SIMULATION MODEL OF YARD TRUCK DOUBLE CYCLING TO IMPROVE CONTAINER TERMINAL PRODUCTIVITY

EssmeilAhmed[(a)], Tarek Zayed[(a)], Sabah Alkass[(b)]

[(a)]Concordia University /Department of Building Civil and Environment Engineering, Montreal, Canada
[(b)]University of Sharjah/ College of Engineering, Sharjah, United Arab Emirates

E-mail: esm_662003@yahoo.com , tarek.zayed@concordia.ca , salkass@sharjah.ac.ae

ABSTRACT

In transhipment container terminals, minimizing vessel turnaround time (time to discharge and load vessels) is always the target of the container terminal operators. This time reduction can be achieved by improving one or more of the containers handling equipment's or improving handling strategy. This research aims at maximizing the yard trucks productivity and minimizes the vessel turnaround time by introducing an efficient strategy of handling containers. This strategy based on combining the efforts of two quay cranes to work as a unit to be able to implement yard trucks double cycling. A computer simulation has been used to test the strategy. The Ezstrobe simulation reveals improvements in yard truck productivity when using double cycling comparing to single cycling. Moreover, a sensitivity analysis is implemented and the result indicates more efficiency when using 7 yard truck for storage yard located within a range of 500 - 1500 meters from the berth.

Keyword: Container terminal, Yard Truck, Double Cycling, Simulation

1. INTRODUCTION

In container terminals, reducing vessel turnaround time improves container terminal productivity and increases the capacity for world trade over the oceans. 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. Iris F.A. Vis et al (2003) 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 to means of minimize container shipment costs. While much research has been done on improving container terminal efficiency, more improvements can still be achieved. Minimizing the empty journeys of yard trucks would improve container terminal efficiency with reasonable time and cost investment. This research aims 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 uniting the efforts of two quay cranes to unload and load a yard truck during its cycle. The EZstrobe simulation system is used to test the efficiency of the proposed strategy. The research is expected to improve 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 indicate an improvement in the productivity rate combined with the unit cost savings using YT double cycling compared to the standard single cycle operation.

This paper is organized as follows. A brief presentation of the background and a literature review is followed by a description of the proposed YT double cycling strategy, compared to the traditional single cycle container handling. The simulation steps and the models for YT single and double cycling are then proposed. A case study is presented to test and validate the strategies and thus the simulation models. A sensitivity analysis implemented on the YTs factor. The conclusions of this work are elaborated in the last section.

2. LITERATURE REVIEW

Vessels today have been upgraded to carry more than 15000 TEUs as one way of minimizing container shipping costs. These large vessels are usually used to transfer containers through large container terminals to be transshipped by smaller vessels between medium or small terminals in a system called transshipment. Large transshipment container terminals now operate 24 hours a day 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 storage yards (SYs) (Matthew &Katta 2009). Quay cranes (QCs), which are huge and costly machines, are used to unload and load containers from and onto sea-going vessels. Vessel can be serviced by more than one QC at a time to minimize vessel turnaround time (Daganzo 1989). 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 or Yard trucks (YTs) are used to transport containers between the berth and a storage yard (SY). The more trucks that are moving at the same time, the more likely that there could be traffic congestion, 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. The rubber-tired gantry crane (RTGC) is one type of Gantry crane. 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 (Linn et al 2003). It has been concluded that, while YCs can stack containers in stacks of up to seven, the optimal stacking height is five containers (Mark B, Dunikerken et al 2001). It is not only YT congestion that needs to be addressed; YC clashing can occur when more than one crane works in the same lane. Katta (2007) studied both YT and YC problems. Katta improved the layout design with buffering to eliminate YT congestion and YC clashing. Any delay in the availability of these resources directly leads to a proportional delay for the other resources, and ultimately lowers the container terminal productivity in general. Conversely, improving any of these resources will improve container terminal productivity.

