

Quayside Operation in Container Terminals and the Concept of Productivity Enhancement

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Abstract

This study examines the productivity of container loading and discharging operation in container terminals using automated and semi-automated Quayside Cranes (QSCs). It analyses the automated cycle time of the operation and introduces a comprehensive definition for the productivity of Quayside (QS) operation. It is argued that a considerable saving in the cycle time of loading and discharging of containers can be achieved by the introduction of automated technologies at the QS. This will help the terminal operators to significantly reduce the turnaround time of container ships at container terminals. The study also sets up a basis for calculating the number of QSCs, transfer and stacking equipment by considering their productivity value and cycle times.

Keywords: Quayside Cranes, Container Loading / Discharging, Productivity, Cycle-Time Analysis

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1 Introduction

At the quayside of every container terminal, one of the major issues is to minimise the cycle times of the QSC operation to maximise its productivity. Significant time saving can be achieved by the adoption of an automatic optimum path generator and smart identification and positioning technologies installed on QSCs. On the other hand, the availability of the optimum number of transfer equipment at the quayside will have a direct influence on the productivity of the loading and discharging operation. The objectives of using automated QSCs along with advanced container identification and positioning systems is to provide a fast, systematic, safe and reliable loading and discharging of containerships within minimum possible turnaround times.

Saanan and Van (2003) have compared the productivity and efficiency of the quayside operation in different scenarios for manually operated Straddle Carriers (SCs), AGVs and ASCs. Vaziri, Khoshnevis (2003) and Cadavid (2003) have provided an overview of a research on the effectiveness of integration of automated container yard cranes and an AGV system. They have compared the productivity and effectiveness of their proposed system with those of the conventional and manual operations. They have shown how a better space utilisation can be obtained with the use of automated systems. Kozan (1997) and Hang (2011) have discussed the major factors that increase the efficiency of container terminal operations. He has presented a network model to reflect the productivity of the structure of a container terminal where he aimed to minimise the total loading / discharging, handling and transfer times of the containers. Fagerholt (2000) and Gupta (1992) have provided a general discussion of different productivity related objectives in container terminals.

Jula (2002) has analysed and evaluated the performance of four different types of automated container terminals in a simulation model. The performance criteria that are used in their study set up a basis to evaluate and compare different terminal systems by considering their throughput, number of moves per hour per QSC, throughput per hectare, truck turnaround time, gate operation and processing time, etc. The authors have concluded that performance and costs of conventional container terminals can significantly be improved by the implementation of automation systems.

2 The Quayside Operation

2.1 Automation of QSCs

Automatic control devices have been in operation in container terminal systems for more than 15 years. Even though many of the automated controlling systems are used in production and warehousing industries, their full application to container terminal and particularly to the quayside cranes has been slow. This is mostly due to difficulties related to the operational environment and safety considerations.

The operational considerations affecting full automation will require scientific solutions which are beyond the scope of this study. They can be divided into two areas:

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1. Difficulties experienced at the shipside due to heave, roll, pitch, surge, sway and yaw of the vessel. These motions cannot be entirely eliminated, although they may be damped and compensated for and
2. Difficulties experienced at the quayside by spreader sway, crane's praying effect and racking stresses of the crane due to high-speed winds and load snag.

However, automation technology is mature and reliable enough today to be adopted for quayside operation. Referring again to Figures (1) and (2), the position and path of the spreader, except its sway, can be determined accurately by measuring the movement and controlling it at each pre planned point. With the semi-automatic manoeuvring, intelligent spreader positioning, and container identification systems, the actual position of each point can automatically be fed into the computer in real time and compared with the pickup and drop positions. The computer will be able to make the necessary calculations and instruct every motor to move accordingly, until the target is reached and the container is positioned into the intended slot (Ursavas 2014, Cranes Today, 1996 and Rosenfeld 1995).

Figures (1) and (2) illustrate a comprehensive schematic view of a conventional single hoist Post-Panamax QSC with a single trolley in a single-cycle mode of a loading operation. A crane is said to be operating in single-cycle mode when it picks up the container from the quayside, loads it on to the containership into the corresponding slot and returns empty to pick up the next container. However, in a double-cycle mode the crane picks up the container from quayside, loads it into the ship and then picks up a new container from the ship to discharge it on to the transfer vehicle at the quayside. The study considers the different steps of operation to find areas for shortening cycle times in the process of the loading operation in a single-cycle mode.

The operation of a single hoist crane with a single trolley can be broken down into different steps. The operator of a crane can load or discharge containers manually with a longer cycle time or use automated optimum path generators installed on the QSCs to complete the cycles in a much shorter time. Some of these steps could be carried out automatically with or without any human intervention to shorten the total cycle times. In the following figures, the dotted line indicates a manual operation and the solid curved line a possible automated and optimised line of operation.

- Step 1.** Manual setting of spreader over containers delivered on trailer, Straddle Carrier (SC), or Automated Guide Vehicles (AGVs) with the help of spreader check personnel. With application of smart identification and positioning systems, this process can be fully automated.
- Step 2.** Manual locking of spreader with container. With the application of smart spreaders, the locking process can be totally automated.
- Step 3.** Manual transport of container with gradual hoisting of spreader towards a specific cell in the containership. This process can be totally automated through systems in which optimum path recognition techniques are used. These systems help the driver to

automatically shift the trolley and the spreader towards the intended cell and vice versa. If the driver does this manually and the path seems to be more optimised than that of the one previously stored in the memory of the crane system, then it can be re-stored in the memory for the next runs and perhaps for the next operation.

Step 4. Finding cell guides.

Step 5. Manual lowering and placing of the container into a pre-specified cell. This step can be semi - automated.

Step 6. Manual unlocking of spreader and releasing the container.

Steps 4, 5 and 6 can also be fully automated if two sets of problems could be permanently solved. These problems are:

i) The crane movement (praying effect⁴), load snag and spreader sway and

ii) The ship movements (yaw, roll, pitch, sway, surge and heave).

Step 7. Manual lifting of spreader from the cell.

Step 8. Manual transfer and gradual lowering of spreader to quayside (reverse action of Step 3).

