Quay Crane Scheduling Based Problem: A Process Optimization for an International Container Terminal in the Philippines

Vincent M. Salosagcol, Princess Faith Z. Fernandez, Mark Angelo D. Martinez, Martin Rafael D.S. Valencia, Giovanni O. Ables, Yoshiki B. Kurata*
Industrial Engineering Department
Technological Institute of the Philippines, Quezon City
qvsalosagcol@tip.edu.ph, qpfzfernandez@tip.edu.ph, qmamartinez2@tip.edu.ph, qmrvalencia@tip.edu.ph, qgables@tip.edu.ph, ykurata.ie@tip.edu.ph

Abstract

Quay cranes are the most expensive and important handling machine in container port operations, as the efficiency of the container terminals depends on it. This study aims to optimize the berth scheduling quay crane service and waiting times by the application of integer programming and queueing theory in identifying the actual waiting time and service time of an international container terminal in the Philippines. The paper utilizes ProModel simulation and Lindo Optimization software to evaluate the berth operation and the scheduling of quay cranes for the container terminal. Results show that the utilization of the berth operation is at 44.44% with an average waiting time of 58.18 hours per week which signifies that there is no congestion with low berth occupancy. Recommendations of the study is a process that optimized the berth and quay crane scheduling applicable to the allocation of quay crane's workload per berthing position as the berth operation process and quay crane scheduling is optimized from 5.62 hours per day to 5.59 hours which saves 0.03 hours daily.

Keywords

Quay crane scheduling problem, integer programming, queueing theory, container terminal

1. Introduction

In the container terminal operating system, quay cranes are the main equipment used in transferring the containers from vessels to land and vice versa (Wang et al. 2013). One of the main indicators in the efficiency of port containers as a whole is the productivity of quay crane and most of the container ports reach as low as seventy percent (70%) and as high as up to eighty percent (80%) of the quay crane productivity (Marek and Bartosek, 2013). The quay cranes in container ports are attached on a single rail to move from one bay to another which simply implies that quay cranes cannot cross each other (Msakni et al. 2018). By that, Chao and Lin (2011) explained that some of the studies aimed to reduce the shipping delay to increase the quay cranes efficiency by optimization of the job scheduling for quay cranes. Also, Msakni et al. (2018) pointed out that the goal of the quay crane scheduling problem is to reduce the work time of the vessel by finding the optimal sequence of tasks performed by quay cranes. Generally, quay crane scheduling problems are involved in these two main matters (1) manage the loading and unloading tasks of a container by the allocation of quay cranes, and (2) the service order of ship bay in a vessel for each quay crane (Chung and Choy, 2012).

The yard utilization of the Port of Manila is increased by fifty-three percent (53%) that leads to port congestion (from 38,000 TEUs to 81,000 TEUs) hence, the decrease of the transfer of container from ship to the yard is from 20 to 25 containers per hour to 10 to 12 containers per hour, furthermore, the waiting time of the vessel is increased from 8 to 14 days from the original time of 1 to 2 days (Philippine Ports Authority, 2015). Also, the Philippine Ports Authority (2018) states that a container terminal in the Philippines has a net service time of 48,545 hours and a waiting time of 50,049 hours in total with a total of 6 berthing positions and 13 quay cranes.

This study aims to optimize the berth scheduling quay crane service and waiting times in a container terminal in the Philippines utilizing operations research by the application of queueing theory and integer programming in identifying the actual waiting time and service time in the berth through a mathematical model formulation in the optimization of the service time and minimization of the waiting time in the container ports. This study will focus on the improvement of the quay crane scheduling of a container terminal in the Philippines.

