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Productivity of Container Terminal Operations Through Automation

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SUMMARY

This study identifies productive movements of containers and examines the productivity of container stacking and retrieval operations in container terminals using automated yard gantry cranes. It uses the indices of accessibility and introduces a comprehensive definition for the productivity of container terminal operation. This study sets up a basis for the enhancement of productivity and utilisation of time and spaces in the modern container terminals. It is argued that a considerable saving in the cycle time and re-handlings of containers can be achieved by the enhancement of the stacking blocks. Reducing the cycle times will help the gantry cranes to significantly contribute in the reduction of the turnaround time of containerships at container terminals.

Keywords: Container Terminal Productivity, Container Stacking, Retrieval and Cycle-Time

1 Introduction

The general movement of all containers within a container yard can be analysed from their productivity point of view. These movements can be categorised into productive and unproductive moves. This study sets up a basis to provide a value of productivity for every container movement in a dynamic condition. The value of productivity can be assigned to containers stacked in the container yard in a static condition too. This means, without considering the movement of containers, they can be given a value of productivity to indicate their retrievability by the yard gantry cranes. Most of the studies carried out on container yard automation technologies do not incorporate the productivity values of the equipment used in terminal operation. This study sets up a basis for incorporating the productivity value and the cycle times for yard gantry cranes such as Automated Stacking Cranes (ASCs), Rail Mounted Gantry Cranes (RMGs), Rubber Tyred Gantry Cranes (RTGs) and Overhead Bridge Cranes (OHBs) used in automated and semi automated container terminals to serve the new generation of the containerships. It will assist the terminal managers in their decision making to plan and or redesign their transfer and stacking sequences of operation to keep pace with the technological changes. The objective of using automated yard gantry cranes along with advance container identification and positioning systems in the container yard is to provide a fast, systematic, safe and reliable stacking and un-stacking of containers with a minimum number of re-handling and shuffling moves. This study argues that the time taken to re-handle, shuffle, retrieve and transfer containers by transfer and stacking equipment can be analysed by providing productivity values to containers in a dynamic or a static condition at different positions in the stacks. Depending on the number, type and stacking capability of gantry cranes, the layout and distance of stacks from the vessel and the density of stacks, the productivity values assigned to any individual container, row or module block in any designated location will be inversely proportional to its cycle time. Therefore, the higher the productivity value becomes, the smaller the cycle time will be.

2 Literature

Bedall and Stent [1] and Masterman [2] have discussed the effect and the impact of new technologies in promoting the productivity of shipside operation. Daganzo [3], Blackstone [4] and Chen [5] have shown how maximum land utilisation can be achieved by stacking container higher. However the have not mentioned how to reduce or at least stop the increase in the cycle times of retrieving containers as stacking height increases.

Vaziri, Khoshnevis and Cadavid [6,7,8] have provided an overview of a research on the effectiveness of integration of automated container yard cranes and an Automated Guided Vehicle (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 [9,10] has 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 handling and transfer times of the containers. Fagerholt and Gupta [11,12] have provided a general discussion of different productivity related objectives in container terminals. Additional works giving more or less general descriptions on the productivity of container terminals have been reflected in [13,14,15,16,17,18,19]. Jula et al [20] have 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 Quayside Crane (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. The discussion of stacking and retrieving operation in this study is based on the method discussed by Watanabe [21] for RTGs. Figure (1) illustrates a simple example of a container terminal with RMG or RTG system with a capacity of 18 module blocks consisting of 15 rows and capable of stacking 6 containers in a row and having a traffic lane for access of transfer vehicles for stacking and retrieving purposes.