Step 9. Arrival of spreader over the container on the trailer chassis.

Step 10. Positioning and locking of spreader on to the next container.

Step 11. Starting a new cycle.

An example of a cycle time obtained from a QSC is shown in Table (1).

⁴ The praying effect of a crane is the movement caused by wind force, load snag and the trolleys de-acceleration momentum when approaching the extremities of the boom.

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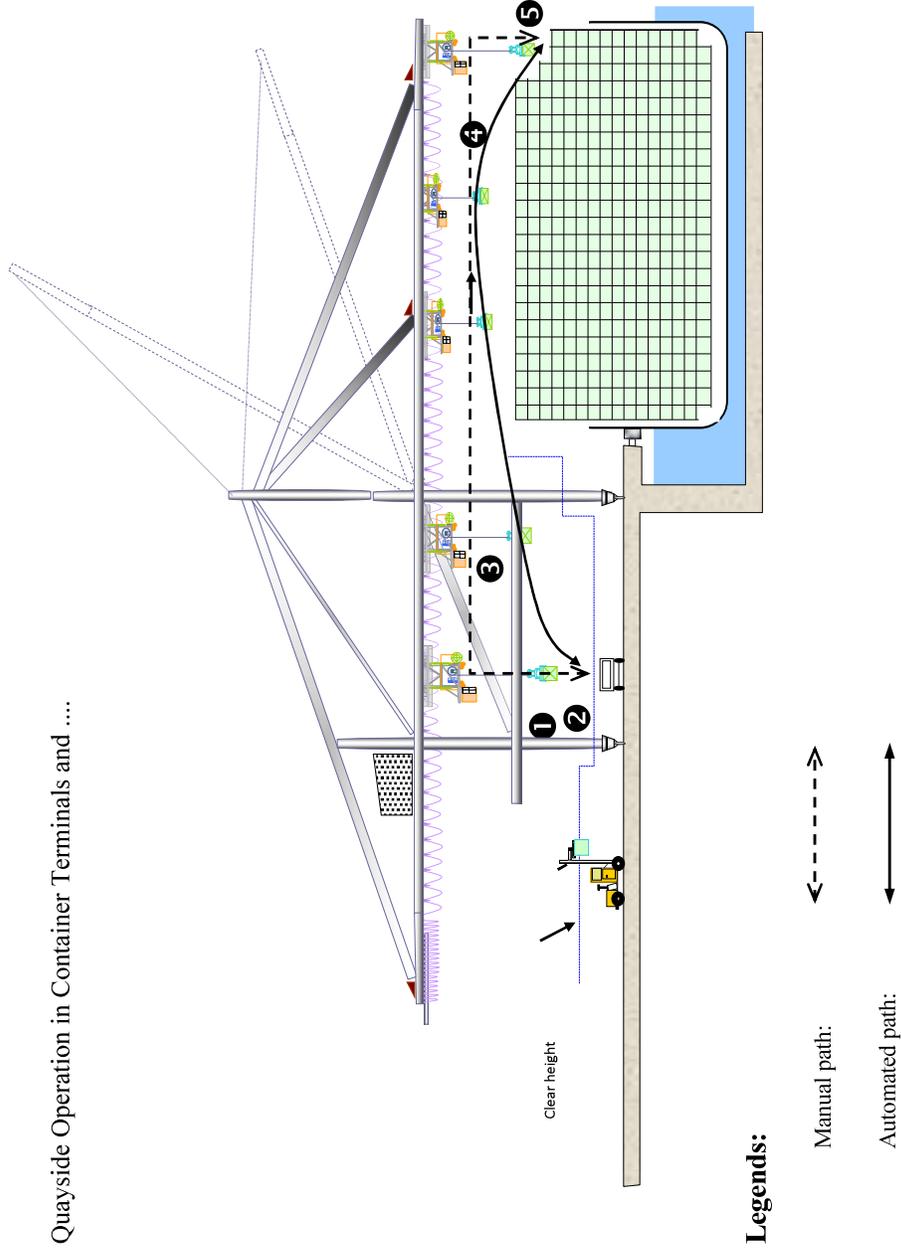


Figure (1) Conventional, single hoist, single trolley gantry crane in a loading cycle

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Table (1) Example of cycle time of the spreader and the trolley movements

ID	Steps	Actions	Start	Finish	Duration, sec.
1	1-2	Setting the spreader	00:00:00:00	00:00:04:00	
2	2-3	Locking the spreader	00:00:04:00	00:00:09:00	05.0
3	3-4	Moving the spreader to shipside	00:00:09:00	00:00:27:00	18.0
4	4-5	Finding cell guides	00:00:27:00	00:00:30:00	03.0
5	5-6	Lowering the spreader	00:00:30:00	00:00:39:12	09.2
6	6-7	Un-locking the spreader	00:00:39:12	00:00:44:00	04.8
7	7-8	Hoisting the spreader	00:00:44:00	00:00:49:30	05.5
8	8-9	Moving the spreader to quayside	00:00:49:30	00:01:03:30	14.0
9	9-10	Positioning the spreader	00:01:03:30	00:01:07:18	03.8
10	10-11	Starting a new cycle	00:01:07:18		

Total cycle time = 00:01:07:18

Legends:

-  Spreader movement
-  Spreader locking / unlocking
-  Driver justification
-  Trolley movement
-  Spreader locking / unlocking

Without automatic devices, manual cycles are carried out through a trial-and-error process, based on feedback provided by the operator's experience and assessment. In most cases a considerable percentage of the cycle time is spent on the positioning of the spreader to the top of container although the operator has repeated almost the same path many times. About 100 manual loading experiences with skilful drivers operating on the crane were studied. The manual cycles (indicated with dotted line) had an average of about 127 seconds per cycle.

The same crane fitted with semi-automated devices can playback a route much faster, safer, more efficiently and accurately than can a human between the picking up points and points of positioning the containers. This route can then be stored into the memory of the operating system installed on the crane and can be used for the next successive runs or perhaps for the next operation.

