Using Systems Engineering Technology to Improve Efficiency of Small Oyster Farmers in the Chesapeake Bay

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Abstract - *The oyster agriculture industry is growing very fast. For the small farmers to achieve profitability, they must grow by meeting the challenge facing their size and economics. This research aims to use system-engineering technology to develop, implement, evaluate, and deliver a process recommendation to improve efficiency for small oyster farming in the Chesapeake Bay in the State of Maryland. In addition, system engineering will provide a structured approach for the analysis and modeling of small oyster farming processes. These models are used for current and future research in the oyster industry. This research explores the small oyster farming gap in the state of the art of small oyster farming research. It develops a methodology and solution for filling this gap. The study explores the small oyster farming process. In addition, this research will explore the challenges small oyster farmers face, recommend, and implement solutions*

***Key Words*: Cages, Equipment, Oysters, Systems Engineering, Systems Development Life cycle (SDLC)**

1.INTRODUCTION

Oysters fall in the family of Ostreidae, which includes the edible oysters [1]. Every aspect of the oyster's life cycle is influenced by salinity and temperature, mainly reproduction, growth, and mortality [2]. Oysters take about 18 to 24 months to grow into adults [3].

The Chesapeake Bay has approximately 173 oyster farms [4]. Each farm has its method of growing oysters. There are many farming methods; the most common are the suspended culture method, surface culture, and bottom culture. Each technique is influenced by factors such as environment, weather, and geographical location, to mention a few. Every growing method affects the oysters' quality of meat, shell, and flavor profile as they all have advantages and disadvantages [5].

1.1 Oyster Farming Process

A confidential small oyster farm operation in the Chesapeake Bay was recorded and studied to understand the oyster farming process well. According to this small oyster farm, the oyster farming environment comprises five essential components: the oyster processing crew, processing platform, oyster boat, oyster field, and the final processing stage. In final processing, oysters are washed, boxed, and shipped to market. These components are situated in the Bay.

The final staging process is carried out in a land-based facility. Oysters are bred and harvested in the oyster farmers' leased portion of the Bay. Oysters are grown in cages and linked by ropes. The cages are used to protect the oyster from predators.

The boat's primary purpose is to assist the crew on the farm to move cages from the oyster fields to the processing platform. Some boats will be fitted with a boom for raising and lowering oyster cages in the area and at the processing platform. Finally, the oyster processing platform is where the oysters are unloaded from the oyster boat onto the dock to begin processing.

1.2 Problem Definition

Starting an oyster farming business for small oyster farmers is difficult. Many techniques and tools are considered, such as farm location, types of tools, and operating procedures. In addition, they must develop an understanding of the process, starting from seedlings to the final delivery. Small farmers find it hard to decide on best farming practices as well as locations. The oyster aquaculture industry is growing. For smaller farmers to achieve profitability, they must grow by meeting the challenges facing their size and the economy. Integrating system engineering technology into the small farming business can enhance the efficiency of oyster farming by considering all the farming components and optimally managing them.

1.3 Purpose of the Study

This research aims to develop, implement, and evaluate a process to improve oyster farming in Chesapeake Bay. The oyster farming process is being viewed as a system. By defining the oyster farming process as a system, it will make it easier for analysis. For example, to understand the farming process more clearly, complex conceptual and object-oriented models are defined. These models are much easier to construct and analyze from a system perspective. In addition, these models are input to a simulation process where systems theory will simplify the simulation and analysis process. Although large farmers will benefit from this research, the primary focus will be on the small farmers. In addition, a python simulation model is developed to simulate and model the oyster farming business activities to evaluate efficiency.

2. REVIEW OF THE LITERATURE

Kraeuter et al [6] in their research article, "Oyster Growth Analysis: A comparison of Methods", have analyzed the growth of the adult oysters on Delaware Bay Seedbeds. The authors used three methods for studying the growth of adult oysters. First, the growth on the lip of the oysters retrieved from the bottom is considered. Second, the oysters are placed individually in a special frame made for the study. Third, the age and size information has been collected through studying the marks on the axis of the oysters. The researcher found out that the existing studies have focused on those regions where the growth of oysters is rapid rather than discussing the climatic conditions. The local climatic conditions determine the average age of an oyster. The salinity affects the growth of the oysters. The more saline the region is the more it is a probability that the growth of the oysters would increase.