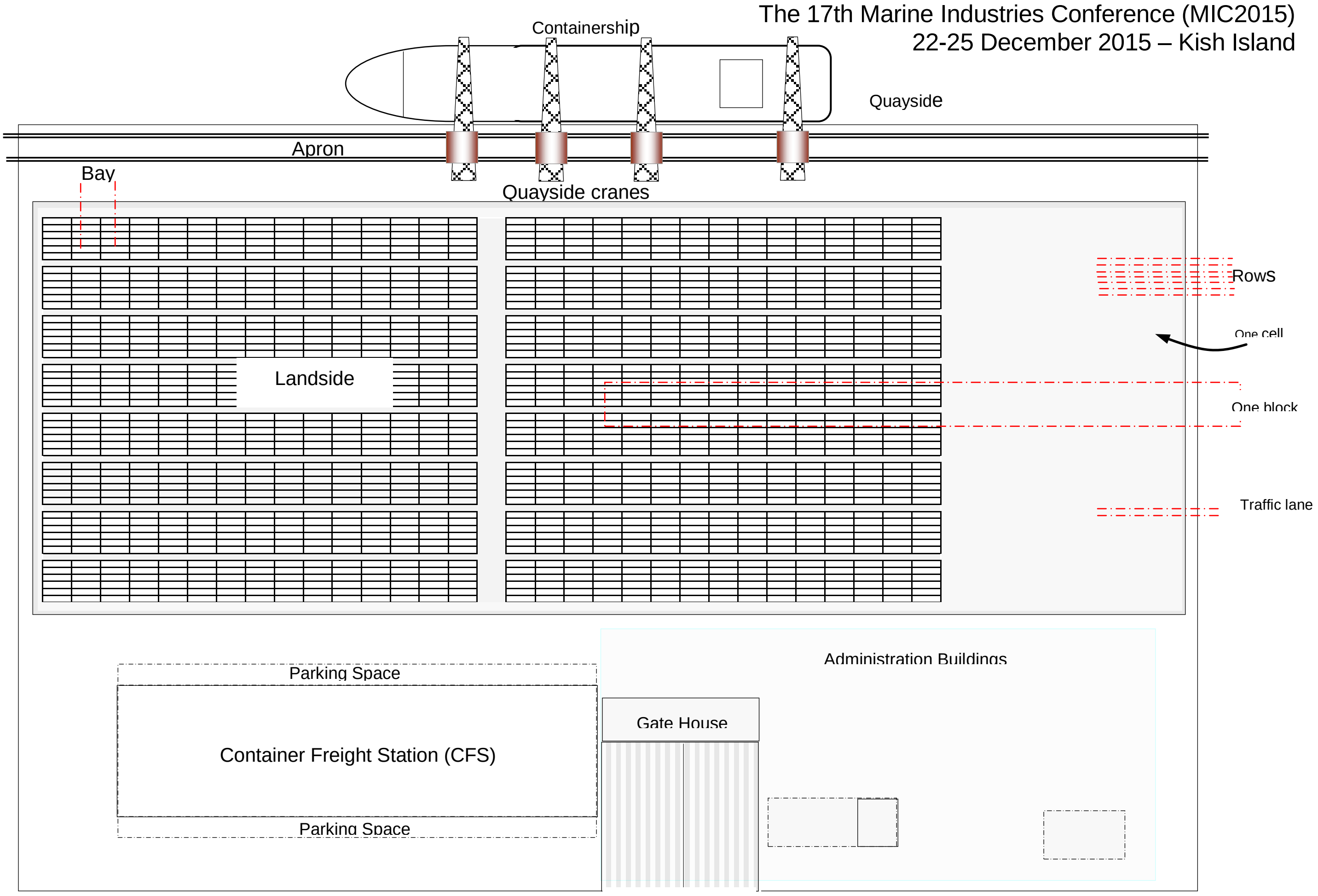


Figure (1) The layout of a typical container terminal with yard gantry crane system

In the above figure, the containers are laid with their length parallel to the wharf direction. The layout, terminal operating systems and the type of stacking equipments used in container terminals generally determine the length and shape of the blocks. The following terms are distinguishable from the above figure:

- "Container cell"[1] is any space which is occupied by one container box;
- "Row" shows a number of container cells under the portal of a gantry crane in a sectional view;
- "Tier" represents a number of containers stacked vertically in a row;
- "Bay" is the number of containers cells in a row shown in a longitudinal view and
- "Block" consists of a group of container row, bay and tiers that a gantry crane drives over them along its pathway according to its stacking span and height capabilities.

3 Movement of containers in container terminals

The general movement of all containers within a container terminal can be analysed from their economic and productivity point of view. The movements can be categorised as "productive" and "unproductive" moves. Figure (2) shows the subcategories that can be derived from the above two main groups.

[1] Also known as "container slot".

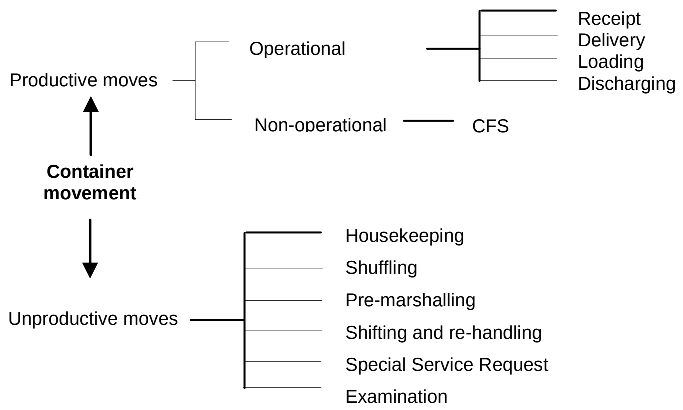


Figure (2) Categories of container movements taken in the yard

3.1 Productive moves

Productive moves are the minimum continuous movements of containers that can be counted as revenue generating moves in the process of terminal operation. These movements are absolutely essential since containers cannot be transferred, stacked, loaded or discharged and / or transhipped properly without making them. All other movements can be categorised as unproductive and therefore non-revenue generating moves. An example of productive moves can be the export containers that are received into the container yard and loaded into the containerships, therefore, the ‘receipt moves’ and the loading moves are productive movements. In the same way, Import containers are stacked in the stack yard and then delivered to the inland hauliers, thus, the ‘discharge’ and ‘delivery’ moves are also productive. Therefore, in the operation of container terminals, productive move are those moves that are relevant to the shipside and the gate operations. There are some processing moves within the container terminals that also can be counted as productive moves, even though they are not related to the shipside and gate operations. An example of these moves is the moves required to be taken to stuff or un-stuff containers in the Container Freight Station (CFS). Productive moves can be divided into operational and non-operational categories according to their relationship to terminal operations.

