10%	0.33633	
6	HVAC	3.00		3.73%	0.112	
7	Plumbing	3.33		3.73%	0.12432	
8	Propulsion	4.00		7.30%	0.292	
9	Steering	4.00		7.30%	0.292	
10	Structure	3.60		24.60%	0.8856	

Table 51: Updated Condition Index for Swan Quarter

SWAN QUARTER						
S.No	**System**	**CI**	**Average CI**	**Weight**	**Weighted CI**	**Final CI**
1	Communication	4.71	4.56	16.10%	0.75831	4.56
2	Electrical	4.57		3.73%	0.17061333	
3	Emergency	4.75		16.10%	0.76475	
4	Engine	4.86		7.30%	0.35478	
5	FFFE	4.60		10.10%	0.4646	
6	HVAC	4.64		3.73%	0.17322667	
7	Plumbing	4.20		3.73%	0.1568	
8	Propulsion	4.00		7.30%	0.292	
9	Steering	5.00		7.30%	0.365	
10	Structure	4.30		24.60%	1.0578	

Table 52: Updated Condition Index for Thomas A. Baum

THOMAS A BAUM						
S.No	**System**	**CI**	**Average CI**	**Weight**	**Weighted CI**	**Final CI**
1	Communication	4.00	3.78	16.10%	0.644	3.90
2	Electrical	3.86		3.73%	0.14410667	
3	Emergency	4.29		16.10%	0.69069	
4	Engine	3.33		7.30%	0.24309	
5	FFFE	3.40		10.10%	0.3434	
6	HVAC	3.43		3.73%	0.12805333	
7	Plumbing	3.80		3.73%	0.14186667	
8	Propulsion	4.00		7.30%	0.292	
9	Steering	3.50		7.30%	0.2555	
10	Structure	4.14		24.60%	1.01844	

5.3 Heat Map Based On Condition Index

After updating the condition index, a heat map was drawn depicting all the condition indexes of the vessels in relation to their systems and the weighted condition index. Figure 21 is the heat map,

	Cape Point	Carteret	Cedar Island	Chicamacomico	Croatoan	Fort Fisher	Frisco	Gov. Daniel Russel	Gov. James B. Hunt Jr	Hatteras	Kinnakeet	Flyod J. Lupton	Neuse	Ocracoke	Roanoke	sea Level	Silver Lake	SouthPort	Stanford 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
Weighted CI	4.08	4.07	4.15	3.92	4.35	4.26	4.29	4.06	4.32	4.35	4.43	4.24	3.81	4.04	4.15	4.59	4.40	3.76	3.91	4.56	3.90

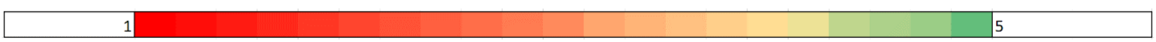


Figure 21: Updated Heat Map with legend.

5.4 Statistical Analysis of Results

To validate the results, a number of statistical analysis were performed. The following tests were performed,

1. Paired T-tests (21 tests) between the Weighted Condition Index and Original Condition Index of all the 21 vessels.
2. One way ANOVA between the Weighted Condition Index for all the 21 vessels.
3. One way ANOVA between the APIs calculated through the Overall method for all the 21 vessels.

4. One way ANOVA between the APIs calculated through the Cost by Class method for all the 21 vessels.
5. One way ANOVA between the APIs calculated through the Everything by Class method for all the 21 vessels.

All of the analysis were conducted through the Minitab Statistical Software package and results are tabulated as below,

Table 53: Paired T-test results for Weighted Condition Index.

S.No	Vessel	Probability
1	Cape Point	0.991
2	Carteret	0.957
3	Cedar Island	0.897
4	Chicamacomico	0.928
5	Croatoan	0.969
6	Fort Fisher	0.974
7	Frisco	0.991
8	Gov. Daniel Russel	0.970
9	Gov. James B. Hunt Jr.	0.802
10	Hatteras	0.921
11	Kinnakeet	0.965
12	Floyd J. Lupton	0.888
13	Neuse	0.905
14	Ocracoke	0.963
15	Roanoke	0.961
16	Sea Level	0.894
17	Silver Lake	0.919
18	Southport	0.987
19	Stanford White	0.876
20	Swan Quarter	0.996
21	Thomas A. Baum	0.888

