Improving Productivity of Yard Trucks in Port Container Terminal Using Computer Simulation

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Abstract

In port container terminals, reducing vessel turnaround time improves the terminal productivity and increases the capacity of world trades across the globe. This time reduction can be achieved by improving one or more container terminal major resources. Much research has been done on improving container terminal efficiency as a means to reduce vessel turnaround time; however, room still available for improvement. Minimizing the empty journeys of yard trucks could improve container terminal efficiency with reasonable time and cost investment. The objective of this research is to maximize container terminal productivity by minimizing vessel turnaround time within reasonable expenses. A handling container strategy is introduced by employing double cycling to reduce the empty travel trips of yard trucks. This double-cycling strategy still requires the use a single-cycle one before the trucks can be incorporated into double-cycle scheduling. The strategy is based on combining the efforts of two quay cranes (loading and unloading) to work as a unit. Simulation is used to test the efficiency of the proposed strategy. Simulation results indicate an improvement in the productivity rate combined with the unit cost savings using yard truck double cycling comparing to the standard single cycle operation.

Keyword:

Container terminal; Quay crane; Yard Truck; Double cycle; Simulation

1 Introduction

In container terminals, Minimizing vessel turnaround time (the time it takes for a vessel to be unloaded and loaded at its berth) accelerates the shipping time and reduces delays in delivering trade goods. This time reduction can be achieved by improving one or more container terminal resources. in [1], it is stated that the capacity of vessels will be increased by up to 800 TEUs (twenty-foot equivalent unit containers). Vessels today have been upgraded to carry more than 15000 TEUs as one way to minimize container shipment costs.. Although, much research has been done on improving container terminal efficiency as a means to reduce vessel turnaround time, it is still space to do more improvements. Minimizing the empty journeys of yard trucks could improve container terminal efficiency with reasonable time and cost investment. The objective of this research is to maximize container terminal productivity by minimizing vessel turnaround time within reasonable hourly and unit costs. A handling container strategy is introduced by employing double cycling to reduce the empty travel of yard trucks. This double-cycling strategy still requires the use a single-cycle strategy before the trucks can be incorporated into double-cycle scheduling. The strategy is based on unite the efforts of two quay cranes to unload and load the yard truck during its cycle. The EZstrobe simulation system will be used to test the efficiency of the proposed strategy. The research is expected to be of value by improving container terminal productivity using existing facilities and resources. Gains will also be realized by reducing vessel turnaround time, which could save shipping costs and accelerate the global trade transported by sea. Simulation results indicates an improvement in the productivity rate combined with the

unit cost savings using YT double cycling comparing to the standard single cycle operation.

This paper is organized as follows. The section follows is a briefly back ground and literature review relating to the topic of this research. Followed is a description in details the proposed strategy of YT double cycling comparing to the tradition single cycling of handling containers at terminals. It also shows the how to calculate the vessel turnaround time in both strategies mentioned. The section after, defines the major factors affect the container terminal productivity and formulates the involved equipment's cycle times. Then after, the section that proposes the simulation steps and models for both YT single and double cycling. Section before the last, proposes a case study to test and validate the strategies and thus the simulation models. In the last section, conclusions of this work have been drawn.

2   Literature Review

Vessels today have been upgraded to carry more than 15000 TEUs as one way to minimize container cost shipment. These large vessels are usually used to transfer containers through large container terminals to be transshipped by smaller vessels between medium or small terminals which called transshipment. Large transshipment container terminals now operate 24 hours a day with no stops, all year long, to meet the demand of the worldwide container trade. Not less than 100,000 containers are transferred weekly between berth side and temporary SYs [2].

Quay cranes (QCs), which are huge and costly machines, are used to unload and load container from and onto sea-going vessels. Vessel can be serviced by more than one QC on time to minimize the vessel turnaround time [3]. When using multiple QCs to service one vessel, the turnaround time is equal to the maximum time one of the QCs must spend to unload and load its assigned hold. The number of QCs also depends on a container terminal's handling equipment availability and its internal road capacity. Horizontal transporters Yard trucks (YTs) are used to transport containers between the berth and a storage yard (SY). The more trucks that move within the same time, the more likely it is that traffic congestion could arise, which would cause delays in the truck cycle time. Gantry cranes are yard cranes (YCs) that unload and load containers from and onto vehicles at a SY. Rubber tired gantry crane (RTGC) is one of types of Gantry cranes. The RTGC has a width of 7 lanes, which are each equivalent to the forty-foot container width; 6 lanes are used to store the containers and the 7th lane is