3.1.1 Operational moves

Operational moves are the optimum movements of containers relevant to the gate operation and the containers that stacked / un-stacked in the stacking blocks for the shipside operation. The operational moves can be sub-categorised as follows:

- **Receipt moves** are the movement of export containers that are received by the terminal operators. Yard gantry cranes pick up the export containers from the rail / road hauliers or from the gate buffers and stack them into the container yard.
- **Delivery moves** are the movement of import containers that are delivered to the inland carriers. In this operation, the import containers will be un-stacked by the yard gantry cranes from the import blocks and will be delivered to the inland hauliers.
- **Loading moves** are the movement of the export containers in which containers are transferred from the yard to the quayside and loaded into the containerships. In this operation, the yard gantry cranes retrieve the export containers from the export blocks according to the loading sequence and load them on to the transfer vehicles.
- **Discharge moves** are the movement of import container that are discharged by QSCs from the containership to the transfer vehicles and then moved to the stack yard. Yard gantry cranes will pick-up the import containers from the transfer vehicles and stack them into the storage slots in the import blocks.

3.1.2 Non-operational moves

The non-operational moves are the optimum movements of containers that are neither relevant to the gate and or to the shipside operations, but are the productive moves that play an important role in the terminal operations. These moves are as follows:

- **CFS moves** are the movement of some empty containers to CFS for stuffing and shifting them to the export stacks. It includes the movement of some import containers to CFS for un-stuffing and shifting the empty containers into the emptys' pool.

3.2 Unproductive moves

Unproductive moves are the extra processes and movements of containers in the container terminals that are imposed by some internal and external factors. Well before the arrival of a containership and commencement of loading operation, the export containers will be shuffled to match the best loading sequence. On the other hand, before the comment of discharging operation, some container re-handling movements would be taken to prepare the storage space available for the incoming import containers. The majority of the above movements are unproductive which can be described follows:

- **Housekeeping moves** are the moves taken for the purpose of recognising the stacking condition of the containers in the yard are called housekeeping moves [22].

The unproductive housekeeping moves are taken in both the import and export stacks. In the export stacking area, the housekeeping movement of containers involves collecting the scattered boxes of containers and relocating them according to their status. In the import stacking area, extra re-handling operations would be carried out to make storage space available for the stacking of expected inward import containers. Quite often, unproductive moves would be taken to collect any scattered containers in the yard to stack them into their designated stack locations. This will provide more ground space available for storage planning.

- **Shuffling moves** are the unproductive moves, which are taken by the terminals adopting the 'sort and store' strategy in the receipt operation [5]. This will require the terminal operators to examine to organise the condition of the export stacks well before the arrival of any containership. Disorganised or haphazard containers will require shuffling or even reshuffling to sort them into a proper stacking sequence to minimise the re-handling moves during the loading operation. Fore example, container terminals with multiple quays but with one export stacking area may experience that containers with different ports of destinations may have been stacked mixed. Upon the availability of yard gantry cranes, shuffling and reshuffling moves would be used to sort the export containers into a more organised stacking condition and a more efficient loading operation will therefore ensue.

- **Pre-marshalling moves**. Terminals that implement the receipt strategy of 'pre-marshalling' will re-position the export containers for the ship to a 'pre-marshalling area' with a well-planned storage sequence before the arrival of the containership [22]. In this case, it will be required to have a buffer area near the quay apron for this purpose. Containers stacked in export stacks can therefore be stacked higher and mixed, because they will be shuffled later in their repositioning to the pre-marshalling area. However, adopting the pre-marshalling strategy will have a disadvantage. The disadvantage will be the need for longer hours of preparatory work and a huge working capacity and engagement of yard equipment before the arrival of the containership. This will require the terminal operators to efficiently transfer all the export containers for the loading vessel into the pre-marshalling area within this preparatory period.

- **Shifting and re-handling moves**. Most of shifting and re-handling moves are carried out during the delivery operation. Most of the container terminals serve the road and rail hauliers on First Come First Served (FCFS) basis. This will make the random delivery of some target import containers difficult since in order to gain access to containers beneath some others, the containers stacked above them have to be shifted and re-handled first. When poor planning of storage is prevalent during a loading operation, the shifting and re-handling moves would be required to be taken too. As a consequence, extra unwanted moves will be required to remove containers stacked above others. A more detailed discussion about this fact will be carried out later in this study.

- **SSR moves**. Special Service Request (SSR) moves are the movements of containers requested by the shipping lines [22]. Any change in the status of containers may require additional movement of containers in the container terminals. This will require some containers to be un-stacked, re-handled and relocated from their original positions into a new location.

- **Examination moves** are the additional movement of some containers in the container yard that may be requested randomly by customs for inspection. Consequently, these containers will be un-stacked and transferred to an inspection area. After the inspection procedures, they will be re-handled back to their previous stack yard.

The objective of classifying container movements into the productive and unproductive movements discussed in this study is to identify the operations which impose extra time and effort to terminal operators. Automation of container terminal operations to guarantee a faster, reliable and safer movement of containers together with the utilisation of space and resources will require the unproductive moves identified in this study to be kept to a minimum.