Molly Marie Rybovich [7] in her master's dissertation, "Growth and Mortality of Spat, Seed, and Market Sized Oysters (Crassostrea virginica) in low salinities and high temperatures", discusses the impact of the change in climatic conditions in affecting the growth of the oyster population. The researcher conducted the study of the low salinity and high temperature on the growth of the oysters. The author conducted an experiment in 2012 and 2013 in which she took the hatchery-produced oysters and placed them in bags, some bags were kept closed while others remained open, in Breton Sound Los Angeles. The growth and the death of the oysters were recorded monthly. The author found out that in the places where the salinity was low the growth of the oysters was low and the places where the salinity was higher the growth of the oysters were high.

Thomas and colleagues [5] in their research article, "the effect of aquaculture gear on the growth and shape of the oyster *Crassostrea virginica* during a "finishing period" in the Chesapeake Bay, USA", discusses the equipment type and tidal zone location impact on the shell shape and the product quality of the oyster *Crassostrea virginica*, which is produced for the market consumption by hatchery in the eastern coast of USA, Chesapeake Bay. The researcher studied the total oysters and the wet meat inside it by examining the shell length, height, weight, and width. The data were collected from August to December 2015. The researchers found out that the oysters grow with a low death rate in all equipment, but the OysterGro had more impact on the weight and height of the Oysters compared to the subtidal cage, rack, and bag gear. Shell shape also improved by using the OysterGro.

2.1 Gap Analysis

An analysis of the literature in oyster farming shows a gap in using systems engineering as an approach for analysis, especially in the Chesapeake Bay. As a small oyster farmer, it is hard to start a farming business since it includes many areas to be considered. Several questions arise when a small farmer tries to start a business. Some of these questions that need to be considered are: where is the best location to farm oysters? What is the optimal water salinity? What is the best farm growing method? Should oysters be farmed on the top or the bottom of the water? What are the farming tools that are needed to enhance the farming operation? The scope of this research focuses on small-scale farmer. This study aims to fill the system engineering gap by improving the efficiency of oyster farming among small-scale farmers in the Chesapeake Bay. There appears to be no research addressing the small oyster farming business from a system engineering perspective. Fig-1 shows how system-engineering technology can aid in filling this gap and help small farmers improve their businesses. The systems engineering approach considers the oyster farming process from growing oyster seedlings to final market delivery.

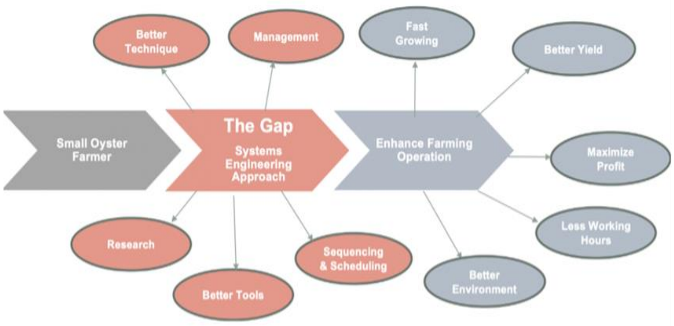

Fig -1: Gap Analysis

3. METHODOLGY

The methodology used in this research is the System Development Life Cycle (SDLC). SDLC is a system engineering approach that defines the stages of bringing a project from inception to solution. This methodology includes planning, analysis, design, development, implementation, integration, and testing. As shown in Fig-2, the initial stage is the planning stage, where the problem definition occurs. The problem definition identifies the issue at hand. This definition sets a level based on initial research conducted as well as engaging different system engineering skills. In the initial phase of the methodology, system information provided by users and stakeholders is used. Consultation with experienced system engineers is conducted through a Joint Application Development (JAD) session. Through the JAD session, the problem is defined and diagrammed. It is a high-level definition of the problem. In preparation for developing the conceptual model, a problem description is created. The problem description is a more detailed description of the problem. It required more in-depth research.

In the next phase, a conceptual model develops from the problem description. The problem conceptualization integrates with that of the solution. In addition, the conceptual model is the base for developing the Use Case model. This model creates the requirements that govern the answer to the problem. In essence, if all the conditions produced by the Use Case model are satisfied, this solves the problem. Following the development of the Use Case Model, the next step is object-oriented analysis. This process produces the following artifacts of analysis: class, object, sequence, activity, and state diagrams. These diagrams capture and define the solution to the problem. In essence, these diagrams become a guide for the design and implementation of the solution. As shown in Fig-2, the solution is tested and evaluated following the design and implementation. As part of the testing and evaluation phase, the users and stakeholders are continually engaged in the input. There will be an interaction between all phases of the analysis to determine the best solution. The evaluation determines whether the objectives and requirements developed in the initial phases have been satisfied. It ensures that any newly developed subsystems work appropriately with the existing system.