customisable for the yard trucks [4]. One conclusion is that, while YCs can stack containers above each other in stacks of up to seven, the optimal stacking height was determined to be 5 levels [5]. It is not only YT congestion that needs to be solved; YC clashing can occur when more than one crane work in the same lane. The research in [6] studied both YT and YC problems. Katta improved the layout design with buffering to eliminate YT congestion and YC clashing. Any delays in the availability of these resources directly leads to a proportional delay for the other resources, and ultimately on the container terminal productivity in general. On the other hand, improving any of these resources will improve container terminal productivity.

Traditionally, vessels are unloaded and then loaded (single cycle) at transhipment container terminals. Recently, a new technique has been proposed by Goodchild in [7]. This technique has been developed in [8], [9] and [10] to optimize QC productivity and minimize vessel dwell time by minimizing the empty travel of QCs. Single cycling means that the imported containers from a vessel must be unloaded first, and then the exported containers can be loaded. In contrast, double cycling means to the loading and unloading of containers is carried out at the same time, in the unloading conditions. QC double cycling is "a technique that can be used to improve the efficiency of quay cranes by eliminating some empty crane moves" [7]. A scheduling problem is presumed by [7] one that can be solved by double cycling. The [10] extended what has been done in [7] research so that it would no longer be limited to just the stacks under a hatch, but would also work for above-hatch stacks. In order to reduce YT empty trips, [11] introduced a heuristic algorithm and test the algorithm by simulation for various scenarios of QCs types (single cycle, double cycling and combination of two QCs one loading and the other unloading) in different locations. One of their conclusion is the YT efficiency is affected by the QC operation type. The [12] supports the advantages of double cycling technique as a service method for improving container terminal productivity. They enhanced the conception that doubly cycling is a cost reduction method which does not require any improvement of existing infrastructure or introduce new technology

Improving the productivity of existing container terminals without introducing new equipment and thereby expanding and/or developing the infrastructure of a facility is the primary objective of this research. This research is focussed on implementing the double cycling of YTs based on this QC double cycling technique, thereby minimizing empty YT journeys.

Anew strategy of handling containers is to be proposed in this work to be able of combining the effort of two QCs to work as a unit. Because of its complexity, container terminal productivity is commonly tested by using simulation. The effectiveness of this proposed strategy will be verified via a simulation model.

3 Study Objectives

The overall objective of this research is to minimize vessel turnaround time and optimize container fleet size and hourly costs by implementing the yard truck double cycling technique to minimize empty truck journeys. Developing a simulation model is a part of this research and will test the technique. An optimization of the simulation outcome's group solutions will be used as an input of the sensitivity analysis to optimize fleet size and the associated hourly costs. Several sub-objectives need to be achieved in order to satisfy the main objective:

- Identify and study the various factors that affect container terminal productivity;
- Build a productivity model to improve container terminal operation; and
- Compare the YT single and double cycling in terms of productivity rates and hourly costs.

4 Methodology

The research methodology consists of three sections. Each section is divided into its sub-phases according to the priority order. The first section addresses the understanding of container terminals, and starts with a comprehensive literature review organized and detailed as in the previous section. This section includes a state of the art review of yard crane scheduling, container transporting between storage yard and berth, temporary container storage yards, quay crane and allocation problems, quay crane double cycling and Yard truck double cycling. This second section focuses on introduce a container handling stratigy and how does container handling method affect the vessel turnaround time. Moreover, it defines the factors that affect container terminal operation in terms of productivity and costs. The third section is the simulation section. It starts with the simulation modeling of both single and double cycling, followed by, case study and collection of the data needed to run the simulation, simulation implementation and model validation. The methodology ends with a conclusion and recommendation based on the results from the previous sections.

The methodology of this research is constructed on introducing a strategy of container handling, called the YT double cycling technique. This strategy depends on being able to combine the effort of two QCs to work as a unit with one crane discharging the vessel while the other loads it. Both QCs will serve the same truck in its cycle. Each truck will transport containers from the storage yard to the vessel and from the vessel to the storage yard in the same cycle. Just as with the QCs, two YCs will load and discharge the trucks at the storage yard.