4 Container accessibility and re-handles

A more profound study of productivity for containers, container rows and module blocks will help the terminal operators to properly position individual boxes with a minimum number of container re-handling and shuffling movements. The analysis is based on the illustrations presented by Watanabe [21]. Figure (3) shows a profile view of a normal stacking arrangement of a yard gantry crane with a span of 6+1 containers (six container rows and one container traffic lane) and a lift height of 1 over 4 that indicates the ability of the crane to stack one container over the fourth tier.

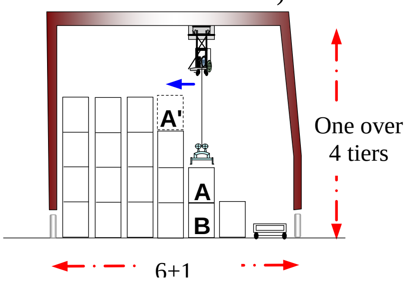


Figure (3) Profile view of a yard gantry crane

The above figure, illustrate a problem in which the yard gantry crane has to perform an extra re-handling move to retrieve container B on to the transfer vehicle waiting in traffic lane. Three alternatives exist for the crane. These options are:

1) To re-handle the blocking container (container A) within the same row in to a new position in another tier and cell above any other container, e.g., position A',

2) To re-handle container A within the same block into any available slot longitudinally along the block to another row and

3) To re-handle container A with the use of a transfer vehicle and moving it to an adjacent and neighbouring block to relocate it into a new position.

The second alternative will demand a higher manoeuvring time, hence cycle time, compared to the first alternative. Similarly, re-handling of container A by using a transfer vehicle to an adjacent neighbouring block requires much higher cycle time compared to the first and second alternatives. Moreover, even though the re-handling of the blocking container in the first alternative is possible in OHBs, ASC, RTG and RMG systems, the re-handling operation would not be easily possible with all of these systems for the second alternative. The reason for this is that RTGs are not normally allowed to make long travels with containers. Therefore, RTGs will preferably perform the first alternative but not transversal movements since they are bonded to move along their rail truck ways. Consequently, a transfer vehicle will be required to shift the blocking container into an adjacent or neighbouring block. In general, export containers are loaded according to the stowage plan sequence based on container data such as class, size, weight, destination port sequence, etc. To maximise the productivity of the operation, the loading sequence has to be performed with the minimum re-handling and shuffling container moves. On the other hand, import containers are generally positioned in the order they are discharged from the vessels. When transfer vehicles deliver these containers to inland carriers at the road and rail interfaces, accessibility is a serious operational problem. This is due to the fact that road trucks and train wagons that arrive at the interfaces in a random order will not be correlated with the location of the stacked containers. To deliver any specific container to the inland interfaces, some containers have to be re-shuffled and re-handled several times. The time taken for these unwanted moves will cause costly delays in the loading operation of the export containers. In addition, delays would be transferred to the hauliers as they are usually served on FCFS basis. These additional delays would be very significant for the hauliers. The need to access designated containers in the stacks has been examined qualitatively [16]. However, to analyse this problem, use must be made of quantitative methods 9,17,21,23]. The study introduces a solution to the above problem.

4.1 Retrieval of containers in a dynamic situation

Retrieval of stacked containers in any container terminal is inextricably tied to the design and layout of the container stacking blocks [21]. The manoeuvrability, scantling characteristics and vertical stacking capability of container handling equipment also play an important role enhancing an efficient stacking and retrieving operation. RTGs have higher manoeuvrability than Overhead Bridge Cranes OHBs, RMGs and ASCs. However, RTGs cannot make long travels with the containers since their flexibility will be reduced while they are loaded. This section of the study discusses the problem of retrieving containers in a highly dense and congested container rows in a dynamic situation. From the terminal operators' point of view, there is a distinction between a full row and a dense and congested one. An example of a full row is illustrated in Figure (4) which can help to visualise a full module row. In Figure (4) there are 21 spaces available for stacking. Sufficient space must be allowed for the spreader of the gantry crane to move and shuffle containers and to allow access for any other container in the lower tiers.

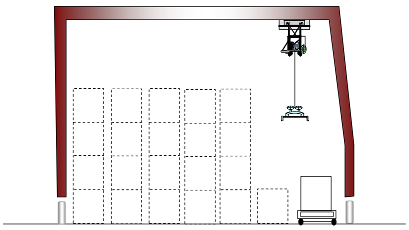


Figure (4) Profile view of a full row

If more than 21 containers are stacked then the row becomes dense and requires a detailed examination in order to finding probable solutions for utilisation of the available spaces and reduction of re-handling and shuffling operations.

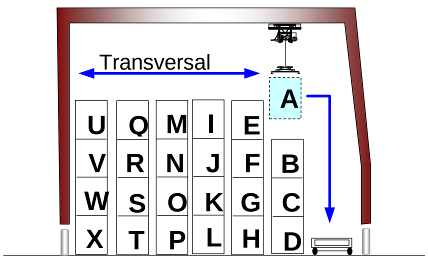


Figure (5) Retrieving a container in a densely stacked row

Figure (5) illustrates a very dense stacking situation for a yard gantry crane. It is obvious that container A can be retrieved to the traffic lane without any difficulty. Therefore, container A can be assigned a productivity value = 1.

Similarly, containers E, I, M, Q and U can be retrieved in the same way as container A and therefore, each can be given a productivity value = 1. Figure (6) illustrates a situation where container B is to be retrieved by the yard gantry crane.