2. Literature Review

The Philippines is facing a maritime transport infrastructure inefficiency and needs to act as the primary impediment to local and international trade. (Msakni et al., 2018). The vessels that have an appointment in Philippine ports have to wait in the queue before receiving services at the berths due to congestion. Furthermore, the cargo owners and vessels operator who is involved in this problem, the entire transaction is creating a waiting time cost and delays in delivery for the costumers (Saeed et al., 2016). Otherwise, the outcome of the high cost of transporting goods has contributed to making higher goods prices and a decrease in the competitiveness of exportation (Limao and Venables, 2001). Gidado (2015) mentioned that port congestion is a situation where there is a delay that could make a bottleneck from a massive input of cargo. AlAwar et al. (2016) discussed that the increase of vessels and the number of containers transported on the sea which leads to overcrowding of vessels waiting for loading and unloading. Port congestion is a major issue that needs to be considered since port productivity has a direct impact on the flow of goods inside and outside of the country (Navarro et al., 2015).

These are the three stages to classify the problems in container ports (1) the berth allocation problem, (2) the quay crane assignment problem, and (3) the quay crane scheduling problem. The first stage addresses the allocation of vessels that depends on the availability of the berth in container ports (Schoonenberg et al. 2015). Furthermore, Segura et al. (2019) defined the berth allocation problem as the feasible berth allocation to the incoming vessels in a container terminal. Also, Jos et al. (2019) explained that the berth allocation problem requires decisions on how to assign the berth space and how to arrange the vessels that need to be load and unload at container ports. Lin and Ting (2014) stated that one of the major issues in the optimization of the port is the berth allocation problem. Comparing the study of Schoonenberg et al. and Lin and Ting, Schoonenberg et al. stated that the berth allocation problem is the allocation of vessels while Lin and Ting explained that it is the allocation of berths. Thus, this means that the berth allocation problem is related to the number of berths needed in the port to accommodate the number of vessels arriving in the port. Then, Guo et al. (2019) said that when it comes to the decision-making problem for the operators in a container terminal, berth allocation problem is a significant matter since good berth allocation planning can effectively reduce the waiting time of the vessel and can improve the total operational efficiency of the ship and terminal.

The quay crane scheduling problem is an operational decision that aims to optimize the exploitation of resources. The goal of the quay crane scheduling problem is to minimize the total work of the vessel by determining the schedule of quay cranes for the vessel. Simultaneously usage of different operations in the port with quay crane assignment problems is a challenge for port operation. (Msakni et al. 2018)

The information for allocation of quay crane is very limited and the application of how many quay cranes should be assigned on how big a vessel is not established. Azza et al. (2014) explained that based on the number of quay crane assigned on how big a vessel is important, it can reduce the process of unloading and loading the container.

According to Legato et al. (2012) quay crane scheduling problem has the main task of managing the maritime container in the terminal. Where the unloading and loading of the vessel are dependent on the set that will be given from the port operator. Ng and Mak (2006) said that every ship has several bays that stack containers in the compartments. According to Zhu and Lim (2006), the process of transporting containers from the vessel can be divided from hold to hold but the cranes are not pre-emptive, so, only a quay crane can do the task completely. One quay crane per vessel can control the stabilization of the ship in the berth. Based on the study of Zhang et al. (2018), the vital role in loading and unloading operations performed in quay crane. The operations manager is keen on minimizing turnaround time using an efficient quay crane schedule for loading and unloading containers without leaning the ship to one side. Also, Sun et al. (2018) proposed the anti-swing tracking design that can hold with the wind going through the containers during the operation that causes a delay in transporting time in the berth.

Many studies focus on port congestion that leads to problems such as berth allocation problems, quay crane assignment problems, and the quay crane scheduling problems. Most literatures suggest that solutions to the problem are answered with the use of the formulation of a mathematical model and using queuing theory. This study will be using Operations

Research (OR) model in addressing the problem of quay crane scheduling and by proposing a process that optimized the berth and quay crane scheduling for an optimal allocation of the quay cranes to each berthing position.