A semi-automatic optimum path system linked with smart container identification systems will produce a considerable time saving in loading and discharging operation. The geometric scantling and configuration of QSCs with well-defined joints and features can be equipped with reliable, inexpensive, computer-based automated devices. A semi-automatic manoeuvring, spreader positioning, and container identification systems installed on a Post-Panamax crane can benefit from a synergy among three parties (Loke, *et al*, 2014 and Cranes Today, 1996):

- i) The operator's human intelligence, judgment, and improvisation skills,
- ii) The computer's programmability, vast memory, and rapid calculation capabilities and
- iii) The sensory devices' accurate, real-time measurements and feedback.

The automation systems offer an additional enhancement that addresses the subsequent intelligent identification and positioning of the containers and smooth manoeuvring steps of the trolley cycles with a view to eliminating the need for spreader locating personnel at the quayside and on board the containership. This enhancement is based on the observation that manually manoeuvring and positioning is neither efficient nor adequately safe, which is especially true when the container reaches far away from the driver or becomes obscured from his or her sight, or when the positioning of the spreader demands high precision for example, when the containers are deep in the holds. Observations conducted during research at the port of Bandar Abbas container terminal revealed that these operators remain idle for half of the cycle at both the loading and the discharging points. The observations strongly support the idea of minimising crane cycle times, which will result in a shorter duration of the entire activity.

2.3 Effect of Cycle Time Shortening

The major economic benefits and productivity of QSCs obtained by adopting advanced automation and sensor technologies are related directly or indirectly to an expected shortening of crane cycle times. The study of optimising these cycle times requires a conversion of the number of moves carried out by any specific QSC per hour into cycle time in seconds per each move completed. Thus a crane with a productivity of, for example, 32 moves per hour will have an average cycle time of 112 seconds per move.

Studies state that, in practice, the productivity of the quayside cranes is far behind that of their calculated cycles (Eric *et al* 2015, Cranes Today, 1996, Jordan, and Rudolf 1993). The average number of moves obtained from the conventional QSCs under study with competent drivers was about 32 moves per hour when operating manually. Having the automatic devices installed on the QSCs has seen productivity increased to 60 to 70 moves per hour. The total productive moves include compulsory idle times, e.g., breaks, stoppages, repairs, etc. In this study they will be based on 50-80% of the crane's calculated efficiency (Cheesman, 1980 and Haghani and Kaisar, 2001).

Extensive academic studies conducted have led to quantitative estimates of time-savings that may be obtained by the use of a semi-automatic manoeuvring and smart spreader positioning along with container identification systems (Eric *et al* 2015, Haghani and Kaisar, 2001 and Daganzo 1989). The data collected for this study was obtained from newly automated QSCs in Bandar Abbas – Iran, while a competent driver was appointed to carry out the operation. The QSC was equipped with a cycle path recognition system coupled with a computing system installed on the crane that enabled the driver to measure the time and distance of different points in the manoeuvring path respective to a fixed point at the quayside or onboard the ship. These points were almost the same points indicated in Figures (1), (2) and Table (1). The results obtained from the cranes were applied to nearly 850 reliable single and double cycles and compared with those of manual cycles. The mean and standard deviations of the above cycle times were calculated using Microsoft Excel. The percentage of manoeuvring time out of the total cycle times, for the observed loading operations was found to be in the range of 15.3% to 27.8%. These values are obtained by dividing the cycle time taken for those steps divided by the total cycle time. For example, in the single cycle experiment, the percentage of manoeuvring time out of total cycle time for Steps 1-2 is 12.0 divided by 67.3 that equals to 17.8%. Potential savings in crane cycle time would be derived mainly from the reduction of these percentages compared to manual cycle times. The results are summarized in Table (2).

With the adoption of automated devices the productivity in terms of number of moves was increased to an average of about 63 moves per hour. This means the total time a containerships stays at the quayside can be reduced by a fraction of $\frac{32}{63} = 0.51$.

The following simple calculation distinguishes the time required to discharge a containership with a carrying capacity of 18,000 containers with four manual QSCs compared with four automated QSCs. It is assumed that the QSCs work 24 hours a day.

▪ **Manual Operation**

1 QSC discharges 32 containers in 1 hour therefore, 768 containers in 24 hours. Allocating four QSCs to operate on the vessel the rate of discharge will be 3,072 containers a day. A containership of 18,000 TEUs will be required to stay at the quayside for at least 5 days and 21 hours.

▪ **Automated Operation**

The same containership served by the same four cranes but with automated devices would require 2^{days}, 23^{hours} (5^{days}, 21^{hours} × 0.51) only.

Therefore, with the introduction of automated systems to QSCs, the container terminal can serve two container vessels rather than one using manual operations. As a result, the turn around of the vessels would be substantially reduced. This will not only bring substantial benefits for port and shipping industries but would enhance customer service and satisfaction, particularly just-in-time deliveries.

2.4 Cycle-time Analysis

According to the cycle times obtained from various steps and activities: If activity j is one of loading or discharging activities in which the crane is engaged during a typical working day, and T is the percentage of the duration of automated cycle times j brought about as result of automation out of the total manoeuvring time ($\sum T_j = 100\%$), then total daily savings in

percentage in crane time, ΔT , would be:
$$\Delta T = \sum_{j=1}^m T_j \left(a_j \alpha_j + b_j \beta_j + c_j \gamma_j \right) \quad (1)$$

where;

a_j = Percentage out of total cycle time j of the path travelled time in loading and discharging period for activity j ,

α_j = Fraction of a_j that can be saved,

b_j = Mean percentage out of total cycle time of spreader and / or trolley manoeuvring time for activity j ,

β_j = Fraction of b_j that can be saved,

c_j = mean percentage of the other time dependent activities other than a_j and b_j for activity j and

γ_j = fraction of c_j that can be saved.

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A crane may be required to fulfil multiple tasks in one full cycle like shifting containers within the holds, shifting the hatch covers and repositioning the container from deck to the appropriate slots or vice versa. This is the reason for recommending c_j and γ_j values to be considered in such multiple manoeuvrings.

The ΔT in equation (1) on average accounts for only 50-80% of productive time periods during the crane's typical working day.