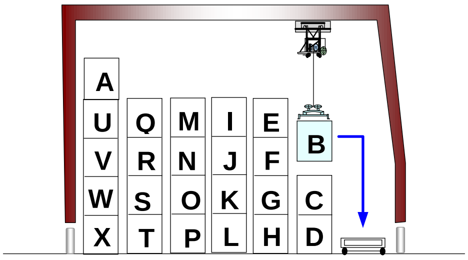


Figure (6) Retrieving container B

To retrieve container B, container A that is located above it has to be re-handled first. Re-handling of container A in order to retrieve container B is an unwanted and unproductive move. Therefore, a reduction in the value of productivity for container B should be considered. Container B can be given a productivity value of ½. In this case, container A would not normally be re-handled back to its original position. Where a container is covered by two other containers, they will both be moved in order to access the required container. In this case, they are normally put to the fifth tire and the container requiring access is given a value of ⅓. Where three containers are to be moved to provide an access to a required container, then a productivity value of ¼ is assigned. Similar to container B, any of containers F, J, N and R can be un-stacked with re-handling and relocating of the containers above them in such away that they would not block the access of other containers to the traffic lane. Therefore, each of containers F, J, N, and R can be given a productivity value = ½. To retrieve container V, container U above it must be re-handled first. Relocating container U to any location above the other containers in the same row will block the way of container V to the traffic lane. This occurs due to the height limitation of the yard gantry crane. Figure (7) illustrates this problem.

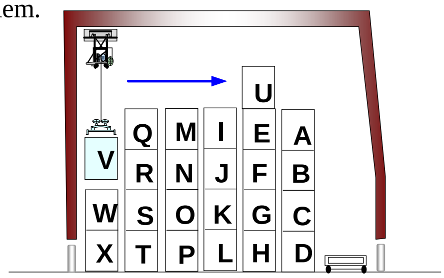


Figure (7) Retrieving container V

In this case, it is impossible to retrieve container V without shifting of container U to the traffic lane and blocking it or a longitudinal movement (forward or aft-ward) of crane to re-handle and relocate container U into any of the adjacent and neighboring row or block. To avoid scattering the group of containers, especially export and reefer containers and avoid a probable confusion from misplacement of these containers, they are normally re-handled back to their original rows. Therefore, container V would be given a productivity value of ½ × ½ = ¼, that is, ½ for re-handling of container U and ½ for re-handling and restoring the container U back into its original row. In Figure (8), to retrieve container C, it is obvious that two additional unproductive moves for containers A and B would be required. Since these two containers can be positioned above the other containers in the same row (i.e., above containers U and Q), a productivity value of ⅓ can be given to container C.

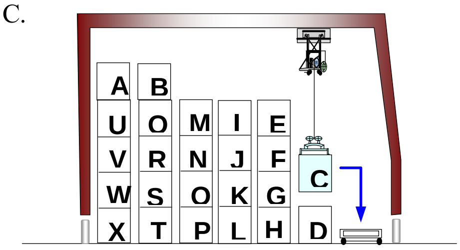


Figure (8) Retrieving container C

In the same way, containers G, K and O will be given a productivity value of ⅓ each. However, there will be a problem to retrieve containers S and W. Figure (9) illustrates the problem of retrieving container S.

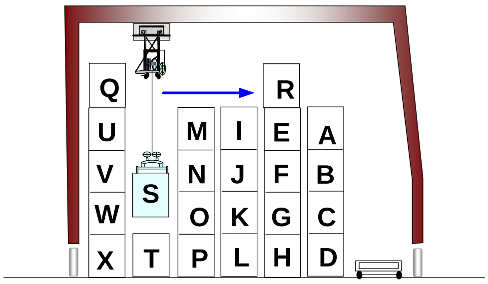


Figure (9) Retrieving container S

The difficulty is that only one container can be relocated above container U and the other one has to re-handled and stored temporary into an adjacent or a neighboring row or block. In this example, container S will be given a productivity value of $\frac{1}{6}$ that is the product of ⅓ for re-handling of container Q and R and ½ for re-handling of container Q or R to an adjacent or neighboring row or block and re-handling it back to its original position after container S is retrieved. However, retrieval of container W in Figure (10) would be more difficult since both containers above it have to be relocated into adjacent rows. In this case, container W will be given a productivity value of $\frac{1}{9}$ that is the product of ⅓ for relocating and re-handling of containers U and V and ⅓ for restoring containers U and V back to their original position after container W is retrieved.

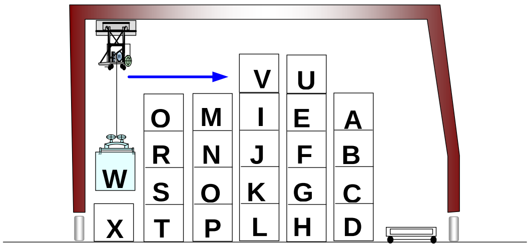


Figure (10) Retrieving container W

In this system of assigning productivity values, each of containers D, H and L would be given a productivity value of ¼.