QCs must be located more than two rows of forty feet container apart. In the interest of safety and to prevent conflicts, the QCs in this system will be three rows of forty feet apart. A YT single cycle loading is still needed to create space on vessel to be able start loading before incorporate to double cycle. At least, two YCs will be allocated on SY to load and discharge the truck. To be able to understand the proposed strategy, it is important to know the traditional strategy (YT single cycling).

4.1 The introduced strategy of YT double cycling

In general, vessel turnaround time starts with the unloading the imported containers until loading the last exported container. When using single cycling technique, loading the vessel should not start until the vessel is folly discharged. The vessel departs after the last exported container has been loaded. The total unloading and loading time is then counted as the vessel turnaround time. The bar chart on Figure 1(a) describes the operation. Then vessel turnaround time using single cycling (T_S) is:

$$T_S = w * [\sum_{i=0}^{n} \sum_{j=1}^{m} Uc\,(i,j) +$$

$$\sum_{\beta=0}^{s} \sum_{\gamma=1}^{g} lc\,(\beta,\gamma)]. \tag{1}$$

Where:

w= average QC unloading/loading cycle time, Uc and Lc containers to be unloaded and loaded respectively,

i= number of containers to be unloaded per row, where $1 \leq i \leq n$;

j= number of rows on the vessel, where $1 \leq j \leq m$;

β= number of containers to be loaded per row, $1 \leq \beta \leq s$; and

γ= number of rows to be loaded, $1 \leq \gamma \leq g$.

As with single cycling, vessel turnaround time starts with the unloading of the first imported container and ends with the loading of the last exported container. However, in double cycling, loading exported containers can be started at a certain time, in parallel to the container unloading. This time has specific constraints and conditions which have been discussed earlier. When it is time to convert to double cycling, two QCs willwork together as a unit to serve YTs with different activities (Loading and unloading).

The overlapping of some of the QCs' cycle time reduces the vessel turnaround time to less than it is in single cycling. This time savings is the main justification for applying the double-cycling technique. A vessel still needs to be loaded with the last exported container before departure. Turnaround time is counted as the sum of the series of single cycle unloading, double cycling and single cycling loading of the imported and exported containers

The vessel turnaround time using the YT double cycling (T_D) then:

$$T_D = w * \{\sum_{i=0}^{n}\sum_{j=1}^{3} Uc\,(i,j) +$$
$$\max[\sum_{i=0}^{n}\sum_{j=4}^{m} Uc\,(i,j)\,,\sum_{\beta=0}^{s}\sum_{\gamma=1}^{(g-3)} lc\,(\beta,\gamma)] +$$

$$\sum_{\beta=0}^{s}\sum_{\gamma=(g-2)}^{g} lc\,(\beta,\gamma)\} \qquad (2)$$

The operation time line of double cycling can be described as in the bar chart in Figure 1(b) where the unloading activity precedes the loading activity.
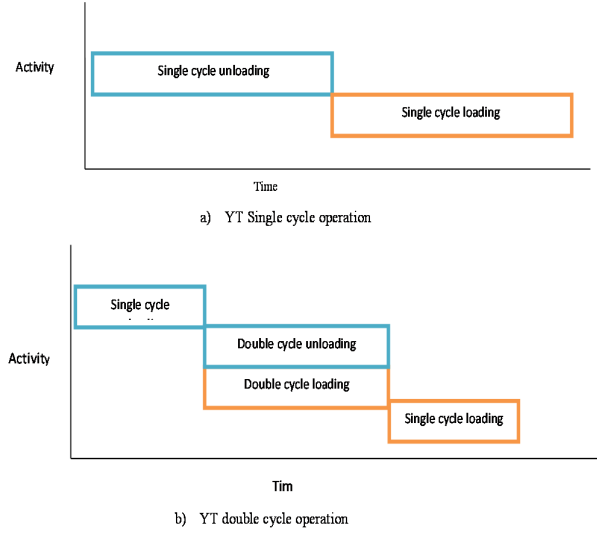