Table (2) Cycle time obtained from a semi-automated Post-Panamax crane

Operation phases	No. cycles observed	Manoeuvring cycle-times in a single – cycle operation (sec.)		Manoeuvring cycle-times in a double - cycle operation (sec.)		Percentage of single cycle manoeuvring time (MT) in total cycle time (%)
		Mean (a)	Standard deviation	Mean (b)	Standard deviation	
Steps 1-2	320	12.0	±2	19	±1	17.8
Steps 3-4-5	184	18.7	±3	22.8	±5	27.8
Steps 6-7	103	14.2	±3	18.7	±12	21.1
Steps 8-9	113	12.1	±2	15.3	±3	18.0
Steps 10-11	130	10.3	±2	16.6	±3	15.3
$\Sigma =$	850	67.3		92.4		100%

The effect of the unproductive times, necessarily resulting in a smaller ΔT will be taken into account later in the analysis. Note that α is the major contributor of ΔT . The values presented for the process of Step 1 to 2 in Table (2) are the initial setting of the spreader. Therefore, in an un-interrupted and continuous operation, it can be considered that these steps become Steps 9 to 10. In certain steps like the time taken for the spreader to ascend from Step 3 to 4 or descend from Step 8 to Step 9, with the use of the semi-automated systems the entire manoeuvring time is expected to be fully optimised. This includes gradual slowdown of the spreader to provide a soft and gentle landing on the trailer chassis at the QS. In practice it happens that loading and discharging operations face undesirable environmental conditions or the containership served is fully loaded and / or the under boom clearance does not provide sufficient room to make the most desirable path and the least cycle times. In this case automated optimum paths will almost be the same as manual ones, that is, α would still be close to its upper limit (e.g., $\alpha = 0.8$). However, in some activities, like lowering the spreader into the cells in the case of cellular containerships, only a smaller fraction of the manoeuvring time may be saved, α will be conservatively assigned a value of 0.5.

In equation (1), the potential time-saver β was taken to be zero. In some laboratory models of the full-scale testing of the semi - automated system installed on a conventional crane, savings of 15-40% have been observed in times of long-distance manoeuvring, that is, $\beta = 0.15$ to 0.40 (Rosenfeld, 1995). Unfortunately, at the time of observation, there was no mega

container vessel or a cellular containership at the quayside to quantify the longest path cycles; therefore no sufficient data was at hand to estimate β for those cases. For the same reason, though it was intended to fully demonstrate the short time cycles of low and medium freeboard containerships, any β related potential savings were left unutilised in the present analysis. On the other hand, since most of the reliable cycles were obtained in single-cycle mode, the other potential time saver in multi-cycle and multi-task operation that could be related to γ was also considered to have a value of zero.

2.5 Operational Analysis

Other factors that may have an effect on the timesaving, ΔT , are the process of spreader manoeuvring explained in Steps 1, 2 and 10 and the values assigned to T_j . It should be mentioned that handling different types of containers with different size, weight, delicacy and condition would result in different manoeuvring times (Cranes Today, 1996 and Haghani, and Kaisar 2001). However, since the range of manoeuvring times in Table (2) is limited to 15.3% to 28.7%, one may reasonably assume that individual steps carried out may have a limited effect on the weighted time-savings in practice.

Results obtained from the average cycle times of the spreader and the trolley movements in the analysis of Figures (1) and (2) and Table (1) and the data calculated in Table (2) are used as a basis for analysis of Table (3). The data has been adapted from detailed case and historical studies conducted in the area of the research topic on ten other QSCs of the same type in the ports of Bandar Abbas and Bandar Imam. The calculations, shown in Table (3), represent three different discharging experiments with three types of containers handled; 20-foot export containers of domestic products, containers of heavy industrialised products and 40-foot export containers of domestic products. The following sets of data are given in Table (3):

1. The first column represents the breakdown of the cycle times (the steps),
2. The second column provides the results of percentage of Manoeuvring Time (MT) in total cycle time derived from Table (2) which will be used as a basis for the calculation in Table (3),
3. The remaining columns represent the calculated summary of the other ten cranes involved in the three types of operation given for various steps. For example, T_j for QSC 1 for Steps 1-2 = 24%, for Steps 3-4-5 = 22%, for Steps 6-7 = 14%, for Steps 8-9 = 28% and for Steps 10-11 = 12% of the average total time taken for the whole cycle. In the same way nine other QSCs engaged in discharging the three different types of containers were tabulated and
4. The weighted proportion of manoeuvring times ascribed to these steps ($T_j a_j$ in percentages) was derived from the second column in Table (3). For example, MT of Steps 1-2 (17.8%) for an average T_j of 24% of QSC1 would provide $T_j a_j$

$$= \frac{17.8 \times 24}{100} = 4.3 .$$

In the same way, the $T_j a_j$ values for other steps can be obtained and a summation (Σ) for all of the QSCs is achieved. The total $\Sigma T_j a_j$ for each column [bottom line in Table (3)] is given as the percentage of the crane's productive time taken by manoeuvring for that respective full-cycle.

The values of a_j and the mean percentage of manoeuvring time for each set of steps were taken from Table (2). The values used for Steps 8-9 and 3-4-5 are conservative assumptions, since smooth operations are subject to total availability of vessels with no stoppages. The steps presented earlier that are the basis of this study reflected in Table (3), only cover data for the trolleys moving empty towards the cells and discharging the full containers on return. Therefore, stoppages have not been considered and the total of T_j for each calculation in practice may appear less than 100%. It could be reasonably assumed that other lifting runs carried out with QSCs, which cannot be counted as cargo operation, also involve manoeuvring times to a certain extent, and thus hold promise for time-savings similar to the assignments included. However, these operations were not taken into account in this study.