Table 54: One Way ANOVA Results for Weighted Condition Index

S.No	Vessel	Probability	Tukey Comparison
1	Cape Point		Not Statistically Different
2	Carteret		Not Statistically Different
3	Cedar Island		Not Statistically Different
4	Chicamacomico		Not Statistically Different
5	Croatoan		Not Statistically Different
6	Fort Fisher		Not Statistically Different
7	Frisco		Not Statistically Different
8	Gov. Daniel Russel		Not Statistically Different
9	Gov. James B. Hunt Jr.		Not Statistically Different
10	Hatteras		Not Statistically Different
11	Kinnakeet	1.00	Not Statistically Different
12	Floyd J. Lupton		Not Statistically Different
13	Neuse		Not Statistically Different
14	Ocracoke		Not Statistically Different
15	Roanoke		Not Statistically Different
16	Sea Level		Not Statistically Different
17	Silver Lake		Not Statistically Different
18	Southport		Not Statistically Different
19	Stanford White		Not Statistically Different
20	Swan Quarter		Not Statistically Different
21	Thomas A. Baum		Not Statistically Different

Table 55: One Way ANOVA Results for API by Overall Method.

S.No	Vessel	Probability	Tukey Comparison
1	Cape Point		Not Statistically Different
2	Carteret		Not Statistically Different
3	Cedar Island		Not Statistically Different
4	Chicamacomico		Not Statistically Different
5	Croatoan		Not Statistically Different
6	Fort Fisher		Not Statistically Different
7	Frisco		Not Statistically Different
8	Gov. Daniel Russel		Not Statistically Different
9	Gov. James B. Hunt Jr.		Not Statistically Different
10	Hatteras		Not Statistically Different
11	Kinnakeet	0.877	Not Statistically Different
12	Floyd J. Lupton		Not Statistically Different
13	Neuse		Not Statistically Different
14	Ocracoke		Not Statistically Different
15	Roanoke		Not Statistically Different
16	Sea Level		Not Statistically Different
17	Silver Lake		Not Statistically Different
18	Southport		Not Statistically Different
19	Stanford White		Not Statistically Different
20	Swan Quarter		Not Statistically Different
21	Thomas A. Baum		Not Statistically Different

Table 56: One Way ANOVA for API Scores through Cost by Class Method.

S.No	Vessel	Probability	Tukey Comparison
1	Cape Point	0.687	Not Statistically Different
2	Carteret		Not Statistically Different
3	Cedar Island		Not Statistically Different
4	Chicamacomico		Not Statistically Different
5	Croatoan		Not Statistically Different
6	Fort Fisher		Not Statistically Different
7	Frisco		Not Statistically Different
8	Gov. Daniel Russel		Not Statistically Different
9	Gov. James B. Hunt Jr.		Not Statistically Different
10	Hatteras		Not Statistically Different
11	Kinnakeet		Not Statistically Different
12	Floyd J. Lupton		Not Statistically Different
13	Neuse		Not Statistically Different
14	Ocracoke		Not Statistically Different
15	Roanoke		Not Statistically Different
16	Sea Level		Not Statistically Different
17	Silver Lake		Not Statistically Different
18	Southport		Not Statistically Different
19	Stanford White		Not Statistically Different
20	Swan Quarter		Not Statistically Different
21	Thomas A. Baum		Not Statistically Different

Table 57: One Way ANOVA Results for API scores through Everything by Class Method.

S.No	Vessel	Probability	Tukey Comparison
1	Cape Point	0.961	Not Statistically Different
2	Carteret		Not Statistically Different
3	Cedar Island		Not Statistically Different
4	Chicamacomico		Not Statistically Different
5	Croatoan		Not Statistically Different
6	Fort Fisher		Not Statistically Different
7	Frisco		Not Statistically Different
8	Gov. Daniel Russel		Not Statistically Different
9	Gov. James B. Hunt Jr.		Not Statistically Different
10	Hatteras		Not Statistically Different
11	Kinnakeet		Not Statistically Different
12	Floyd J. Lupton		Not Statistically Different
13	Neuse		Not Statistically Different
14	Ocracoke		Not Statistically Different
15	Roanoke		Not Statistically Different
16	Sea Level		Not Statistically Different
17	Silver Lake		Not Statistically Different
18	Southport		Not Statistically Different
19	Stanford White		Not Statistically Different
20	Swan Quarter		Not Statistically Different
21	Thomas A. Baum		Not Statistically Different