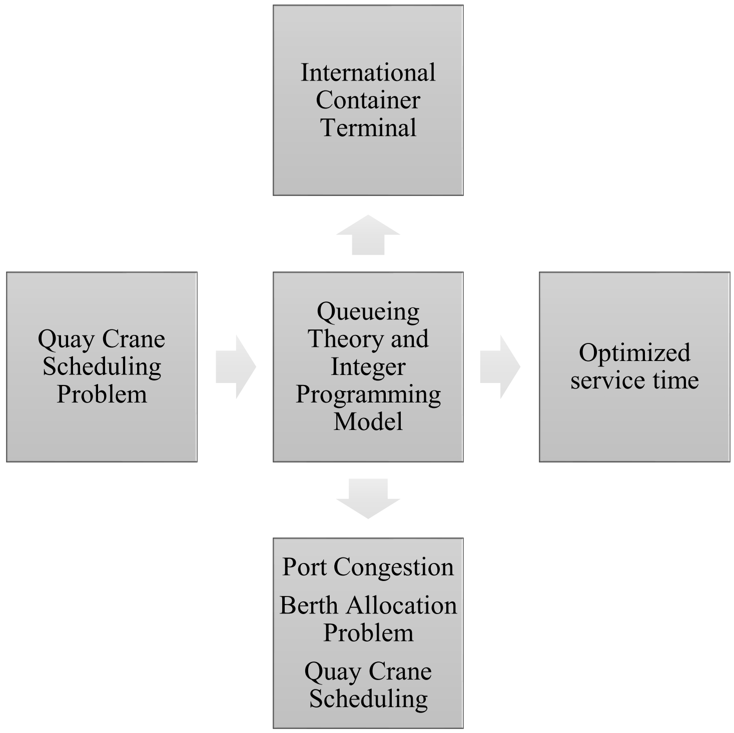

Figure 1. Conceptual Framework

The figure above shows the conceptual framework of this study. This study applies the queueing theory and integer programming model in the study. To do that, different information about port congestion, berth allocation problem, quay crane scheduling, and quay crane scheduling problem in container terminals is needed to come up with the optimized service time of quay crane scheduling.

3. Methodology

This study focuses on the application of queueing theory and integer programming on the current operation of quay crane scheduling to ease the congestion at the container terminal in the Philippines. The research approach used in this study is descriptive. Descriptive research allows to gather information needed and present it using charts and tabulation (Glass and Hopkins, 1984).

3.1 Queueing Theory Model

Queueing theory deals with the issue that is related to waiting lines. According to Saeed et al. (2016), it is a necessary tool in solving any congestion problems. Queueing theory solves average waiting of vessels, average queueing length, the average number of vessels in the port, and the berth utilization factor. By analyzing the waiting line using the queueing theory, the arrival rate, and service time rate in the berth are needed. The system has multiple servers and the following equations will be used.

The equation (1) is the utilization rate in the berth operation where λ as the expected number of arrivals for vessels per hour, *s* as the number of berth in the operation, and μ as the service rate of each vessel per hour.

$$\rho = \frac{\lambda}{s\mu} \tag{1}$$

The equation (2) is the probability that there is no vessel in the berth operation.

$$P_0 = [\sum_{n=0}^{s-1} \frac{\left(\frac{\lambda}{\mu}\right)^2}{n!} + \frac{\left(\frac{\lambda}{\mu}\right)^s}{s!(1-\rho)}] \tag{2}$$

The equation (3) is the expected average number of vessels in the queue.

$$L_q = \frac{Po\left(\frac{\lambda}{\mu}\right)^s \rho}{s!(1-\rho)^2} \tag{3}$$

The equation (4) refers to the expected average number of vessels in the berth operation.

$$L = L_q + \left(\frac{\lambda}{\mu}\right) \tag{4}$$

The equation (5) refers to the average time of the vessel spent in the berth operation.

$$W = \frac{L}{\lambda} \tag{5}$$

The equation (6) refers to the expected average waiting time of vessels in the queue.

$$W_q = W - \frac{1}{\mu} \tag{6}$$

3.2 Integer Programming Model

This study utilizes binary integer programming in the mathematical formulation of the quay crane scheduling problem experienced by the container terminal in the Philippines. Through the use of the operations research technique, this will enable the study to minimize the service time of the quay cranes to yield an optimum value.