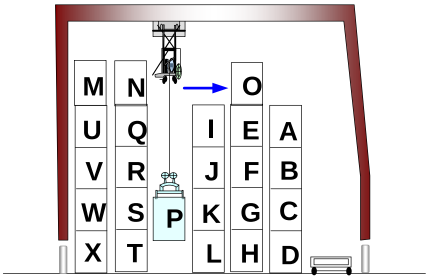


Figure (11) Retrieving container P

Figure (11) shows that to retrieve container P, only one of the containers above it has to be re-handled to an adjacent row or neighboring block and the other two can be accommodated above containers U and Q. The productivity of container P would be a product of $\frac{1}{8}$ (¼× ½) that is the product of ¼ for re-handling of containers M, N and O and ½ for restoring one of these containers back to its original location.

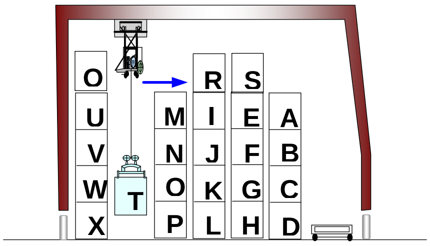


Figure (12) Retrieving container T

On the basis of the above considerations, the productivity values for containers T in Figure (12) would be $\frac{1}{12}$ (¼ × ⅓), that is ¼ for moving containers Q, R and S and ⅓ for moving and restoring at least two of these containers back into their previous positions. In the case of container X, as shown in Figure (13), all of the containers above it should be relocated into the adjacent row or neighbouring block. Therefore, container X would be given a value of $\frac{1}{16}$ (¼ × ¼) that is ¼ for removing all the containers above it and ¼ for restoring them back to their original row.

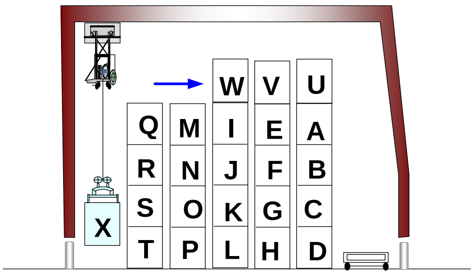


Figure (13) Retrieving container X

Table (3) provides a summary of productivity values for the module block discussed in this study. The number of container re-handles that can be considered as unproductive moves are given for every individual container in the module block. From the table, it can be concluded that the higher the number of moves require to access any container become the lesser the value of productivity will be. In addition, any increase in the number of container movement indicates an increase in the cycle time of retrieving containers. Therefore, the value of productivity would be inversely proportional to the cycle time required to re-handle, shuffle and remove containers from the stacks. This means that any attempt to reduce the cycle time of retrieving containers by reducing the number of re-handling and

shuffling moves will result in and produce a higher value of productivity. Automated technologies employed in container terminals are aiming to process containers faster, safer and accurately with the minimum cost as possible. Utilisation of time and spaces and maximisation of productivity value would be possible by accurate identification and positioning of containers and a precise calculation of the minimum number of unproductive moves of containers.

Table (1) Summary of productivity values of individual containers and required number of re-handles for a gantry crane with 6+1 containers span and a lift height of 1 over 4

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
S_{ret}	1	½	⅓	¼	1	½	⅓	¼	1	½	⅓	¼	1	½	⅓	⅛	1	½	⅙	1/12	1	¼	1/9	1/16
No. of container re-handles	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	2 + 2	0	1	1 + 2	1 + 4	0	2	4	6

4.2 Formulating the value of productivity

The productivity of a row and or module block can be defined and obtained by the following equation [24]. Let S_{con} represent the productivity value of retrieving the target-stacked containers, therefore;

$$S_{row} = \frac{\sum_{n=1}^{N} S_{con}\ (n)}{N_{row}} \tag{1}$$

where, N= Number of containers stacked in the row, S_{row} = Productivity of a module row, S_{con} (n) = Productivity value of container (n) in the module row and , N_{row} = Total number of containers stacked in a row. Example: The productivity of the module row illustrated in Figure (5) and Table (1) consisting of six container rows and four container tiers can be obtained by the following process:

$$S_{row} = \frac{\sum_{n=1}^{N} S_{con}\ (n)}{N_{row}},\ S_{row} = \frac{S(A+B+,...,\ +X\ )}{N_{row}}\ ,\ S_{row} =$$

$$\frac{S(1+\tfrac{1}{2}+\tfrac{1}{3}+\tfrac{1}{4}+1+\tfrac{1}{2}+\tfrac{1}{3}+\tfrac{1}{4}+1+\tfrac{1}{2}+\tfrac{1}{3}+\tfrac{1}{4}+1+\tfrac{1}{2}+\tfrac{1}{3}+\tfrac{1}{8}+1+\tfrac{1}{2}+\tfrac{1}{6}+\tfrac{1}{12}+1+\tfrac{1}{4}+\tfrac{1}{9}+\tfrac{1}{16}\ )}{24}$$

$$S_{row} = \frac{11.382}{24} = 0.474$$

The above study indicates that the productivity of any individual container may vary as containers are progressively retrieved from the stacks. Consequently, this will have a direct effect on the productivity of the entire row. When containers are stacked to only one tier, then the productivity of a row becomes 1. This implies that every container in the row can be retrieved without any re-handling. Although a productivity value of one in a row is possible, a zero value of productivity for a module row will never happen. This study believes that every container will always retain a positive value of productivity the magnitude of which would depend on the location of it in the tiers, column and height limitation of a gantry crane. This would mean that the target container would be retrievable even under the worst stacking situation. This can be illustrated in Figure (14).