Traditionally, vessels are unloaded and then loaded (single cycle) at transhipment container terminals. Goodchild (2005) proposed Quay Crane double cycling to improve effiency. This technique has been developed by Goodchild and Daganzo (2006); Goodchild and Daganzo (2007); and Zhang and Kim (2009) to optimize QC productivity and minimize vessel quay 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, while double cycling means 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" (Goodchild 2005). A scheduling problem is presumed by Goodchild and Deganzo (2005), one that can be solved by double cycling. Zhang and Kim (2009) extended Goodchild and Deganzo's (2005) 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, Nguyen Vu Duc and Kim Kap Hwan (2010) introduced a heuristic algorithm and test it by simulating various scenarios of QC types (single cycling, double cycling and a combination of two QCs, one loading and the other unloading) in different locations. One of their conclusions is that the YT efficiency is affected by the QC operation type. Pap et al (2011) supports the advantages of the 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 to the existing infrastructure or introduce any 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. A new container handling strategy is proposed, one that is able to combine 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 is verified via a simulation model.

3. 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 makes it possible to test the technique. An optimization of the simulation outcome's group solutions will be used as an input to a sensitivity analysis to optimize fleet size and the associated 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. This section also 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. The second section introduces a container handling strategy and shows how this method will affect the vessel turnaround time. The simulation is developed in the third section. It starts with the simulation modeling of both single and double cycling, followed by a case study and the collection of the data required for the simulation, the simulation implementation and model validation. The methodology ends with a conclusion and recommendation based on the results. This study introduces a strategy of container handling, called the YT double cycling technique. The new strategy depends on being able to combine the efforts of two QCs to work as a unit, with one crane discharging a vessel while the other loads it. Both QCs will serve the same truck, unloading a container from the truck to be loaded into the vessel and loading it with a container discharged from the vessel. 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 SY. 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. YT single cycle unloading is still needed to create space on a vessel to be able start loading and thus switching to double cycling. At least two YCs will be allocated at the SY to load and discharge the trucks. These could be in the same lane, in two neighbouring lanes or even further apart, depending on the SY layout. Certainly, shorter distances produce better results. To be able to fully understand the proposed strategy, it is important to know the traditional strategy (YT single cycling).

4.1. YT Double Cycling

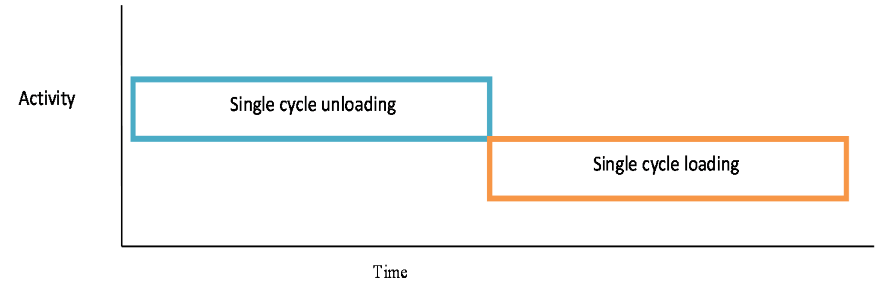
In general, vessel turnaround time starts with the unloading the imported containers and continues until the last exported container has been loaded. With the single cycling technique, loading the vessel should not start until the vessel has been fully discharged. The total unloading and loading time is then counted as the vessel turnaround time. Figure 1(a) describes the operation. In YT double cycling, 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 unloading process. When it is time to convert to double cycling, two QCs will work 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, which 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 operation timeline of double cycling begins with the unloading activity and continues with simultaneous unloading and loading activity. The total time T_D is the summation of the single cycling unloading, the double cycling and single cycling loading times see Figure 1(b)