Figure 1: Different scenarios of vessel turnaround time lines

4.2 Factors that affect container terminal productivity

4.2.1 Quay crane cycle times:

The quay crane cycle time starts from the movement of the trolley (empty or loaded) from the truck lane to the (discharged or loaded) container position in the bay. The trolley makes different forward and backward moves. The trolley's vertical speed is purposely different between its loaded and empty movements. When discharging containers, the trolley starts empty, moving forward up vertically and horizontally at the same time (diagonally) in order to save time. Then, it moves horizontally to be close to the container location. The trolley again makes a diagonal movement, downward to be able to lift the container. If the container is above the hatch, lifting the container is the next step. If not, the trolley will move toward the container vertically down and then lift the container. After lifting the container, loaded backward moves will be applied, see Figure 2 for more details. The same steps of moving forward, but in the opposite direction, begin from where the bay ends to the truck lane. If the truck is available, the QC will load the container on the truck. To load the vessel, the trolley makes the same moves, only replacing the empty with loaded and the loaded with empty moves. In order to formulate the QC cycle time referring to the QC trolley motions, Let wu represent the QC unloaded cycle time and considering that all distances are in feet and times are in minutes, where:

wu= Quay crane cycle time=
[∑(forward times when empty) +
t_{lift}+∑(backward times when loaded)]+ t_{load} + lt.

$$wu = \{(max[\frac{dP}{dv2},\frac{ds}{dv1}]+\frac{dx}{dv1}+ max[\frac{dH}{dv2},\frac{dR}{dv1}]+\frac{dh}{dv2})+t_{lift}+(\frac{dh}{dv3}+ max[\frac{dH}{dv3},\frac{dR}{dv1}]) +$$

$$(\frac{dx}{dv1} max[\frac{dP}{dv3},\frac{ds}{dv1}]) + lt+ t_{load}\} \qquad (3)$$

Where: lt Represents the late time that the QC has to wait for the truck;

P, S, X, b, R, H and h are the vertical and horizontal distances the trolley makes when loading or discharging the vessel.

t_{lift} and t_{load} are the time to lift the container from the vessel and the time to load the container on the truck, respectively.
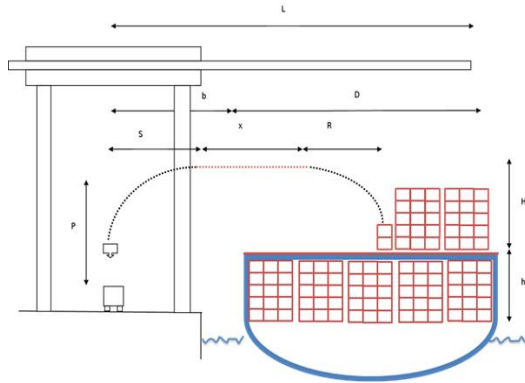v1, v2 and v3 are The QC trolley horizontal, vertical empty and vertical loaded speeds respectively.

Figure 2: QC unloading cycle time

4.2.2   YC cycle time

As with the quay crane, the yard crane cycle time starts from the movement of the trolley (empty or loaded) from the truck lane to the (discharged or loaded) container position on the pre assigned storage yard. The trolley makes the same set of forward and backward moves. YC trolleys also have different vertical speeds when they are loaded than it is empty. As with QCs, diagonal movements are applied to save time. As it is detailed, almost all of the QC's forward and backward movement steps can be implemented by YCs (except those for the hatch as storage yards do not have hatches). The truck delay will lead to YC delay time. This delay is added to the cycle time and counted as a late time.

4.2.3   YT cycle time

YT single-cycle unloading starts with a YT moving from the truck pool or storage yard to the berth side. At the truck lane on the berth side, the truck will be loaded by the QC if it is ready. Otherwise, the truck waits for the QC to be ready. After being loaded, the YT returns to the storage yard to a pre-assigned lane, where an YC discharges the truck when it is available. A waiting time will be added if the YC is not ready. The YT will repeat the process until the last imported container is fully unloaded from the vessel. A specific number of YTs is needed to do the job in order to keep the cranes busy. Yard truck single cycle loading starts at the same place as YT single cycle unloading, in the storage yard. The only difference is that the YT has to be loaded with the exported container before it departs the storage yard.

$$Ts = w1 + \left(\frac{dx1}{dv2}\right) + w2 + \left(\frac{dx2}{dv1}\right) + \sum ly + \sum lb \qquad (4)$$

Where: (Ts) Represents the yard truck unloading cycle time;
w1, w2 are container unloading time by QC and YC respectively
x1 Empty and loaded trucks' travel paths between the storage yard and bay side;
v1 Truck's speed when loaded and v2 is the truck's speed when empty;
ly , lb Truck waiting times at the yard zone; and bay side.