3.2.1 Model Assumptions

The following are the assumptions made upon constructing the mathematical formulation.

1. The number of quay cranes and berth is known.
2. The vessels are already assigned to the berth.
3. Each quay cranes handles one container at a time.
4. Only one vessel can be served per berth.

3.2.2 Nomenclatures

The binary integer programming formulation for this study are as follows:

Decision Variable:

$$X_i = \begin{cases} 1, if\ a\ vessel\ is\ served\ by\ a\ quay\ crane \\ 0, otherwise \end{cases}$$

$$Y_{ij} = \begin{cases} 1, if\ a\ quay\ crane\ is\ assigned\ to\ berth \\ 0, otherwise \end{cases}$$

Objective Function:

$$Minimize\ Z = T_{s1}X_1 + T_{s2}X_2 + T_{s3}X_3 + T_{s4}X_4 + T_{s5}X_5 + T_{s6}X_6 + T_{s7}X_7 + T_{s8}X_8 + T_{s9}X_9 + T_{s10}X_{10} + T_{s11}X_{11} + T_{s12}X_{12} + T_{s13}X_{13} \tag{7}$$

The objective function (equation 7) aims to minimize the time needed to unload the workloads in all vessel per berthing positions subject to the following constraints:

$$\sum_{i=}^{n} Y_{ij}\, x_i = 0 \quad (8)$$

$$T_{service} \geq 0 \quad (9)$$

$$X_i = 0{,}1 \text{ and } Y_{ij} = 0{,}1 \quad (10)$$

The constraints (equation 8) ensures that both of the decision variables must be zero unless at least one quay crane is assigned. On the other hand, constraints (equation 9) establish that the time needed to unload all workloads must be greater than zero. The final constraint (equation 10) ensures that the variable X_i and Y_{ij} is a binary integer (either 0 or 1 as stated in parameters).

3.2.3 Model Description

Table 1. Notations of Parameters

Parameters	Description
T	Time of service
X	Quay crane
Y	Berthing Position

Wherein the indices are:

$$i = sets\ of\ vessel$$

$$j = sets\ of\ berthing\ position$$

$$s = service\ time$$

In modeling the integer programming in this study, the paper identified first the actual number of the quay cranes and berthing position in the container terminal. Then, determine the number of quay crane per berthing position and the total service time of the quay cranes in the container terminal. After that, find the total number of quay cranes that will be used in the berthing positions and the total savings on the service time when the quay crane is scheduled.

4. Results and Discussion

4.1 Promodel Simulation

According to Yandug and Santos (2020), Promodel is a simulation software used in improving and evaluating a system, also this will determine the outcome of modifying a process by analyzing the output created by the software. This study will evaluate the simulation by identifying the performance on the berth operation which is presented in this section.