5. SIMULATION OF CONTAINER TERMINAL OPERATION

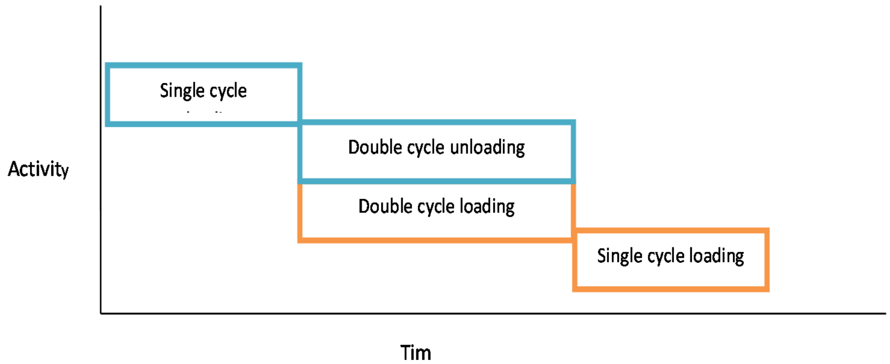
Single and double-cycling simulation models are designed in accordance with pre-defined steps. The EZstrobe simulation system has been used to model the container terminal operation due to its simplicity and power. To apply the EZstrobe simulation system, some steps must be followed, as mentioned above. 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. The single- and double-cycling steps are presented in more detail, as part of the simulation model development.

5.1. Double-cycle simulation model

The double-cycle simulation model is designed as a form of integration between single and double cycling. This process begins with the single-cycle unloading of three or more rows before starting double cycling-, in order to minimize the fleet size and maximize the crane use. Next, the unloading QC_1 will change from unloading to loading the containers on the vessel. Another QC, (QC_2), is introduced to the fleet to continue unloading the containers from the fourth row to the end while 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 bedischarged by YC_2, which should be ready for this discharge.



a) YT Single cycle operation



b) YT double cycle operation

Figure 1: Different scenarios of vessel turnaround time lines

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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-cycle simulation.

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 QC, YTs and the YC cycle times must first be calculated. It is assumed that the timeswill vary according to the speed variance. Any delay or acceleration of the cycle times will relate to the variations in speed. For instance, a crane operator's skills should have an impact on the vertical and horizontal speeds of the trolley, i.e. a skilled operator's machine would work faster than that of an inexperienced operator. The same variability occurs if the weather changes, affecting the machine's efficiency and/or the road conditions. The YT cycle time is calculated according to the expected distances from the vessel to the SY.

Finally, To mimic reality, the durations are assumed to vary from one cycle to another. This has been represented by changing the speeds and motions of the equipment. Decreases in the speeds were set to descend from 90% of the maximum speed to 60%, decreasing 5% each time, and were assumed to result in related increases in the cycle times. The derivation function of each equipment cycle time was used to calculate each equipment's cycle time. The resulting 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 a vessel and a YT was estimated using a deterministic of 0.166 minutes. Because it is a very small time compared to the other durations, moving the QC between rows is neglected.