The results of these tests summarize the following points,

1. The Paired t-tests indicate that the weighted condition index and the condition index are not statistically different for all the 21 vessels.
2. The One way ANOVA test for the weighted condition index indicates that the means of all the data points do not differ significantly. The R-sq. value is 0.68% which proves that there is very little variation between the data points.
3. The One way ANOVA test for API scores through Overall method also indicate that the values do not differ significantly. The R-sq. value is 10.80% which proves that there is a minimal amount of variation in the distribution of data.
4. The One way ANOVA test for API scores through Cost by Class method showcase that the API scores do not differ significantly. The R-sq. value is 13.48% which proves that there is a variation in the distribution of data more than the previous method.
5. The One way ANOVA test for API scores through the Everything by Class method prove that the data point do not differ significantly. The R-sq. value is 8.70% which indicates that there some variation in the distribution of data.

5.5 Integration of API and Weighted CI

The final step and objective of this research is to produce a readable, modifiable and usable graph by combining the two metrics. This Chapter and the previous one have discussed about the calculation and the results of these two metrics. This sub-chapter will focus on combining both of them together. This integration will help in combining two unrelated information together to get better knowledge of the current situation of an asset and to quantify the changes an asset over time. The following are the graphs based on the three methods discussed in the calculation of the asset priority index,