The model was created starting with the layout of the berth operation to identify the sequence of events. The queue of a vessel and the number of the berth are assigned as the location and the vessel as the entity. Then the number of arriving entities, the time of arrivals, and the processing for each location were inputted in the software as well. See the figures below for the result formatted listing of the model.

```
******************************************************************************
*                                                                            *
*                        Formatted Listing of Model:                         *
*                    C:\Users\ACER E15\Downloads\MICT.MOD                    *
*                                                                            *
******************************************************************************

  Time Units:                        Minutes
  Distance Units:                    Feet

******************************************************************************
*                                  Locations                                 *
******************************************************************************

  Name       Cap      Units Stats       Rules          Cost
  ---------- -------- ----- ----------- -------------- ------------
  QVessel    INFINITE 1     Time Series Oldest, FIFO,
  Berth1     1        1     Time Series Oldest, ,
  Berth2     1        1     Time Series Oldest, ,
  Berth3     1        1     Time Series Oldest, ,
  Berth4     1        1     Time Series Oldest, ,
  Berth5     1        1     Time Series Oldest, ,
  Berth6     1        1     Time Series Oldest, ,

******************************************************************************
*                                  Entities                                  *
******************************************************************************

  Name       Speed (fpm)  Stats       Cost
  ---------- ------------ ----------- ------------
  Vessel     150          Time Series

******************************************************************************
*                                 Processing                                 *
******************************************************************************

                           Process                      Routing

Entity   Location Operation          Blk  Output   Destination Rule     Move Logic
-------- -------- ------------------ ---- -------- ----------- -------  ------------
Vessel   QVessel  WAIT 2.184 HR
                                     1    Vessel   Berth1      FIRST 1  Time_in_Queue = Clock() - Time_in_Queue
                                                                        Total_Time_in_Queue = Total_Time_in_Queue + Time_in_Queue
                                                   Berth2      FIRST
                                                   Berth3      FIRST
                                                   Berth4      FIRST
                                                   Berth5      FIRST
                                                   Berth6      FIRST
Vessel   Berth1   WAIT 58.18 HR
                  Customer_Number = Customer_Number + 1
                                     1    Vessel   EXIT        FIRST 1  Time_in_System = Clock() - Time_in_System
                                                                        Total_Time_in_System = Total_Time_in_System + Time_in_System
                                                                        Average_Time_in_Queue = Total_Time_in_Queue / Customer_Number
                                                                        Average_Time_in_System = Total_Time_in_System / Customer_Number

Vessel   Berth2   WAIT 58.18 HR
                  Customer_Number = Customer_Number + 1
                                     1    Vessel   EXIT        FIRST 1  Time_in_System = Clock() - Time_in_System
                                                                        Total_Time_in_System = Total_Time_in_System + Time_in_System
                                                                        Average_Time_in_Queue = Total_Time_in_Queue / Customer_Number
                                                                        Average_Time_in_System = Total_Time_in_System / Customer_Number
Vessel   Berth3   WAIT 58.18 HR
                  Customer_Number = Customer_Number + 1
                                     1    Vessel   EXIT        FIRST 1  Time_in_System = Clock() - Time_in_System
                                                                        Total_Time_in_System = Total_Time_in_System + Time_in_System
                                                                        Average_Time_in_Queue = Total_Time_in_Queue / Customer_Number
                                                                        Average_Time_in_System = Total_Time_in_System / Customer_Number
Vessel   Berth4   WAIT 58.18 HR
                  Customer_Number = Customer_Number + 1
                                     1    Vessel   EXIT        FIRST 1  Time_in_System = Clock() - Time_in_System
                                                                        Total_Time_in_System = Total_Time_in_System + Time_in_System
                                                                        Average_Time_in_Queue = Total_Time_in_Queue / Customer_Number
                                                                        Average_Time_in_System = Total_Time_in_System / Customer_Number
Vessel   Berth5   WAIT 58.18 HR
                  Customer_Number = Customer_Number + 1
                                     1    Vessel   EXIT        FIRST 1  Time_in_System = Clock() - Time_in_System
                                                                        Total_Time_in_System = Total_Time_in_System + Time_in_System
                                                                        Average_Time_in_Queue = Total_Time_in_Queue / Customer_Number
                                                                        Average_Time_in_System = Total_Time_in_System / Customer_Number
```

```
Vessel   Berth6   WAIT 58.18 HR
                  Customer_Number = Customer_Number + 1
                                 1    Vessel   EXIT       FIRST 1  Time_in_System = Clock() - Time_in_System
                                                                   Total_Time_in_System = Total_Time_in_System + Time_in_System
                                                                   Average_Time_in_Queue = Total_Time_in_Queue / Customer_Number
                                                                   Average_Time_in_System = Total_Time_in_System / Customer_Number

********************************************************************************
*                                  Arrivals                                    *
********************************************************************************

 Entity   Location Qty Each   First Time Occurrences Frequency  Logic
 -------- -------- ---------- ---------- ----------- ---------- ------------
 Vessel   QVessel  1          0          INF         1          Time_in_Queue = Clock()
                                                                Time_in_System = Clock ()

********************************************************************************
*                                  Attributes                                  *
********************************************************************************

 ID             Type         Classification
 -------------- ------------ --------------
 Time_in_System Real         Entity
 Time_in_Queue  Real         Entity

********************************************************************************
*                               Variables (global)                             *
********************************************************************************

 ID                     Type         Initial value Stats
 ---------------------- ------------ ------------- -----------
 Average_Time_in_Queue  Real         0             Time Series
 Average_Time_in_System Real         0             Time Series
 Customer_Number        Integer      0             None
 Total_Time_in_Queue    Real         0             None
 Total_Time_in_System   Real         0             None
```