2.6 Results

The results obtained for $\Sigma T_j a_j$ in Table (3) indicate that the weighted cumulative time taken by manoeuvring is in the range of 20.2% to 24.2% of the crane's productive time. It is noticeable that heavy containers and perhaps non-standard containers (21.6% to 24.2 %) have T_j values more than 100% that indicates that they possibly require more time and effort than those of 20 and 40-foot domestic products (20.2% to 20.9%, 20.5% – 21.2%) (Vaziri, and Khoshnevis, 2003, Rosenfeld, 1995 and Cheesman 1980). The average value therefore is about 22% and a conservative value applied to the remainder of the analysis (20% of the average value) is about 18%, which is only slightly lower than the mid-range for all calculations. According to equation (1) and applying the value $\alpha = 0.5$ and the analysis in Section 4.2, will result in combined savings in effective crane time of 9% ($\Delta T = 9\%$). As mentioned earlier, cranes are found to have an average productivity of 50–80%. Thus the value of ΔT could be moderated by a correction factor of 0.65 (the mid range of 50–80%). In the same way, a saving of 6% of the entire crane time is used as the basis for the economic analysis in this study.

3 Productivity of QS Operation

The operations at the quayside involve allocating berths to containerhips, assigning and operating a required number of QSCs served with an optimum number of transfer vehicles. These activities are interrelated and productivity of each operation may impact or being impacted by each other. Therefore, the productivity of the quayside operation is a multi functional productivity and needs to be clearly defined.

3.1 Gross Productivity of QSCs

Figure (3) illustrates a QSC which serves a containership. The berthing time and the time of containership departure from the quayside are known and may be different from the time of commencing loading / discharging and ceasing the operation. Stoppages, QSC idle times and other times used for activities which cannot be accounted as cargo operation should be excluded from the QSC working time. The following terms provide a comprehensive definition of productivity for quayside operation.

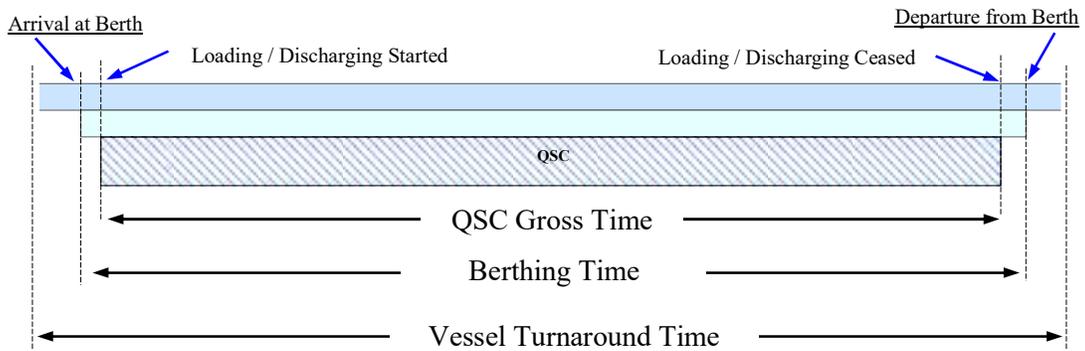


Figure (3) Containership Berthing Plan

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Table (3) The cumulative manoeuvring times (percentage of effective operation time) based Table (2)

Operation phases	a_j (% of MT in total c/t)	Discharging 20 foot containers of domestic products						Discharging heavy industrialised containers												Discharging 40 foot containers of domestic products					
		QSC. 1		QSC. 2		QSC. 3		QSC. 4		QSC. 5		QSC. 6		QSC. 7		QSC. 8		QSC. 9		QSC. 10					
		T_j %	$T_j a_j$	T_j %	$T_j a_j$	T_j %	$T_j a_j$	T_j %	$T_j a_j$	T_j %	$T_j a_j$	T_j %	$T_j a_j$	T_j %	$T_j a_j$	T_j %	$T_j a_j$	T_j %	$T_j a_j$	T_j %	$T_j a_j$				
Steps 1-2	17.8	24	4.3	20	3.5	22	3.9	28	4.9	26	4.6	19	3.4	21	3.7	20	3.5	16	2.8	17	3.0				
Steps 3-4-5	27.8	22	6.1	25	7.0	28	7.8	33	9.2	33	9.2	24	6.7	26	7.2	33	9.2	26	7.4	22	6.1				
Steps 6-7	21.1	14	3.0	13	2.7	15	3.2	19	4.0	15	3.2	20	4.2	18	3.8	18	3.8	22	4.9	23	4.9				
Steps 8-9	18.0	28	5.0	29	5.2	24	4.3	17	3.0	29	5.2	31	5.6	30	5.4	23	4.2	20	3.6	28	5.0				
Steps 10-11	15.3	12	1.8	13	2.0	11	1.7	9	1.4	13	2.0	11	1.7	21	3.2	21	3.2	16	2.5	10	1.5				
Total, ($\sum T_j a_j$)	100%	100	20.2	100	20.4	100	20.9	106	22.5	116	24.2	105	21.6	116	23.3	115	23.9	100	21.2	100	20.5				

T_j = Percentage of cumulative duration of loading and discharging assignment j out of effective crane operation time calculated from the experiments.

$T_j a_j$ = Percentage of cumulative duration of loading and discharging assignment j out of effective crane operation time.

3.1.1 Key Definitions

- Berth Arrival Time (BAT) is defined as the time at which vessel berths at the quayside and all the mooring lines are made fastened (Valenciana 1999).
- Berth Departure Time (BDT) is the time at which the vessel leaves the berth and the vessel casts off the berth.
- Vessel Berth Time (VBT) is the total time from the BAT to BDT.
- Gross Crane Time (GCT) is the total time of a crane from the start to the finish over which it serves a vessel at a quay in hours / QSC / vessel.
- Gross Crane Productivity (S_{gross}) is the total number of moves of a crane over the GCT in a containership operation.
- Crane Net Time (CNT) is the total time from the start to the finish time over which a crane serves a vessel where delays, stoppages, downtime and idle times are deducted. CNT is measured in terms of hours / QSC/ vessel.
- Crane Net Productivity (S_{net}) is the total number of moves of a crane over the CNT in a containership operation.
- Berth Net Productivity (BNP) is the total number of moves carried out by all cranes allocated a vessel over the VBT time.

Figure (4) and Table (4) provide a real example of a container vessel berthing time and loading and discharging schedules.