In double cycling, the first YC starts the cycle by loading the YT. The YT then moves, loaded with its container, to the berth side to be discharged by the first QC. After discharging, the YT moves empty to the second QC to be loaded. Next, it returns to the storage yard to unload the container at an imported lane. Figure 3 explains the YT double cycling procedure. The second YC should be ready to discharge the truck, which then departs empty to the exported lane to be loaded by the first YC, thus starting a new cycle. Any delay or waiting time for a crane will be added to the cycle time as late time.   A fleet of YTs will continue the work until reverting back to single cycle loading to load the remaining containers.

For YT double cycle, the YT cycle time is:

$$TD = 2 * (w1 + w2) + \left(\frac{dx1+dx3}{dv1}\right) + \left(\frac{dx2+dx4}{dv2}\right) + \sum ly + \sum lb. \qquad (5)$$

Where: TD = yard truck unloading and loading (double) cycle time;

w1 = container loading or unloading time by QC_s;

w2 = container loading or unloading time by YC_s;

X1 and X3 are loaded trucks' travel path from the storage yard to the bay and vice versa.

X2= empty trucks' travel path between loading and unloading QCs;;

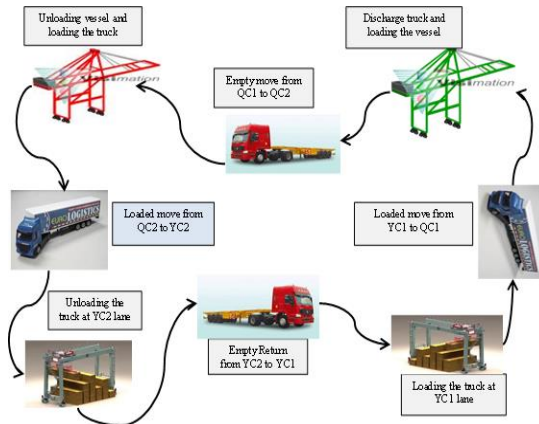X4= empty trucks' travel bath between the export and import lanes.

Figure 3: YT double cycling procedure

5 Simulation of Container Terminal Operation

The single and double cycling simulation models are designed in accordance with pre defined steps. The EZstrobe simulation system has been used for modeling the container terminal operation due to its simplicity and power. To apply the EZstrobe simulation system, some steps must be followed as shown mentioned above. The data collection stage will be clarified in depth in the next section, followed by a case study to test and validate the simulation models. Single and double cycling steps are more detailed next.

5.1 Single cycle simulation model

A single cycle simulation model is designed according to the condition of discharging the vessel first then start loading after the unlading is completely done. The truck cycle will start moving empty from the storage yard or truck pool toward the berth side. At the same time, the QC starts its cycle by empty movement toward the target container to be unloading from the vessel. Once a truck arrives at the berth, the QC loads the container on the truck. The truck then moves loaded to the storage yard to be discharged by the YC, and then it travels back to the berth side (empty) to make another cycle. Meanwhile, the YC moves the container into the lane at the storage yard. The other trucks repeat this process until the last container is unloaded. Next, the loading process starts by loading containers on the truck at the export storage yard, to be transported to the berth, where the QCs load the containers on the vessel the opposite way of unloading. The proses continue loading until the last exported container is to be loaded. At this time, the vessel turnaround time is done and the vessel free to depart.

5.2 Double cycle simulation model

The double cycle simulation model is designed as a form of integration between single and double cycling. This integration begins with unloading three or more rows before starting double cycling as a pre-condition, in order to minimize the fleet size and maximize crane use. Next, the unloading QC_1 will change from unloading to loading the containers on the vessel. Another QC_2 will be introduced to the fleet to continue unloading the containers from the fourth row to the end. QC_1 starts loading the containers from the first to the last row. The trucks, loaded by YC_1 at the export storage yard, arrive at the berth side to be discharged by QC_1. After being discharged, each truck will precede empty to QC_2, to be loaded with a container unloaded from the vessel. QC_1 simultaneously starts its cycle to load its container on the vessel. The loaded truck will move back to the (import) storage yard to be discharged by YC_2, which should be ready for this discharge. After being discharged by YC_2, the truck will proceed to the export SY to be loaded by YC_1 and start a new cycle. YC_2 starts its cycle as soon as it lifts a container from a truck. The YTs, QCs and YCs continue repeating their cycles until the last container has been fully unloaded. The fleet will then be reduced to one QC and one YC and fewer trucks to complete loading the vessel as a single cycle, as described earlier in the single-cycling simulation. is the designed YT double cycling simulation model of the procedure.