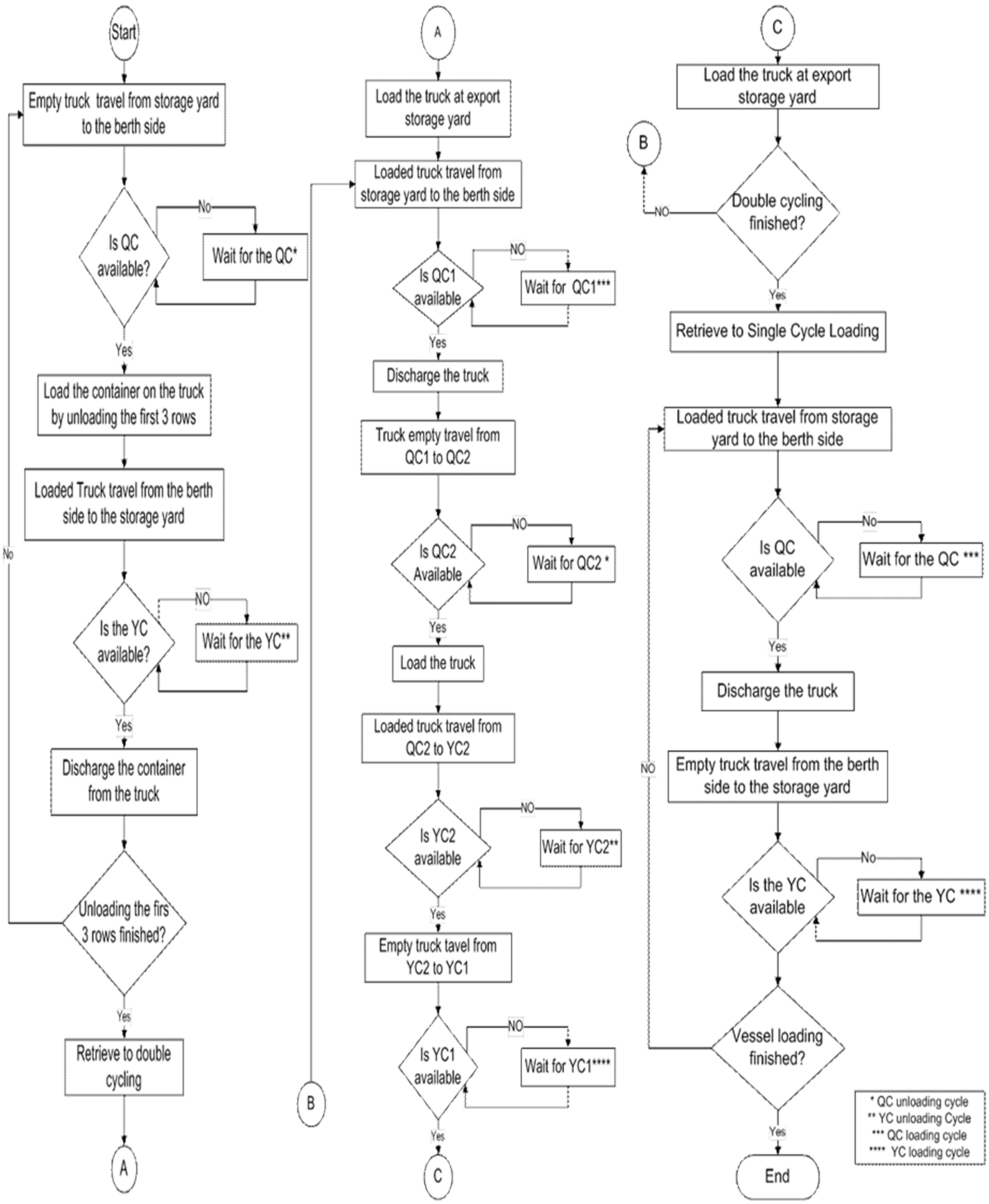
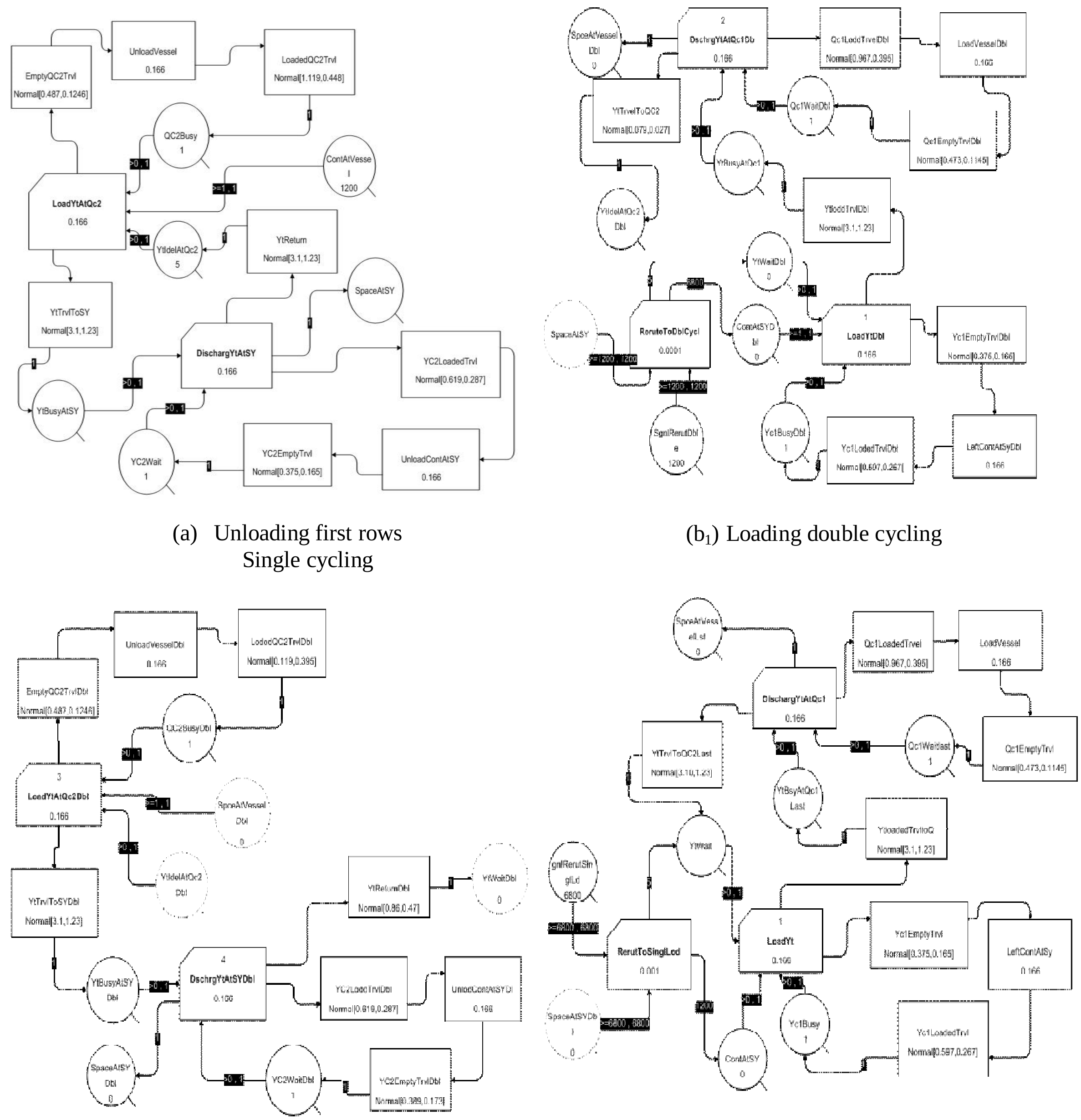