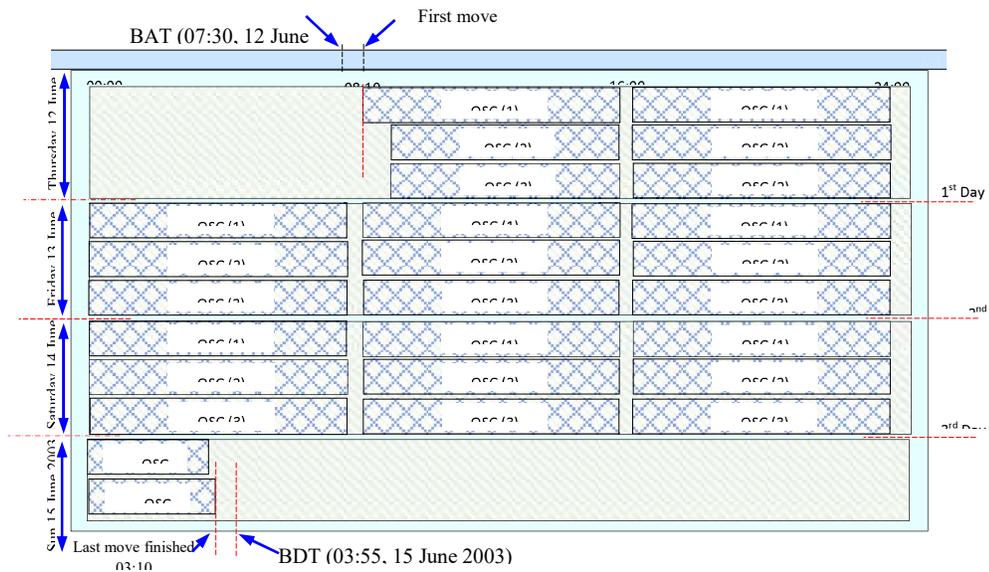


Figure (4) The Quayside Cranes and Containership Working Times

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Case (1):

The container vessel Teyfour (4,700 TEUs) berthed at Bandar Abbas Container Terminal where, 3 QSCs with the registered operational rate of 37 moves per hour per crane were allocated to her. The start and finish times and the delays, stoppages or idle times for each crane in every shift is been recorded and has been illustrated in Table (4) as delays. Deducting delays will provide the net working times for each shift (column titled 'sum') which enables to calculate the CNT. The number of containers loaded or discharged is known.

Vessel berthed at 07:30 on Thursday 12 June 2003 and un-berthed at 03:55 on Sunday 15 June 2003 (VBT=2days 19 hours 35 minutes)												
First move started at 08:10, 12 June Last move finished at 03:20, 15 June	QSC 1				QSC 2				QSC 3			
	start	finish	delays	sum	start	finish	delays	sum	start	finish	delays	sum
1 st shift, Thursday 12 th June 2003	08:10	16:00	-0:05	7:45	08:15	16:00	-0:05	7:40	08:15	16:00	-0:10	7:35
2 nd shift	16:00	24:00	-0:12	7:48	16:00	24:00	-0:08	7:52	16:00	24:00	-0:08	7:52
3 rd shift, Friday 13 th June 2003	24:00	08:00	-0:05	7:55	24:00	08:00	-0:05	7:55	24:00	08:00	-0:10	7:50
1 st shift	08:00	16:00	-0:10	7:50	08:00	16:00	-0:12	7:48	08:00	16:00	-0:05	7:55
2 nd shift	16:00	24:00	-0:10	7:50	16:00	24:00	-0:05	7:55	16:00	24:00	-0:12	7:48
3 rd shift, Saturday 14 th June 2003	24:00	08:00	-0:14	7:46	24:00	08:00	-0:05	7:55	24:00	08:00	-0:05	7:55
1 st shift	08:00	16:00	-0:08	7:52	08:00	16:00	-0:15	7:45	08:00	16:00	-0:12	7:48
2 nd shift	16:00	24:00	-0:05	7:55	16:00	24:00	-0:10	7:50	16:00	24:00	-0:10	7:50
3 rd shift, Sunday 15 th June 2003	24:00	03:10	-0:05	3:05	24:00	03:20	-0:05	3:15	-	-	-	-
GCT	67:00		-1:14	65:46	67:05		-1:10	65:55	63:45		-1:12	62:33
CNT	65:46				65:55				62:33			
VBT	67:35											
Number of TEUs loaded / discharged (observed)	2445				2530				2305			
Total TEUs loaded / discharged	7280											

Table (4) Gross Productivity of QSCs

The following equation defines the gross productivity of QSCs as the number of TEUs (moves) handled by a crane over the crane gross working time.

$$S_{qsc}^{gross} = \frac{N_{con}}{GCT}$$

where:

S_{qsc}^{gross} = Gross productivity of a QSC,

N_{con} = Number of containers loaded and or discharged by the same crane and

GCT = Gross working time of the crane.

By dividing the number of containers moved by each crane by the gross time of each crane the gross productivity of each crane can be obtained. Therefore, the following results are obtained for the 3 QSCs from Table (4):

$$S_{qsc(1)}^{gross} = \frac{2445}{67} = 36.5 \text{ TEUs/hour}$$

$$S_{qsc(2)}^{gross} = \frac{2530}{67.08} = 37.7 \text{ TEUs/hour}$$

$$S_{qsc(3)}^{gross} = \frac{2305}{63.75} = 36.2 \text{ TEUs/hour}$$

3.2 Net Productivity of QSCs

At the quayside, the net productivity can be defined as the net time taken to load / discharge the containers over the gross time of the containership at berth. This is in conflict with the previous statement of productivity which was the number of container movements per period of time taken by a crane per ship.

The efficiency and productivity of QSCs used to load and discharge containers and transfer vehicles can also be measured and analysed on a qualitative basis.

The net productivity of QSCs is directly related to the number of working hours that container vessels are at the quayside, which can influence the productivity of most of the container transfer equipment at any terminal. The net productivity of a QSC (S_{qsc}^{net}) can thus be defined as (Daganzo, 1989 and Maguire 1986):

$$S_{qsc}^{net} = \frac{N_{con}}{GCT - T_{qsc}^{idle}}$$

where:

S_{qsc}^{net} = Net productivity of a QSC,

N_{con} = Number of containers loaded and / or discharged by the same crane,

GCT = Gross working time of the crane and

T_{qsc}^{idle} = Total idle time of QSC during GCT .