4.3 Relation between the value of productivity and the number of re-handles

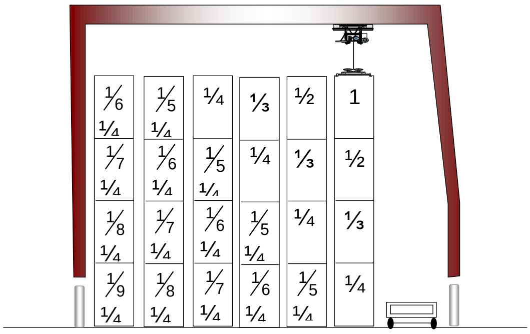
It is possible to determine the expected number of container re-handling moves from the value of the productivity of a target container located in a row. To retrieve a single container, the number of re-handling moves can be defined as:

$$E[R] = S_{con}(n) \times \ (N^2 - N) \tag{2}$$

where; N= Number of container tiers in a row, S_{con}= Productivity value of a target container in a module row and $E[R]$ = Total number of re-handles required to retrieve a container.

4.4 Retrieval of containers in a static situation

The examples shown in Figures (14) and (15) illustrate the statical productivity of containers in yard gantry crane system with a span of 6+1 and stacking capability of 1 over 3 and 1 over 4. A static situation is a situation in which container movements to the adjacent rows and blocks are not considered. In this situation containers are picked-up randomly where no containers will be added to the bay under the analysis until all containers are retrieved. Therefore, the values assigned to any container only indicate the number of re-handling moves within a row that are required to access any required container. The situation shown in Figure (14) may be allowed by the terminal operators in empty and transshipment containers. The maximum productivity value of this system is 0.261.



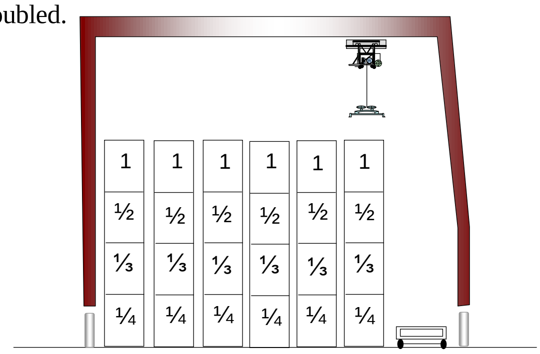
$$S_{row} = \frac{\sum_{n=1}^{N} S_{con}(n)}{N_{row}}$$

$$S_{row} = \frac{4 + \frac{4}{5} + \frac{2}{3} + \frac{3}{7} + \frac{1}{4} + \frac{1}{9}}{24} = 0.261$$

Figure (14) Productivity value of containers in a yard gantry crane system with a span of 6+1 and stacking capability of 1 over 3

4.5 Improvement of the productivity in yard gantry crane systems

An increase in the height of the gantry crane will increase the productivity value of container rows. Let's consider the same crane in Figure (14) but with a stacking height of 1 over 4. All containers would be easily retrievable. In this case, the productivity value of the system would be doubled.



$$S_{row} = \frac{6 \times \left(1 + \frac{1}{2} + \frac{1}{3} + \frac{1}{4}\right)}{6 \times 4} = 0.521$$

Figure (15) Productivity value of containers in a yard gantry system with a span of 6+1 and stacking capability of 1 over 4

Even a higher productivity is possible for the illustration of Figure (15). An observation from ASC system in the Thamesport Container Terminal showed that maximum land utilization can be obtained in empty and export containers. The terminal operators arrange the stacks in such away that they fully stack containers even inside the traffic lanes as well as stacking slots. At each end of the blocks, a space is left available for lorries to be loaded and un-loaded. In this case, the traffic lane provides a surplus value of productivity for which its lane would not be counted for calculation. The example of this is illustrated in Figure (16).

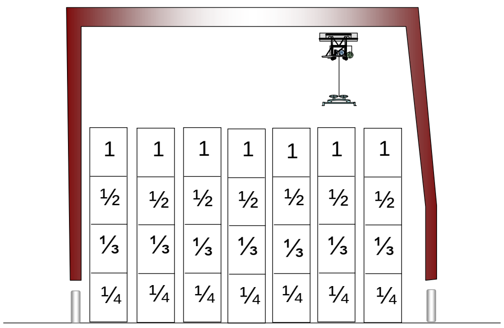


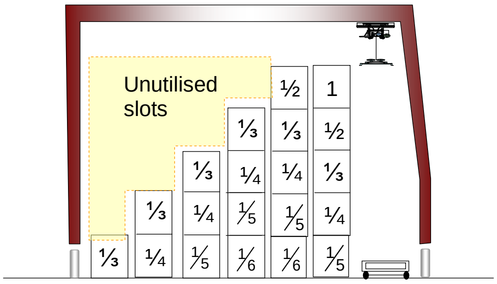
Figure (16) Productivity value of stacking container in the Thamesport Container Terminal

However, a higher utilisation of space and a value of productivity are obtained in the expense of sacrificing the number of re-handles

and the ease of retrieving a target container. In cases where all the neighbouring rows and blocks have the same dense condition, the blocking containers have to be re-handled to an empty space outside of their present location.