1. Overall Method

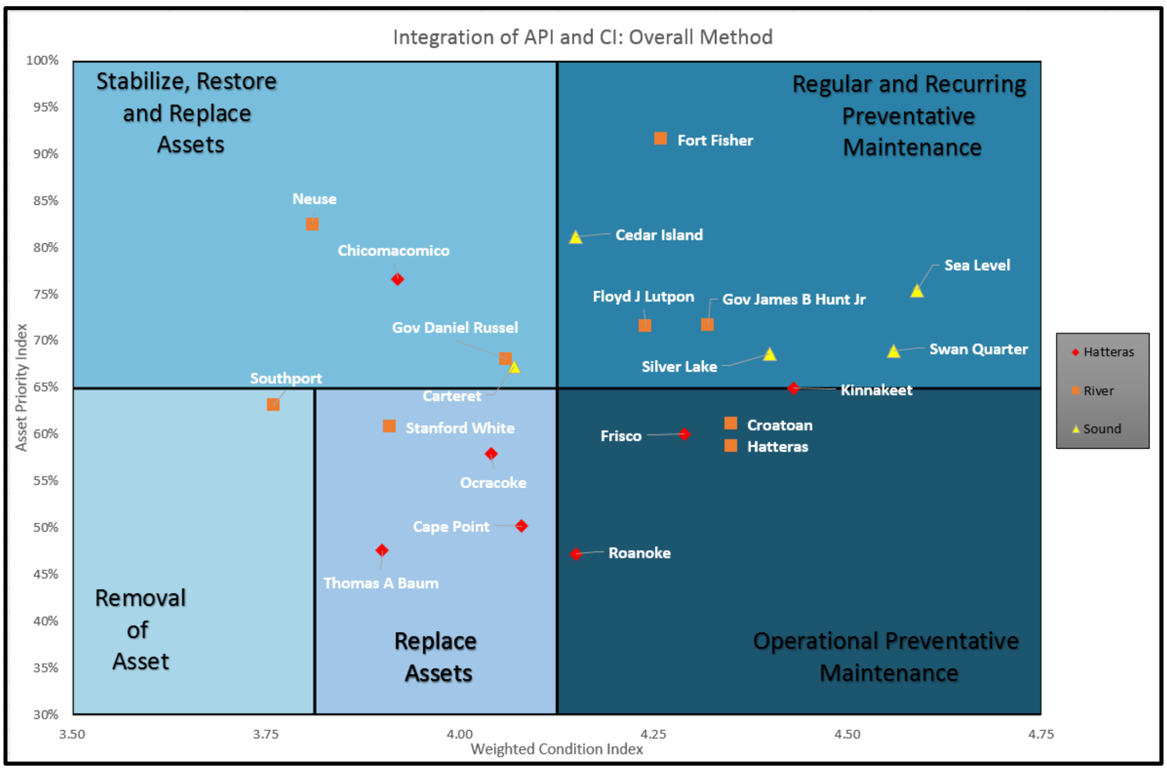


Figure 22: Integration of API & CI by Overall Method

2. Cost by Class Method

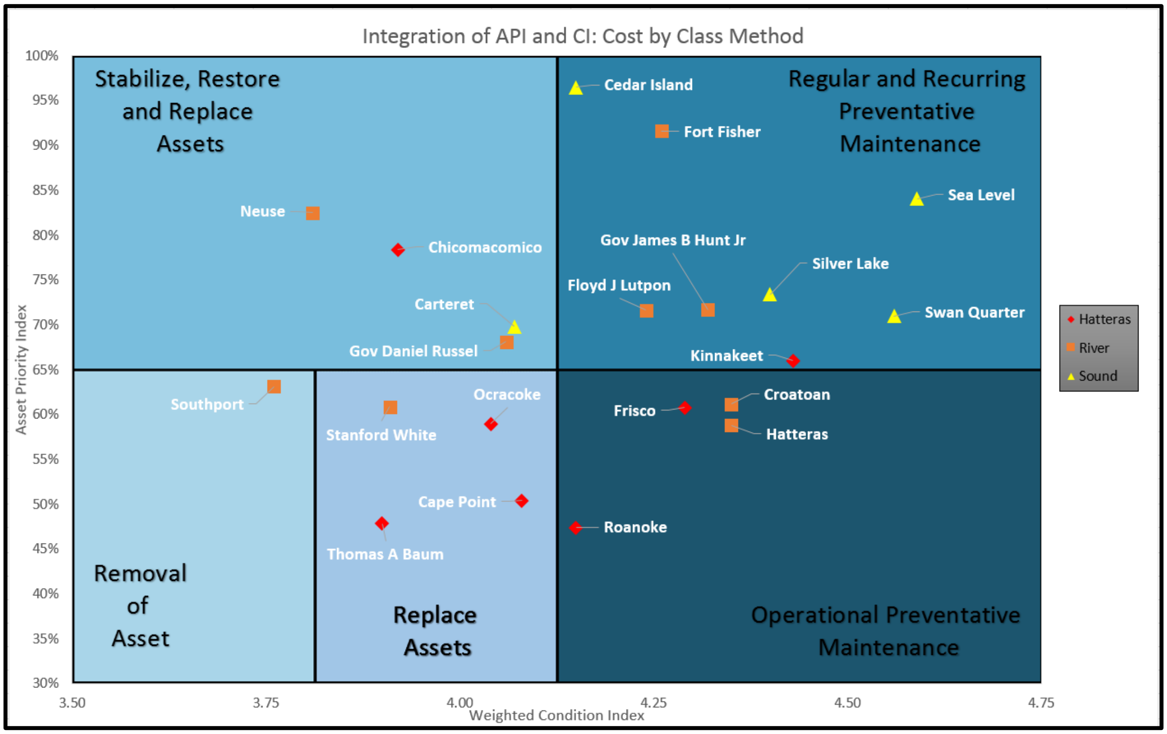


Figure 23: Integration of API & CI by Cost by Class Method

3. Everything by Class Method

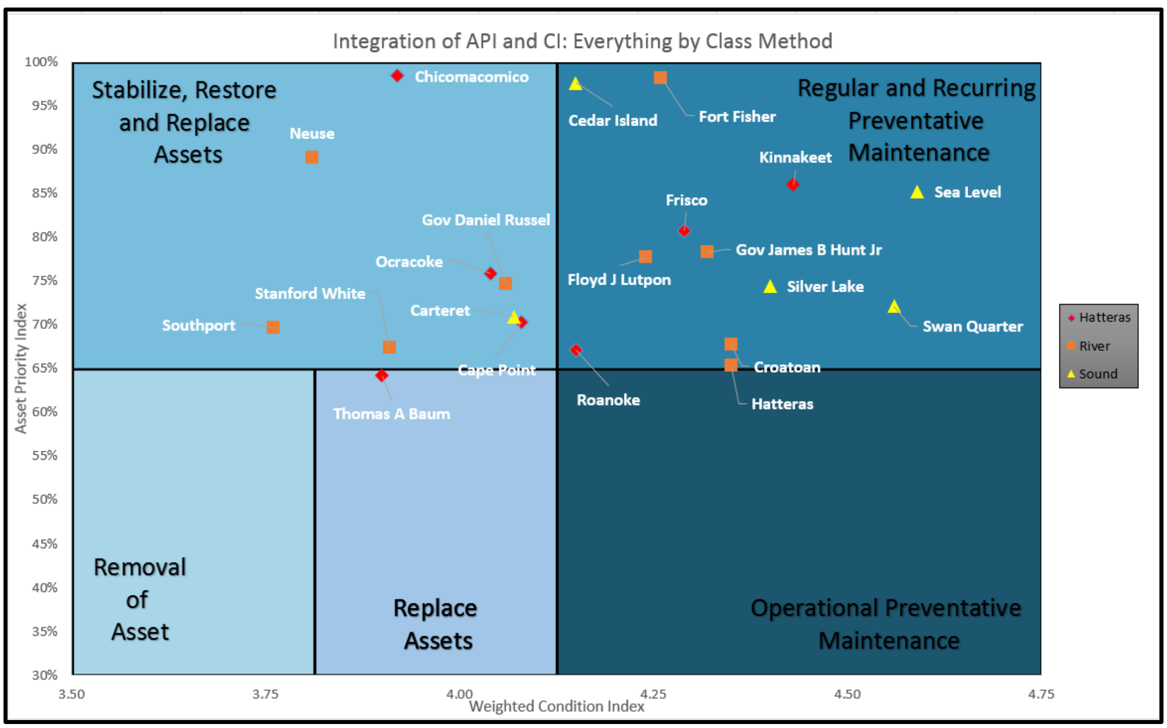


Figure 24: Integration of API & CI by Everything by Class Method

The graph area has been divided based on the relative scores of the Asset Priority Index and the Condition Index. These are the following regions,

1. Removal of Asset

   When an asset has low CI and low API the asset is categorized into this region. This suggests that the asset has a minimal role in satisfying the organization's needs and is also in poor condition. Hence a recommendation is made to remove the asset from the fleet.

2. Replace Assets

   This region contains assets that have a low API and a moderate CI. Since the asset is not in a bad condition, recommendations are made to replace the asset partially or completely.

3. Operational Preventative Maintenance

   This category comprises of assets having a high CI and a low to moderate API. Since the asset is in good working condition, a recommendation to conduct a regular operational maintenance is made.

4. Stabilize, Restore and Replace Assets

   The assets in this case have a high API but a low CI. Due to its importance these assets need to stabilized and restored using any favorable means. The asset can be replaced if needed.

5. Regular, Recurring and Preventative Maintenance

   Both the CI and API of the assets are high in this category. Hence a preventative maintenance strategy can be employed to prevent deterioration.

CHAPTER 6: CONCLUSION

The calculation of the metrics like Asset priority Index and the Condition Index can give an organization a clear cut idea about their current situation in regards to their asset inventory. Additionally, the integration of both the metrics together can give a better understanding of their condition and their role towards the organization's goal. It also helps in understanding which of the assets need more time and money to be invested on. Without understanding the importance of an asset to the organization precise investment decisions cannot be taken. In this research, three methods to define the API were discovered. Since, the business model of the NCFS in unknown, it is left to the management to choose a method that best suits them. From the researcher's point of view, the Cost by Class method will be suitable regardless of their decision making model. This is because, each ferry is different from one another and the cost of maintenance cannot be compared. But, the other criteria used in the definition of the API are general to all the ferries and is best when all the ferries are compared together. The advantage of this research is that, the analysis and results are modifiable. This means that the same model can be used in future asset planning by changing their inputs which will result in new metric values and eventually a new graph. All of this analyzed data and metrics can be used as decision driving factors in the capital planning process. Some of the other recommendations to the NCFS are,

1. Standardizing the Condition Assessment with the calculated weights for each system and regularly update the CI index.
2. Standardize the API and internally audit the scores once in 2 or 3 years.
3. Can use CMMS to avoid errors occurred when hand written.