6 Data Collection and Case Study

6.1 Data collection

Since it is not yet possible to collect the data directly in this research, a technique to estimate the data needed to run the simulation is utilized. To employ this technique, the QCs, the YTs and the YCs cycle times must first be calculated. It is assumed that the times will vary according to the speed variance. Any delay or acceleration of the cycle times will relate to the movement speed. For instance, a crane operator's skills

and or weather changes should have an impact on the vertical and horizontal speeds of the. The YT cycle time is also calculated, according to the expected distances from the vessel to the storage yard. Finally, this data is analyzed by using probability distribution to determine the mean and standard deviation of each machine's cycle time. Commercial software, the Easy fit distribution, has been used for the statistical analysis. A simulation of container terminal productivity operation will be done in the framework of this research. The simulation requires each activity to be run over its complete duration.. It is understood that a huge amount of random data for all three types of equipment must be collected, and then statistically analyzed to get the mean time (μ) and standard deviation (σ) of each type of equipment's cycle time. The result data was collected and analysed using an EasyFit distribution to draw the histogram and to calculate the mean and the standard deviation. Lifting and loading containers into or from vessel and YT was estimated using a constant of 0.166 minutes. Because it is a very small time compared to the other durations, QC moving between rows is neglected.

6.2 Cost estimation

As previously described, the hourly costs are estimated. These estimates are not exactly 'real' and are not confidential. To make this data useful and easier to manipulate, the percentage saving in each category of productivity rate, hourly cost and unit cost is utilized. The estimated hourly costs are to be followed in simulation inputs.

6.3 Case study description

The proposed case study considers a hatched vessel with a 16000 TEU (8000, 40 -t containers) capacity. The vessel will totally unload and be loaded with the same number of containers. The containers are estimated to be distributed uniformly on the vessel in 20 rows and 20 stacks. The number of stacks above the hatch is equal to the number of stacks below the hatch, with 10 levels of containers each. The total number of containers per row is 400. For single cycling, only one QC and one YC will do the job of unloading and loading the vessel. However, for double cycling, two QCs and two YCs are needed to do the job. Each activity (loading and unloading) requires one QC and one YC. The same trucks will work as duel loading/unloading to serve the QCs and the YCs. The small movement of QCs between the rows is neglected due its minor time value compared to the total time of unloading each row. The YCs are the RTG type. The trolley speeds of the QCs and the YCs have been quoted from the cranes' manufacturer publications The hourly costs are estimated, as real data from container terminals is not yet available.

Table 1: YT single and double cycling simulation inputs

Strategy	Numbers of resources					Hourly costs $/hr			
	Loaded containers TEUs	Unloaded containers TEUs	QCs	YCs	YTs	QC	YCs	YTs	Overhead cost
Single cycling	16,000	16,000	1	1	5	150/QC	100/YC	50/YT	110
Double cycling	16,000	16,000	2	2	5	150/QC	100/YC	50/YT	110

Table 2: YT single and double cycling simulation results

simulation output	Single cycle	Double cycle	Difference	Improvement
Productivity rate (TEU/Hour)	63.73	107.6	43.87	68.83% (increases)
Unit cost ($/TEU)	9.57	7.99	1.58	16.50% (saving)
Total cost ($)	30,625	25,574	5,051	16.49% (saving)
Total hours	502	297.3	205	40.77% (saving)

Additional to the durations, other inputs are needed to run the simulation model. Simulation parameters and hourly costs are identified in Table 1. The result of the simulation reveals an improvement in terms of productivity, time and cost. This improvement can be seen in Table 2. In summary, it is concluded that double cycling can improve CT productivity which leads to minimize vessel turnaround time with reasonable cost saving.

7   Conclusions

Container terminal customers (shipping companies) believe that "**Vessels do not make money while berthing**", which means that minimizing vessel turnaround time is crucial to satisfy these customers. It is clear that improving the productivity of any container terminal's resources leads to the improvement of the other elements' productivity and of terminal productivity as a whole. QC double cycling has been introduced recently to improve container terminal productivity and minimize vessel turnaround time. This work introduces a new strategy that implements double cycling on YTs to improve container terminal productivity. This new strategy of handling containers has been modeled, tested and verified. The simulation indicates a reasonable improvement in maximizing productivity and minimizing hourly and unit costs.. The simulation models reveal a productivity improvement of about 68% in terms of (TEU/hr) or about 34% in terms of (TEU/hr/QC) and cost savings of about 16% in both unit cost and cost per vessel of 16000 TEUs capacity.

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