Figure 2. Formatted Listing of Berth Operation

Upon the application of simulation on the berth operation using the Promodel, the performance of berth operation has been determined (see table 2). According to UNCTAD (2012), high berth occupancy which is (>70%) is a sign of congestion that leads to a decline of services while (<50%) indicates low berth occupancy that implies underutilization of resources in the container terminal. Since the utilization rate of the berth is only 44.44% with an average waiting time of 58.18 hours per week in the berth operation, thus, data shows that there is no congestion in the berth operation at the container terminal.

Table 2. Calculated Performance on Berth Operation

Utilization of server	Probability of no vessel	The average number of vessels in the queue	Average waiting time of vessel in the queue	Average waiting time spent in the system	The average number of vessels in the system
44.44%	14.49%	0.1042 vessels	2.18 hours	58.18 hours	2.77 vessels

4.2 Data Analysis of Integer Programming in Quay Crane Scheduling

Huang and Wang (2011) pointed out that the integer programming problem is built on linear programming problems with the constraints of the decision variable to be an integer. Furthermore, the binary integer variable serves as a help to make a yes or no decision. By establishing the total number of quay cranes and berthing position and the service time of the quay crane per berth, the quay crane scheduling can be evaluated using the Lindo software.

```
NEW INTEGER SOLUTION OF    5.58999968     AT BRANCH      0 PIVOT      27
RE-INSTALLING BEST SOLUTION...

       OBJECTIVE FUNCTION VALUE

       1)      5.590000

  VARIABLE        VALUE          REDUCED COST
        XA         1.000000          0.430000
        XB         1.000000          0.430000
        XC         1.000000          0.430000
        XD         1.000000          0.430000
        XE         1.000000          0.430000
        XF         1.000000          0.430000
        XG         1.000000          0.430000
        XH         1.000000          0.430000
        XI         1.000000          0.430000
        XJ         1.000000          0.430000
        XK         1.000000          0.430000
        XL         1.000000          0.430000
        XM         1.000000          0.430000
       YAA         0.000000          0.000000
       YAB         1.000000          0.000000
       YBA         0.000000          0.000000
       YBB         1.000000          0.000000
       YCA         0.000000          0.000000
       YCB         1.000000          0.000000
       YDC         0.000000          0.000000
       YDD         0.000000          0.000000
       YDE         1.000000          0.000000
       YEC         0.000000          0.000000
       YED         0.000000          0.000000
       YEE         1.000000          0.000000
       YFC         0.000000          0.000000
       YFD         0.000000          0.000000
       YFE         1.000000          0.000000
       YGC         0.000000          0.000000
       YGD         0.000000          0.000000
       YGE         1.000000          0.000000
       YHC         0.000000          0.000000
       YHD         1.000000          0.000000
       YHE         0.000000          0.000000
       YIC         1.000000          0.000000
       YID         0.000000          0.000000
       YIE         0.000000          0.000000
       YJC         0.000000          0.000000
       YJD         1.000000          0.000000
       YJE         0.000000          0.000000
       YKF         1.000000          0.000000
       YLF         1.000000          0.000000
       YMF         1.000000          0.000000
```