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Therefore, the gross results obtained in section 3.1 should be corrected for QSC idle times to become net results as follows:

$$S_{qsc(1)}^{net} = \frac{2445}{67 - 1.23} = 37.2 \text{ TEUs/hour}$$

$$S_{qsc(2)}^{net} = \frac{2530}{67.08 - 1.17} = 38.4 \text{ TEUs/hour}$$

$$S_{qsc(3)}^{net} = \frac{2305}{63.75 - 1.2} = 36.9 \text{ TEUs/hour}$$

It should be noted that the theoretical productivity of container terminals differ from each other depending on the size and type of containerships calling at ports, the location and position of containers, port facility, type of QSCs (Panamax, Post Panamax, Malacca Max, etc.) and the level of automation technology adapted and can range from 30 to 75 moves (units) per hour (Ioannou, E. et al, 2000 and Bhimani, and Karasuda 1996). This latter rate is not generally achievable in a real loading and discharging operation.

4 Number of QSCs to Allocate to a Ship

Knowing the productivity of the QSCs, it is possible to calculate the number of cranes to be allocated to each vessel from the following integer formula (Ioannou, and Chasiakos 2002). By increasing or decreasing the number of QSCs it is also possible to set up an estimated time for the departure of a containership from the quayside.

$$N_{qsc} = \left\lceil \frac{N_{TEUs}}{S_{qsc} \times (ETD_{ship} - ETA_{ship})} \right\rceil$$

where:

N_{TEUs} = Number of containers to be loaded or discharged,

S_{qsc} = Average productivity of QSCs (TEUs / hour) to be used,

ETA_{ship} = Estimated Time of Arrival of vessel at berth, and

ETD_{ship} = Estimated Time of Departure of vessel from berth.

Using the above statements, an optimum number of QSCs to allocate to a containership is provided in Case (2).

Case (2):

The number of QSCs to allocate to discharge a Panamax containership of 8,000 TEUs, where the average loading and discharging rate for each semi automated QSCs is 65 containers per hour (moves / hour) and where the containership is allowed to stay at the quayside for a maximum of one day ($ETD_{ship} - ETA_{ship} = 24$ hours) can be calculated as follows:

$$N_{qsc} = \left\lceil \frac{8,000}{65 \times 24} \right\rceil \approx 5$$

Therefore, at least 5 QSCs would be needed to discharge 8,000 containers in one day.

5 Number of Transfer Vehicles at a Terminal

5.1 Number of Transfer Vehicles in a Normal Terminal

The number of transfer vehicles required in a terminal will depend on the number of containers a vehicle can carry and the cycle time of the transfer vehicle. Generally, the transfer vehicles carry only one container at a time. There has been an attempt to increase the carrying capacity of the SCs as well as automating them. Some prototype Cases of SCs under observation in Port of Singapore Authority (PSA) in year 2000 with a carrying capacity of two containers were tested that not only helped to reduce the total cycle time of the operation, but also, resulted in a much higher average cycle time compared with two SCs of the same type that could only carry one container. Two reasons were caused the higher cycle times. The first reason was that SCs needed more time to lift, lower, drop off and straddle two containers at the same time compared to time taken by single container SCs carrying the same containers. An extra time was required to lay containers when sequence of stacking was mismatched. Spending extra time to land and re-straddle the lower container that is shown as container 2 in Figure (5), in order to lay container 1 first was another reason for the higher cycle times.

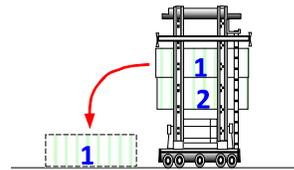


Figure (5) The Problem of Landing Containers with Double Container SC

After calculating the cycle time and productivity values of a typical transfer vehicle, it is possible to calculate the number of same type of transfer vehicles to carry out the transfer operation from the following equation (Tuypens 1985):

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$$N_{tra} = \frac{\lceil N_{TEUs} \times T_{tra} \rceil}{(ETD_{ship} - ETA_{ship}) C_{tra}}$$

where:

N_{TEUs} = Number of containers to be loaded or discharged,
 T_{tra} = Average cycle time of transfer vehicles,
 ETA_{ship} = Estimated Time of Arrival of vessel at berth,
 ETD_{ship} = Estimated Time of Departure of vessel from berth, and
 C_{tra} = Carrying capacity of transfer vehicle.

Case (3):

The approximate number of SCs capable of carrying two containers ($C_{sta} = 2$) to allocate to a containership when the total number of containers to be transported to or from the stack yard, $N_{TEUs} = 12,000$ and where the average cycle time of transport vehicle, $T_{tra} = 15$ minutes when containership is allowed to stay at the quayside for a maximum of 3 days ($ETD_{ship} - ETA_{ship} = 72$ hours) can be calculated as follows:

$$N_{SCS} = \frac{12,000 \times 0.25}{\frac{(72)}{2}} \approx 21$$

Therefore, at least 21 SCs with a capacity of 2 containers would be needed to transfer 12,000 TEUs of containers to or from the quayside to the stack yard.

Container terminals using AGV system with a carrying capacity of only one container, the number of AGVs required would be doubled. In the same way, terminals using a tractor – trailer convoy system with a capacity of 6 containers and cycle time (T_{tra}) of 20 minutes, the number of transfer vehicles required would be equal to 9.

To ensure that transfer vehicles are always available, a conservative estimation can made with the following equation:

$$N_{tra} = \frac{N_{qsc} \times S_{qsc} \times T_{tra}}{C_{tra}} \quad (6)$$

where:

N_{qsc} = Number of quayside cranes assigned to a vessel,
 S_{qsc} = Productivity value of quayside cranes,
 T_{tra} = Average cycle time of transfer vehicles, and
 C_{tra} = Carrying capacity of transfer vehicle.