4.6 Avoiding mistakes in the process of stacking

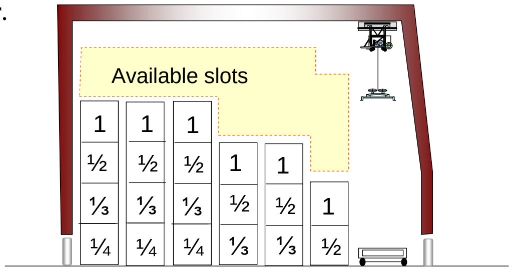
Figure (17) illustrates a situation where 10 slots are left unutilised. It clearly shows that containers that are stacked in the columns other than the first column in the right-hand side of the figure are inaccessible and therefore are not easily retrievable. This will result in the individual productivity of the inaccessible containers and unutilised spaces to be reduced.



$$S_{row} = \frac{1+2\times\left(\frac{1}{2}\right)+6\times\left(\frac{1}{3}\right)+5\times\left(\frac{1}{4}\right)+4\times\left(\frac{1}{5}\right)+2\times\left(\frac{1}{6}\right)}{20} = 0.319$$

Figure (17) Wrong way of stacking in a yard gantry crane system

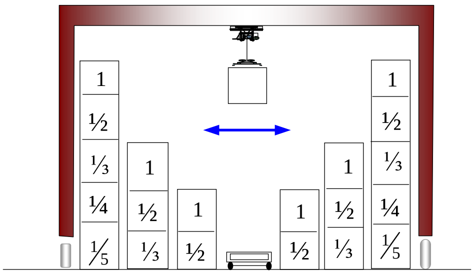
Figure (18) illustrates a correct form of stacking action for the position shown in Figure (17). If the terminal operator was only allowed to stack the containers to the opposite side of the traffic lane or the stack was limited by only four tiers, the productivity of the block could be higher.



$$S_{row} = \frac{6+6\times\left(\frac{1}{2}\right)+5\times\left(\frac{1}{3}\right)+3\times\left(\frac{1}{4}\right)}{20} = 0.571$$

Figure (18) Correct stacking

Although it is uncommon for import and export module block stacks to have a stowage appearance as shown in the row in Figure (17) or become fully sowed as illustrated in Figure (14), this may happen in empty and transshipment stacks. As a demonstration of the use of productivity index, consider a crane shown in Figure (14) with 1 over 4 6 wide RTG stack. The original value of productivity of the full module row was equal to 0. 261. The majority of container terminals with yard crane systems have their yard traffic lanes set in the inner left or right hand side of the crane legs. Figure (19) illustrates the same crane with the traffic lane shifted to the centre line. Shifting the traffic lane to the centre of the rows to provide easier access to containers and reducing the number of re-handles would double the value of productivity of the same row. This would result in a considerable reduction of retrieving or stacking cycle times.



$$S_{row} = \frac{\left(6+6\times\frac{1}{2}+4\times\frac{1}{3}+2\times\frac{1}{5}\right)}{20} = \frac{10.733}{20} = 0.537$$

Figure (19) Improved productivity of a row with the traffic lane shifted to center of the row

However, there is a drawback with this approach that the overtaking of transfer vehicles, which was probably possible before cannot take place due to the width of the lane. Nevertheless, recommending automated technologies to increase the productivity of transferring and stacking equipment would be better justified than horizontally expanding the area of land. It should be noted that land is scarce and expensive in many Asian and European countries. The former option is significantly possible by transferring containers safer and quicker, stacking higher and retrieving them quicker through advanced automated technologies in the yard. This in turn will result in a faster receiving and delivery operation and thus smaller turnaround of the containerships.

5 Conclusion

This study has analysed the productivity enhancement of container terminal operation and problems associated with retrieving and stowing operations. The movements of container in a container terminal are categorised as productive and unproductive movements. Productive moves are the necessary movement of containers in the process of logistics supply chain, which contribute towards revenue generating in container terminals. The study has also profoundly analysed the problems of stacking and retrieval cycle times at container terminals using yard gantry cranes by introducing the concept of productivity values for container retrieval and re-handling requirements. This analysis is carried out for containers in the static and dynamic conditions. It is concluded that the time taken to re-handle containers at lower tiers will depend on the type and stacking capability of equipment and the size and density of the stacking rows. It has been discussed that the cycle time taken to retrieve a container is inversely proportional to its retrieval productivity value. Therefore, the higher the productivity value, the smaller the cycle times will be. Minimisation of the cycle times can be achieved by maximising the productivity value of containers and container rows. The enhancement of the maximum productivity values will be required for operators who are aiming to establish automation technologies in their container terminals. To reduce the total cycle time for retrieving and transferring operation, the throughput performance of the automated RTGs is an important factor to consider. A large portion of activities in container yards results from re-handling other containers to pick-up a target container. This study has provided indices for retrieving containers using State Probability. It was demonstrated that a significant difference in the probability of retrieving containers in a stack would occur if the initial stacking configuration changes, while, the same number of containers in each stack remain unchanged.

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