Figure 3. Result of the Integer Programming Model Formulation

The solution was provided by solving the integer programming in Lindo Software. From the generated results, the study can infer that Lindo was able to solve the problem optimally. The first, second, and third quay crane should serve the second berthing position, while, the fourth, fifth, sixth, and seventh quay crane should serve the fifth berthing position. Also, the eighth quay crane should be used in the fourth berthing position, the ninth quay crane will serve the third berthing position, and the tenth quay crane should serve also the fourth berthing position. Lastly, the eleventh, twelfth, and thirteenth quay crane should serve the sixth berthing position which is the last berthing position in the container terminal. Therefore, the optimal service time of the quay crane is reduced from 5.62 hours per day to 5.59 hours per day (0.03 hours per day saved).

5. Recommendations

The goal of this study is to optimize the berth scheduling quay crane service and waiting times in a container terminal in the Philippines through the formulation of an integer programming model and queueing theory. With the use of ProModel simulation and Lindo Optimization software, results show that the utilization on the berth operation is only 44.44% with an average waiting time of 58.18 hours per week which signifies that there is no congestion since it has low berth occupancy and the scheduling of quay crane can be optimized from 5.62 hours per day to 5.59 hours which saves 0.03 hours daily.

The study proposes a process that optimized the berth and quay crane scheduling applicable to the allocation of quay crane's workload per berthing position (see figure 4). Based on the sorted study of Bruzonne and Longo (2013), using a simulation model can create a complexity study to determine the delays in berthing. The paper complied with the recent study of Grubisic and Maglic (2018) that incorporates the allocation of berth for every vessel and scheduling of quay cranes per berth.