Case (4):

The approximate number of Automated Guide Vehicles (AGVs) capable of carrying one container ($C_{agv} = 1$) to be allocated to a mega containership where at least 4 QSCs with an average productivity of 62 containers per hour (moves / hour) and the average cycle time of transport vehicle, $T_{tra} = 15$ minutes can be calculated as follows:

$$N_{AGV} = \frac{4 \times 62 \times 0.25}{1} = 62$$

Therefore, 62 AGVs with a carrying capability of one container would be required to carry out the operation. It should be noted that in the case of SC system with a carrying capability of two, the number of SCs required would be at least 31. In the same way, terminals using a tractor – trailer convey system with a carrying capability of 6 containers and cycle time (T_{tra}) of 20 minutes, the number of transfer vehicles required would be about 14.

5.2 Cycle Times of Transfer Vehicles

The cycle time of transfer vehicles like AGVs can be measured as the average time taken to transfer a container from the stack location to the shipside or vice versa. The cycle time should be corrected for the delay times that could be experienced by the appropriate transfer vehicles. Since the cycle time of transfer vehicles will depend on the distance and layout and the number of bends in the path of the vehicle, it can be estimated from the conventional equation of distance travelled by velocity of the vehicle and corrected for the delays. Therefore:

$$T_{tra} = \left(\frac{D_{sta} \times 2}{V_{tra}} \right) - \tau_{tra} + T_{ret}$$

where:

T_{tra} is defined as the average time for a vehicle to transfer one export container from the stack location to the quayside and transfer an import container back to the stack yard or return empty when there is no traffic congestion,

D_{sta} = Distance between the stack location and the quayside,

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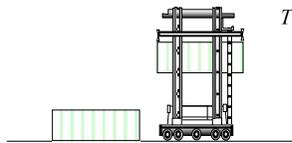
V_{tra} = Average speed of the vehicle,

τ_{tra} = Total delay time that can be experienced by one transfer vehicle in one complete cycle which should be a positive number, and

T_{ret} = Total time taken to retrieve and or restore a container to and from the stack location.

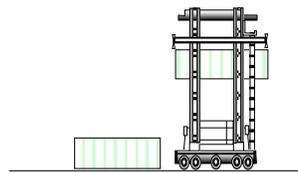
Straddle carriers are used for transferring containers as well as stacking them to the stack yard. This will provide a smooth and continuous operation compared to others systems where stacking is to be carried out with yard gantry cranes. Bonsall (2001) has formulated the retrieval and restore time of containers for SCs with different stacking capabilities as follows:

i) Two high stacking with one over two SC



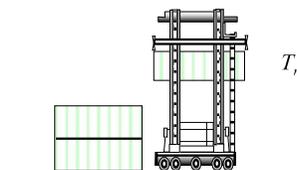
$$T_{ret} = \left[\left(\frac{9B_h}{h_s} \right) + 3L_o + \left(\frac{2B_l(N_s - 1)}{16.67T_s} \right) \right] \text{mins} \quad (8)$$

ii) Two high stacking with one over three SC



$$T_{ret} = \left[\left(\frac{15B_h}{h_s} \right) + 3L_o + \left(\frac{2B_l(N_s - 1)}{16.67T_s} \right) \right] \text{mins} \quad (9)$$

iii) Three high stacking with one over three SC



$$T_{ret} = \left[\left(\frac{22B_h}{h_s} \right) + 5L_o + \left(\frac{4B_l(N_s - 1)}{16.67T_s} \right) \right] \text{mins} \quad (10)$$

where:

B_h = Container height (2.6m),

h_s = Hoist speed (m/min),

B_l = Container length (6.09m),

N_s = Number of containers in row,

T_s = Travel speed of SCs (km/h),

L_o = Container lock – on / lock – off time (min), and 16.67 is a constant converting km/h to m/min.

iii) 5.3 Productivity of Transfer Vehicles

The value of the productivity of container transfer equipment such as AGVs, SCs, RTGs, Rail Mounted Gantry cranes (RMGs), Reach Stackers (RSs), tractor-trailers *etc.*, can be defined in the same way as QSCs as follows (Maguire, 1986):

$$S_{tra} = \frac{\alpha \times \gamma_{tra} \times 3600}{T_{tra}}$$

where:

T_{tra} = Theoretical cycle time of container transfer equipment in seconds,

γ_{tra} ($\gamma_{tra} < 1$) = Coefficient to convert theoretical cycle time to actual transfer time,

α = Coefficient to convert container units to TEU in which $\alpha = \frac{(200-B)}{100}$ or $\alpha = \frac{(200)}{(100+B')}$,

B = Ratio of 20 foot containers to the total number of containers in units in percentage, and

B' = Ratio of 20-foot containers to the total number of containers in TEUs.

The theoretical cycle time for ASCs can be obtained in a similar way to QSCs. Most of the theoretical cycle times given by the designers of ASCs do not take into account the time required by the cranes to move from one block, row or lane to another. This is due to the different layouts, traffic rules and operational policies employed by different container terminals. Therefore, γ_{tra} would always be less than 1. On the other hand, it will be difficult to exactly calculate the theoretical cycle times of AGVs, SCs, tractor trailers, *etc.* because those values will greatly depend on the layout and area of marshalling yard and the route layout and distance travelled by such transfer equipment to and from the quayside to the stack yard.

iv) 6 Conclusion

This study has analysed the cycle time and the productivity enhancement of container terminal operation and problems associated with containers loading / discharging and stowing operations.

This manuscript illustrated that installing existing quayside cranes with semi-automatic manoeuvring features is not only technologically feasible, but would also enhance a potential improvement in productivity. The promise lies mainly in the ability of the port operators, especially for ports in the developing countries to upgrade the majority of their existing cranes. Eventually, the initially limited purpose of a semi-automatic manoeuvring system will gradually transform QSC into more efficient, user-friendly and safer cargo handling equipment.

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Full automation of the QSCs is at its infancy and developments towards such a policy should first solve the following two sets of problems:

- Vessel movements (yaw, roll, pitch, sway, surge and heave).
- Praying effect and racking stresses of the crane due to high-speed winds and load snag.

A comprehensive analysis was conducted to discuss the productivity of quayside operation. Taking into account that the productivity of the loading and discharging operation is directly proportional to the availability of the transfer vehicles at the quayside, the study has proposed the concept of productivity values to determine the optimum number of transfer vehicles required to be dedicated to a container vessel while at the quayside.

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