Figure 2: Double cycling simulation process



(a) Unloading first rows
Single cycling

(b_1) Loading double cycling

(b_2) Unloading double cycling

(c) Loading remaining rows
single cycling

Figure 3: YT double cycle simulation model

6.2. Cost estimation

As previously described, the hourly costs were estimated. These estimates are not exactly 'real' and are not confidential. To make this data useful and easier to manipulate, the savings in each category of productivity rate, hourly cost and unit cost are given as percentages.

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 outputs

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)

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. 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 YTs 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 RTG-type. The trolley speeds of the QCs and the YCs have been quoted from the cranes' manufacturer publications .The hourly costs are estimated, asreal data from container terminals is not yet available. Other inputs are also needed to run the simulation model. The simulation parameters and hourly costs are presented in Table 1.The simulation results reveal 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 minimizes vessel turnaround time with reasonable cost savings.

6.4. Sensitivity analysis

A sensitivity analysis is carried out to modify the model resources. |Only the number of YTs has been implemented to date. The other resources (number of QCs and number of YCs) will be done in future work, as the model requires further development. For instance, to add one more YC, another YC cycle has to be developed and a probabilistic routing element introduced to connect the process. The number of YT changes modifies the number of trucks from 3 to 12 in both single and double cycle. See Table 3

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 of YTs to improve container terminalproductivity.

Table 3: YT single and double cycling sensitivity analysis results

No. of YTs	Single Cycle					Double Cycle					Single	Double
	No. Hrs	Productivity rate TEUs/hr	Hourly cost $/hr	Unit Cost $/TEU	Cost Index	No. Hrs	Productivity rate TEUs/hr	Hourly cost $/hr	Unit Cost $/TEU	Cost Index	Total cost ($)	Total cost ($)
3	658.04	48.62	510	10.487	0.21	421.96	75.83	760	10.02	0.132	335603.46	320689.6
4	543.04	58.92	560	9.503	0.16	338.26	94.60	810	8.56	0.090	304102.40	273989.79
5	502.06	63.73	610	9.57	0.15	297.38	107.60	860	7.99	0.074	306259.65	255745.94
6	494.02	64.77	660	10.189	0.15	281.02	113.87	910	7.99	0.070	326053.20	255730.93
7	494.60	64.69	710	10.974	0.16	275.72	116.06	960	8.27	0.071	351170.97	264688.32
8	494.30	64.73	760	11.739	0.18	276.96	115.53	1010	8.74	0.075	375668.76	279733.64
9	494.66	64.69	810	12.521	0.19	275.64	116.09	1060	9.13	0.078	400681.89	292182.64