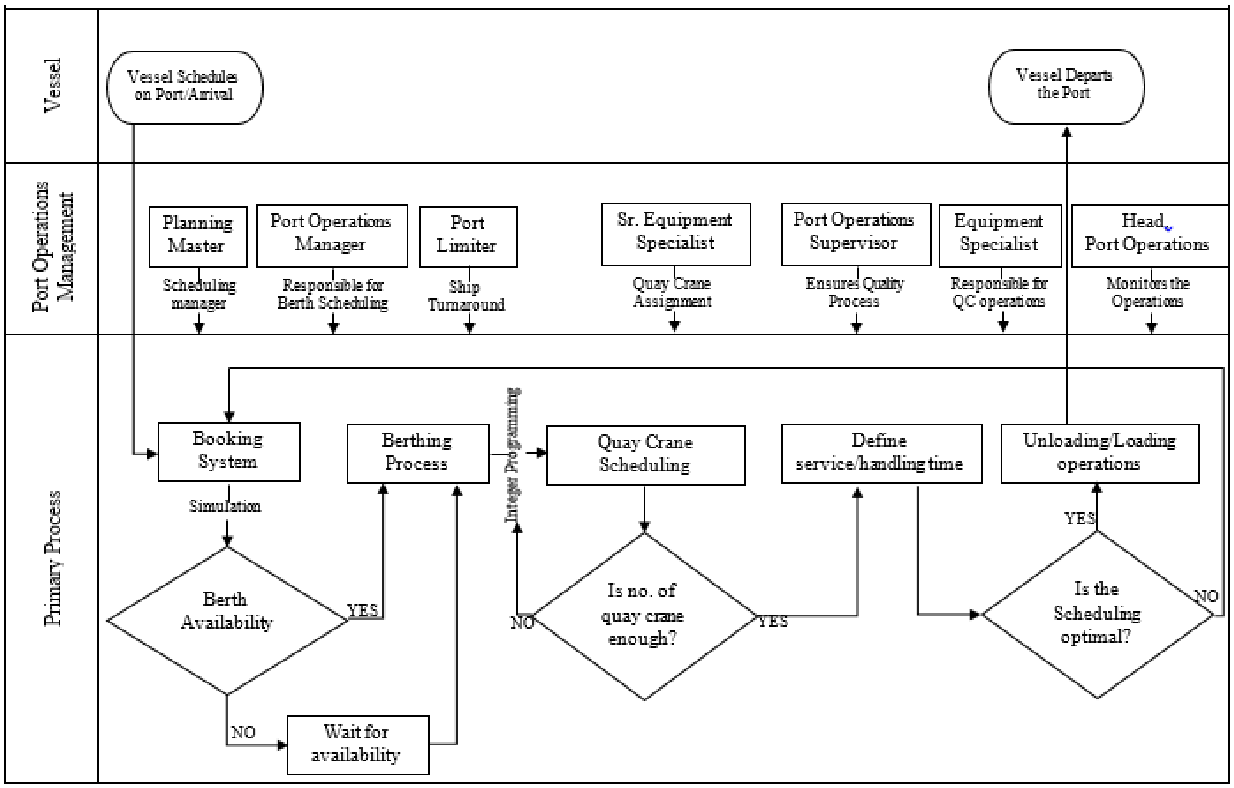

Figure 4. Proposed Process for Optimized Berth and Quay Crane Scheduling

The proposed process for an optimized berth and quay crane scheduling starts with the arrival of the vessel and will be assisted with the Planning Master who decides where the vessel will be located. With the use of a simulation program, the proposed process comes with the decision in berth availability. If the berth is available, the port limiter team will fetch the vessel to maneuver going to the berth. Before the vessel is docked in the berth, integer programming will be utilized to ease the allocation of quay crane for each berth. The senior equipment specialist will take over the works in the transporting of containers from the vessel. The port operation supervisor will be mentioned on how the process is going thru, supervising the equipment specialist and the command will be followed. Lastly, once the process is succeeded the supervisor will come over with the port limiter team to assist the vessel for departure.

Seeing that the utilization in berth implies low berth occupancy at 44.44% and the service time of quay crane scheduling saves 0.03 hours daily, thus, this study shows that the proposed process for the berth and quay crane scheduling at the container terminals has no congestion and optimized.

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Biographies

Vincent M. Salosagcol is currently a fifth-year Industrial Engineering student at Technological Institute of the Philippines. He is a member of the Organization of Industrial Engineering Students (ORIENTS).

Princess Faith Z. Fernandez is currently a fifth-year Industrial Engineering student at the Technological Institute of the Philippines. She is a member of the Organization of Industrial Engineering Students (ORIENTS).

Mark Angelo D. Martinez is currently a fifth-year Industrial Engineering student at the Technological Institute of the Philippines. He is a member of the Organization of Industrial Engineering Students (ORIENTS).

Martin Rafael D.S. Valencia is currently a fifth-year Industrial Engineering student at the Technological Institute of the Philippines. He is a member of the Organization of Industrial Engineering Students (ORIENTS).

Giovanni A. Ables is currently a fifth-year Industrial Engineering student at the Technological Institute of the Philippines. He is a member of the Organization of Industrial Engineering Students (ORIENTS).

Yoshiki B. Kurata is a Certified Industrial Engineer (CIE) awarded by the Philippine Institute of Industrial Engineers (PIIE) and an Associate ASEAN Engineer (AAE) awarded by the ASEAN Federation of Engineering Organizations. Currently, he is an Assistant Professor IV in the Department of Industrial Engineering and a Professor of the Graduate School Program in the Technological Institute of the Philippines – Quezon City. He earned his B.S. in Industrial Engineering from the University of Santo Tomas, Manila, Philippines, and Master of Science in Industrial Engineering from the University of the Philippines Diliman, Quezon City, Philippines. Currently, he is completing his Doctor of Philosophy in Industrial Engineering from De La Salle University-Manila. He has published several journal and conference papers in human factors and ergonomics, production optimization, operations research, and service system operations. His research interests include ergonomics, production systems, technopreneurship, and service science. At present, he is the president of the Philippine Institute of Industrial Engineers – Young Engineers Section (PIIE-YE).