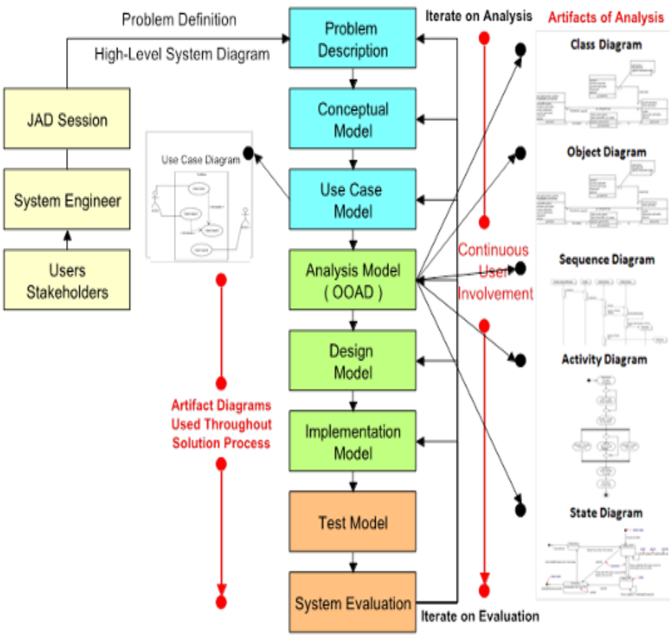

Fig -2: Enhanced Systems Development Life Cycle [8]

4. RESULTS

The primary objective of this research is to make oyster production and processing more structured and organized to increase productivity and profitability. The methodology section explains the term "structure.' A business cannot advance and become efficient unless the various stages and processes are structured. Working with oyster farming personnel, an eight-hour day was modelled using object-oriented technology. This modeling captured the farming process, including many stages: setup and shut down of machines such as motors, pumps, hopper, tumbler, and conveyors. The model also included accessing oysters in the field, transferring and staging oysters on the platform, returning oyster cages to the field, and finally processing oysters, including delivering oysters to market. This model a guide for simulation of farming processes before and after improvements. Models are used to ask what-if questions. Some questions include the speed of the tumbler, the number of crew, the size of the hopper, the number of oyster cages available, and other system variables.

4.1 Class Diagrams

During the analysis phase, class diagrams define the oyster farming process. Class diagrams illustrate participants and any entities (i.e., machinery, boats, trucks, etc.), attributes, and methods (i.e., the class's actions) that describe the oyster processing environment. In addition, class diagrams are the templates for object diagrams Fig- 3 outlines the class diagrams for the main path of the oyster processing: start-up, hopper, tumbler, sorter, final processing, and close-down.

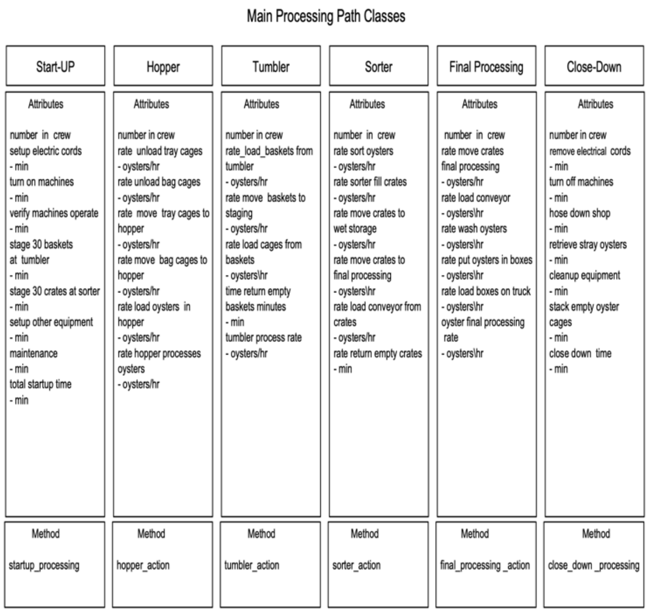

Fig -3: Main Oyster Processing Class Diagrams

Fig-4 outlines class diagrams for filling tray and bag cages for staging at the dock. These cages will be returned to the field for further oyster growth.