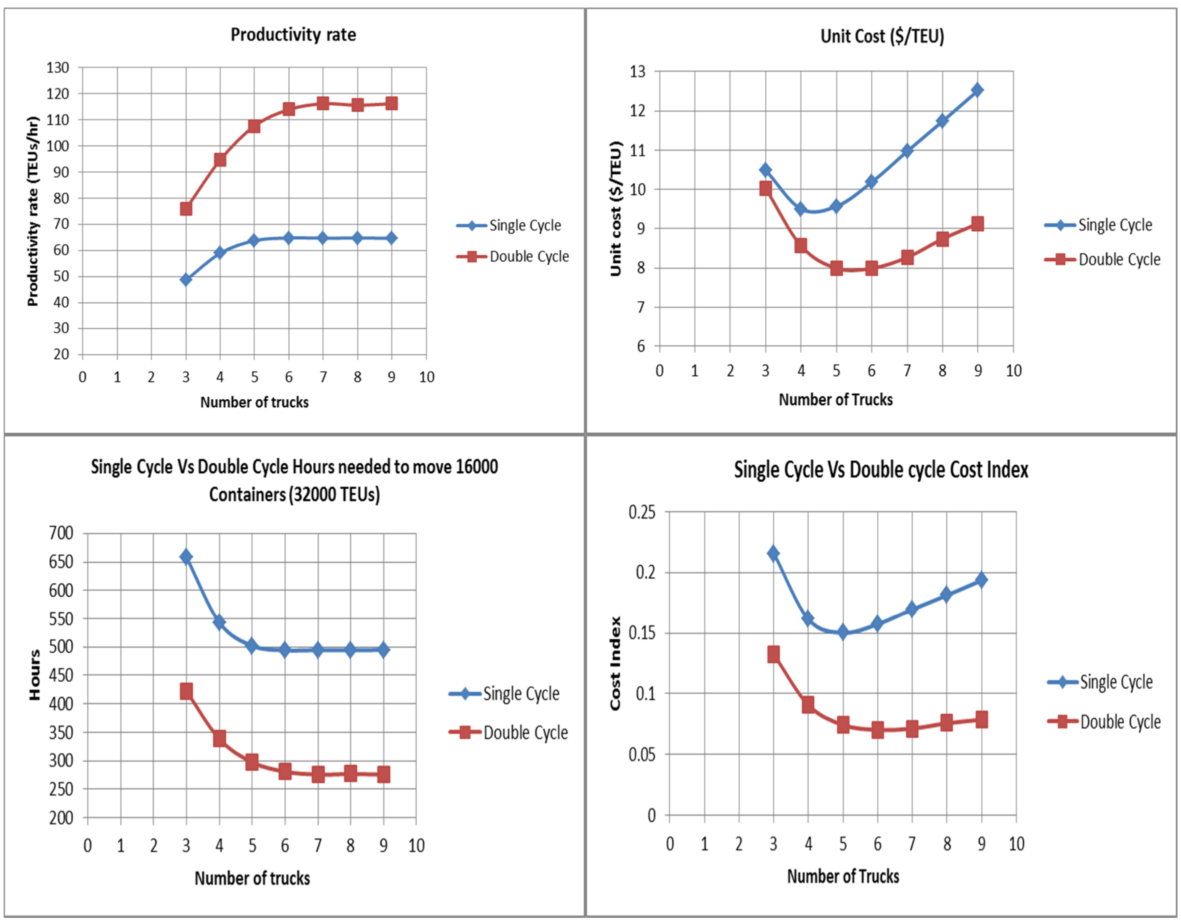


Figure 4: Sincetivity analysis comparision between YT single and double cycling

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This new strategy of handling containers has been modeled, tested andThe simulation indicates a reasonable improvement in productivity while reducing 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.The sensitivity analysis shows the use of 6 trucks is more productive and les cost when using double cycling comparing to the use of 4 trucks in single cycling.

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