CHAPTER 7: RECOMMENDATIONS FOR FUTURE RESEARCH

The literature review and this research suggests that the scope for asset management is continually developing. Future research could focus on variables the affect the two metrics used in this research or metrics that can be used to add more information to the current model. The literature review suggested that asset management for the marine and ferry industry is not effective as the building industry or other industries have. The following are the areas where the researchers felt that more study is needed,

1. Developing a more detailed Condition Index and Asset priority Index. This means that these metrics will have to be calculated for each component.
2. Considering more criteria and variables that will help depict the conditions of the ferries much better.
3. Developing a more sophisticated software especially for the ferry industry due to the complex nature of the asset.
4. Develop an effective system to collect and store the data from all the components of the vessels.

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APPENDIX A. SURVEY QUESTIONS

1. Please provide your name. The researchers will only utilize this information to validate respondents. All information will remain confidential.

2. Please rank the classes of ferries with regard to your perception of the value each class serves to fulfill the needs of the organization.

	Maximum Value	Moderate value	Least Value
Hatteras	○	○	○
Sound	○	○	○
River	○	○	○

3. Please rank the Level of Service (LOS) for each of the following (for the Hatteras vessel class):

	Highest LOS	Moderate LOS	Lowest LOS
Thomas A Baum	○	○	○
Roanoke	○	○	○
Frisco	○	○	○
Chicamacomico	○	○	○
Cape Point	○	○	○
Ocracoke	○	○	○
Kinnakeet	○	○	○

4. Please rank the Level of Service (LOS) for each of the following (for the River vessel class):

	Highest LOS	Moderate LOS	Lowest LOS
Gov Daniel Russel	○	○	○
Gov James B Hunt Jr	○	○	○
Southport	○	○	○
Neuse	○	○	○
Flyod J Lupton	○	○	○
Fort Fisher	○	○	○
Stanford White	○	○	○
Croatoan	○	○	○
Hatteras	○	○	○

5. Please rank the Level of Service (LOS) for each of the following (for the Sound vessel class):

	Highest LOS	Moderate LOS	Lowest LOS
Silverlake	○	○	○
Swan Quarter	○	○	○
Sea Level	○	○	○
Cedar Island	○	○	○
Carteret	○	○	○

6. Please answer this based on your perception of Unplanned Downtime for the vessels. Which of the ferries do you perceive to have the most downtime?

	Most Downtime	Moderate Downtime	None/Least Downtime
Thomas A Baum	○	○	○
Roanoke	○	○	○
Frisco	○	○	○
Chicamacomico	○	○	○
Cape Point	○	○	○
Ocracoke	○	○	○
Kinnakeet	○	○	○
Gov. Daniel Russel	○	○	○
Gov. James B Hunt Jr.	○	○	○
Southport	○	○	○
Neuse	○	○	○
Flyod J Lupton	○	○	○
Fort Fisher	○	○	○
Stanford White	○	○	○
Croatoan	○	○	○
Hatteras	○	○	○
Silverlake	○	○	○
Swan Quarter	○	○	○
Sea Level	○	○	○
Cedar Island	○	○	○
Carteret	○	○	○

7. Please classify the ferries based on your perception of their ability to serve accessibility needs.

	Addresses Accessibility	Does not Address Accessibility	Not Sure
Thomas A Baum	○	○	○
Roanoke	○	○	○
Frisco	○	○	○
Chicamacomico	○	○	○
Cape Point	○	○	○
Ocracoke	○	○	○
Kinnakeet	○	○	○
Gov. Daniel Russel	○	○	○
Gov. James B Hunt Jr.	○	○	○
Southport	○	○	○
Neuse	○	○	○
Flyod J Lupton	○	○	○
Fort Fisher	○	○	○
Stanford White	○	○	○
Croatoan	○	○	○
Hatteras	○	○	○
Silverlake	○	○	○
Swan Quarter	○	○	○
Sea Level	○	○	○
Cedar Island	○	○	○
Carteret	○	○	○

8. Please rank the following criteria based on the information provided above. (Example: If A is more important than B, your answer will be on the left side of the scale.)

   EQ: Equally Important

CRITERION A | CRITERION B	CRITERION A								EQ	CRITERION B							
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Main System | Auxiliary System	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Main System | Life-Saving System	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Main System | FFE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Main System | Structure	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Auxiliary System | Life-Saving System	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Auxiliary System | FFE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Auxiliary System | Structure	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Life-Saving System | FFE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Life-Saving System | Structure	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
FFE | Structure	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