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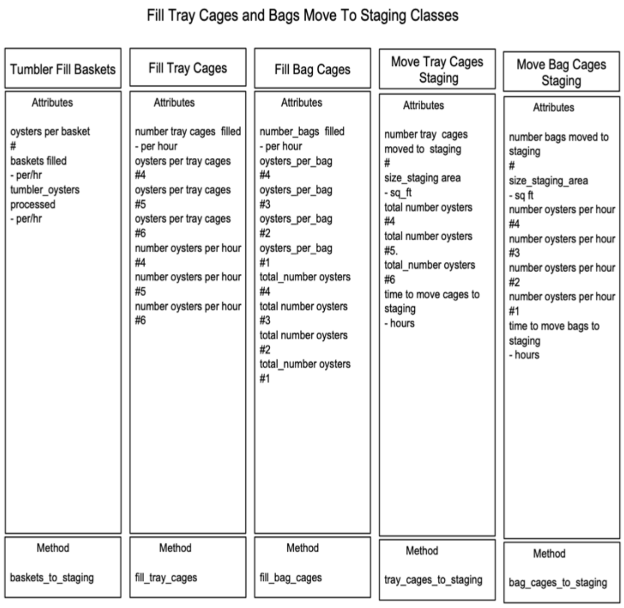

Fig -4: Fill Tray and Bag Class Diagram

Fig- 5 outlines class diagrams for moving cages by boat to the oyster field and returning to the dock. In addition, a boat requires a crew of two to operate.

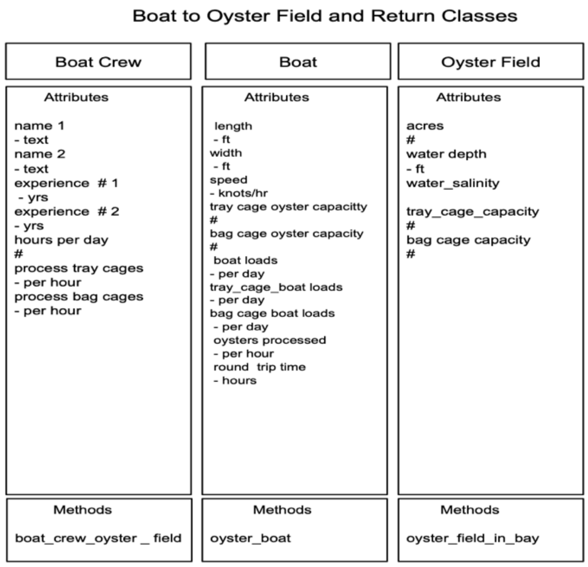

Fig -5: Move Boat to Oyster Field Class Diagram

The last group of class diagrams is the final processing of oysters summarized in Fig-6. Each class diagram contains attributes and methods. Attributes can vary and play an important part in understanding productivity, working hours, and business expenses. In Fig-3, for instance, the tumbler class has six attributes. One of these attributes is the tumbler-processing rate. If the tumbler process rate increases, it could affect the overall production rate of oysters.

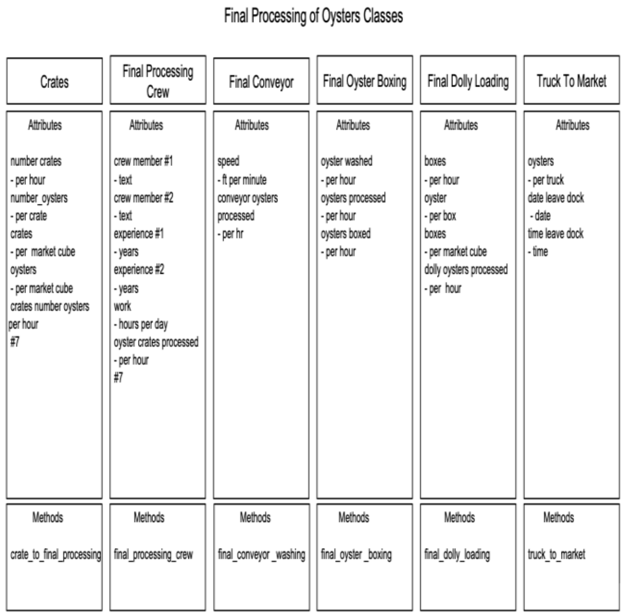

Fig -6: Final Processing of Oysters Class Diagram

4.2 A Numerical Model

Oyster farms in the Chesapeake Bay were visited and studied for two years as part of this study. For the object-oriented model and the python simulation, this farm's operations were recorded and timed. This section's data, numbers, measurements, and farming operations are according to this small oyster farm in the Chesapeake Bay.

The goal of this research is to help small oyster farms in Maryland's Chesapeake Bay improve their practices. Oysters are grown and sold at this oyster farm every year. Three times a week, 52 weeks a year, they harvest. The farming action was timed and recorded on videotape. Table 1 shows a breakdown of farming operations on this small oyster farm, from morning set up through closing. This is a representation of the daily cycle. It is the purpose of the numerical timing model to define and govern the Object-Oriented diagrams and the Python model. Class diagrams are used to construct object diagrams in Python. At a given point in time, the state of objects can be captured in an object diagram (through the diagram's attributes). Since they define the data structures required for coding, object diagrams serve as a guide for the Python model. There can be dynamic changes to attribute values that are defined using object diagrams. The Python farming model is affected by changes in attribute values, which can identify potential bottlenecks. Amount of tray/bag cages and oysters used in the daily processing cycle are among the attributes.

Table -1: Summary of Numerical Timing Model

1. Summary of Oyster Farming Resources, Volumes, and Timings
2. Morning Setup
3. Processing Functions
    1. Telescoping Crane Process
    2. Unload cages returning from the oyster field
    3. Open Tray Cages
    4. Open Bag Cages
    5. Dump Tray Cages into Hopper
    6. Dump Grow Bag Cages into Hopper
    7. Concurrent Operations Commenced by Starting the Hopper
        1. Tumbler
        2. Sorting Table
        3. Stage Tray Cages and Fill
        4. Stage Bag Cages and Fill
    8. Telescoping Crane Process
    9. Load cages for deployment to the oyster field
    10. Boat delivers cages to the field
4. Evening Clean-up

4.3 Python Model

Small oyster farming procedures are simulated using Python in this study. It was feasible to operate multiple CPUs in parallel using the system's multi-processing capabilities. As a result, it was now able to run many oyster processing operations at once. Certain application functions required to be performed in parallel rather than sequentially since they occurred at the same time. The current oyster processing system under study is outlined in Fig-7. There are four steps in this model. As a last step before oysters are delivered to market, they go through a series of steps that include the use of a hopper, tumbler, sorter, and a conveyor belt. The next process is loading oysters into baskets from the tumbler, where baskets of oysters are placed in cages and staged for shipping back by boat to the oyster field for further growth. The third process is modeling the boat trip to and from the oyster field. The final stage of oyster processing is washing, packing, and shipping the oysters to market.

Using class diagrams as a starting point, these processes' object models were created to demonstrate the values of many general properties. In Fig-8, the results of this modeling work can be shown. Oysters handled over the course of an 8-hour day can be seen in the report's output. Although oysters are staged at a rate of 90,000 oysters per hour at the hopper during the evaluation of the present small oyster business understudy, hopper processes 60,000 oysters per hour. Overall, 8 hours of oyster processing is depicted in Fig-8. The hopper and tumbler process 480,000 oysters in an eight-hour shift. At the sorting table, oysters are manually sorted. Therefore, the processing rate drops to 15,000 oysters per hour. Final processing (i.e., #7 sized oysters) or return to the oyster field (i.e., #6 sized oysters) are the options for oysters processed at the sorting table. In addition, a large number of oysters processed at the tumbler returned to the field (i.e., 45,000 oysters). In the main path, the tumbler was found to be the bottleneck, as predicted by the modeling effort. As a result, purchasing a new tumbler to match the hopper's speed capabilities of 90,000 oysters per hour was recommended.

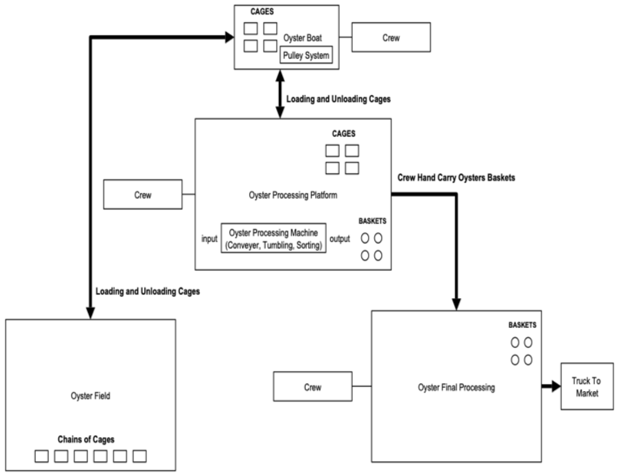

Fig -7: The Current Oyster Processing System

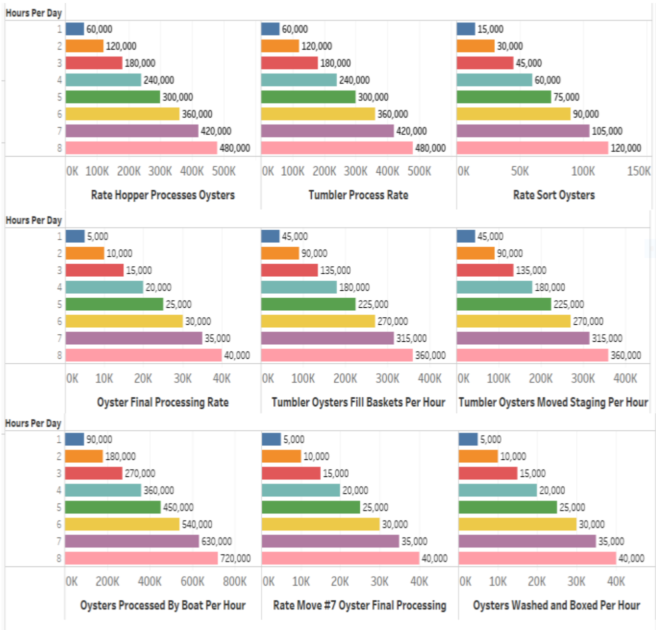

Fig -8: Current Oyster Processing Outputs

4.4 Recommendation Based on Results

There is a need to reimagine the platform design to improve the efficiency and productivity of oyster farming. The recommended platform design is shown in Fig-9. It is pertinent to mention that the size of the platform is especially important. If the size of the platform is small, the overall efficiency and productivity will be average or below average. A large platform can exponentially increase the efficiency of the work. Secondly, it is advisable to use baskets to carry oysters from the boat to the platform. Moving cages of oysters to the platform is not only time-consuming, but it involves physical attrition. Physical pressure on the crew can reduce productivity and increase working hours. Cartable hand baskets are used in place of heavy cages. In addition, the dock may be covered with a roof so crews can cope with bad weather such as wind, rain, storm, or hot sun. Also, it is recommended to purchase a new tumbler to upgrade the speed to 90,000 oysters per hour, matching the speed capability of the hopper. This process increases productivity across the board. With one additional crew at the sorting table, sorting is now producing 30,000 oysters per hour.

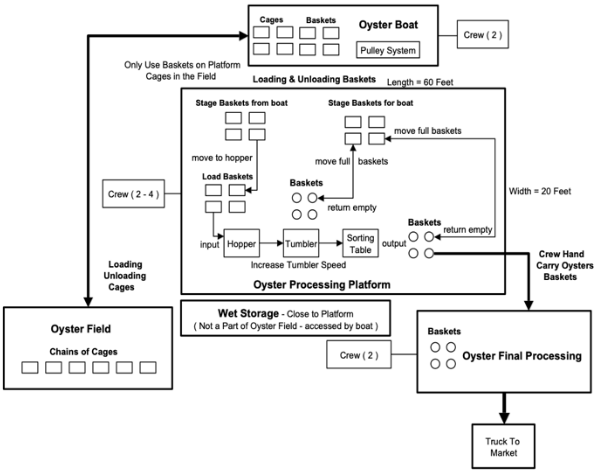

Fig -9: Newly Redesigned Oyster Processing System

5. CONCLUSIONS

Oyster farming is a highly complex operation, and there is a need to break the process into subsystems to improve system analysis. The systems engineering approach addresses the small oyster farming business in a more detailed and structured way than most previous analysis. From the literature review, it can be concluded that small oyster framers need to enhance their farming operations to compete favorably with other farmers in the market. The current environment puts small-scale oyster farmers at a disadvantage in their market share compared to other farmers since their existing system is inadequate to service the current oyster business. Small farmers need to consider all oyster farming subsystems such as the farming operation, tools, and techniques.

The current research study addresses the best ways to farm oysters, improve the growing cycle and maximize farming profits. In addition, propose a more efficient way to operate the oyster farm using systems engineering technology. A simulation model is developed to evaluate the oyster farming process to improve farming operations from the first stage of introducing oyster seedlings to the final stage of delivering oysters to market.

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BIOGRAPHIES

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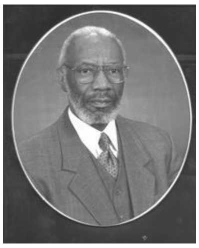

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