MODELING AND ANALYSIS OF CONTAINER TERMINAL OPERATIONS CONTAINER STACKING DECISIONS

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ABSTRACT: This paper introduces the container stacking decisions in container terminals and some solution methods. Also, a case study in Eldekheila terminal is presented.
Keywords: container Terminal, operations research, container stacking, pre-marshalling.

INTRODUCTION

Generally, the stacking decisions of containers have three levels; strategic, tactical, and operational level. In the strategic level, decisions related to the layout of the container yard, equipment used, and the design of the container terminal must be made. In the tactical level, decisions such as the presence of a pre-stacking area should be made. While in the operational level, the identification of containers slots, and rehandling of containers are the decisions that have to be made. Rehandling decisions include remarshaling, pre-marshalling, and container retrieval problems.

The pre-marshalling problem is the problem of converting an initial layout of a bay into a desired final layout within which containers are stacked above each other with the priority of stacking the containers that will be served first at the top of the stack. This will minimize or eliminate future additional reshuffles by the YC. In the case of the container retrieval problem, it is desired to fetch a container from the bay with minimum number of reshuffles, and then remove another container and so on till the bay is empty. The container re-marshalling problem is a general case from the container pre-marshalling problem, in the re-marshalling problem, the initial layouts of a set of bays is converted to the desired final layouts of the bays, the bays are located in the same block. The three classes of the problem are of prime importance knowing that in large container terminals, the average number of movements made by yard cranes is 15,000 movements per day, which means that the reduction of such moves will dramatically improve operations and efficiency. Also, reducing the number of container movements will have a significant impact on operational costs.

Using Rail Mounted Gantry Cranes (RMGC), containers in the yard can only be accessed from the top. Therefore, they are served according to Last In First Out (LIFO) strategy. Therefore, a balance between the use of the yard area and the minimization of the container handling operations is needed. From one side, the limited area of the yard leads to the increase in the height of the stacks to maximize the number of containers that can be stacked in the yard. On the other side, the minimization of containers rehandles leads to the creation of new stacks.

Containers arrive randomly to the yard before being loaded to the vessel, and data related to these containers such as weight information may not be known at that time. However, the detailed loading sequence becomes available just before the loading process by a short time. By that time, the containers are stacked in a wrong order.

A stowage plan is the plan which determines the location of each container on the vessel. The location of a container is determined according to many factors such as: weight of the container, destination of the container, and type of goods transported in the container. This affect the locations of the containers in the yard, and as a result the container re-marshalling and the pre-marshaling have to be made. The scope of the thesis is the container pre-marshalling problem.

THE CONTAINER PRE-MARSHALLING PROBLEM

The berthing time of vessels is the generally accepted performance indicator in a container terminal. It is desired to minimize the berthing time of a vessel, which increases if containers are not stacked in the yard in a configuration that facilitates the work of both, the yard crane and the quay crane. In order to collect a container that is not located on the top of the bay, additional movements have to be made to change the location of the containers that are above the desired one in order to make it accessible. These additional movements are called ‘reshuffles’ and they consume much time leading to reduced work efficiency of the yard crane and quay crane especially during vessels loading operations. That is why containers may need to be re-ordered to improve their retrieval rate when it is time to pick them up from the bay. The re-ordering of containers problem is called the container pre-marshaling problem.

The container pre-marshalling problem (see figure 1) is the problem of converting an initial layout of containers in a bay into a desired final layout within which containers are stacked above each other with the containers that will be served first at the top of the stack while minimizing the total number of movements required to reach the final layout. This will minimize or eliminate the need for additional reshuffles by the Yard Crane (YC) when fetching the container for dispatching to the vessel [1].

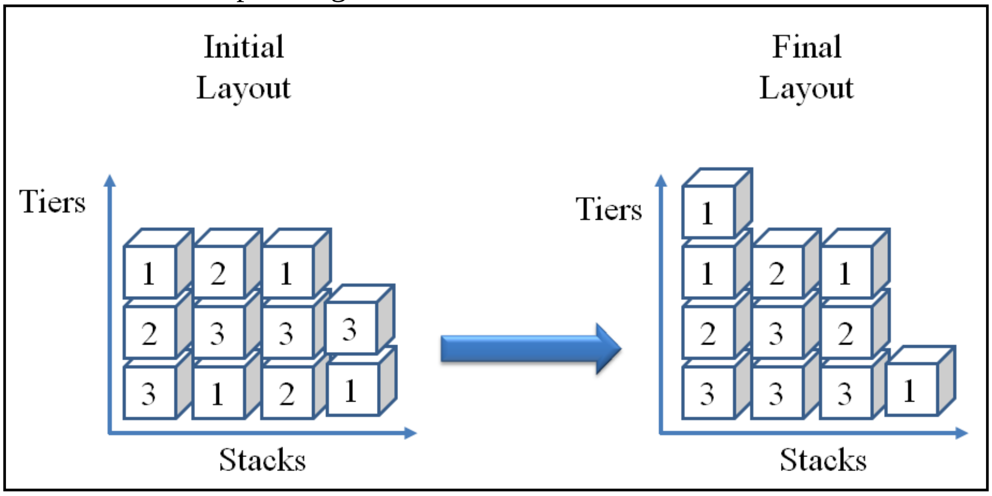

Figure (1) Input and output of the container pre-marshaling problem

CHARACTERISTICS OF THE CONTAINER PRE-MARSHALLING PROBLEM

The container pre-marshalling problem is restricted to the bay size (e.g. maximum width, and maximum height) which is determined by the yard crane dimensions. The maximum width of the yard crane determines the number of stacks, while the maximum height of the yard crane determines the number of tiers in the bay. Containers are grouped into categories, and each category contains a number of containers that have the same destination terminal. The categories are numbered based on their required handling priorities, the lower the number of the category, the higher the priority.

A cell lies in the intersection between a stack and a tier, and each cell can accommodate only one container. In order to get a container that is not on the top of the stack, additional movements have to be made to make it accessible. A yard crane can access only one container each time a movement is made. Figure 2 shows the characteristics of the container pre-marshalling problem.

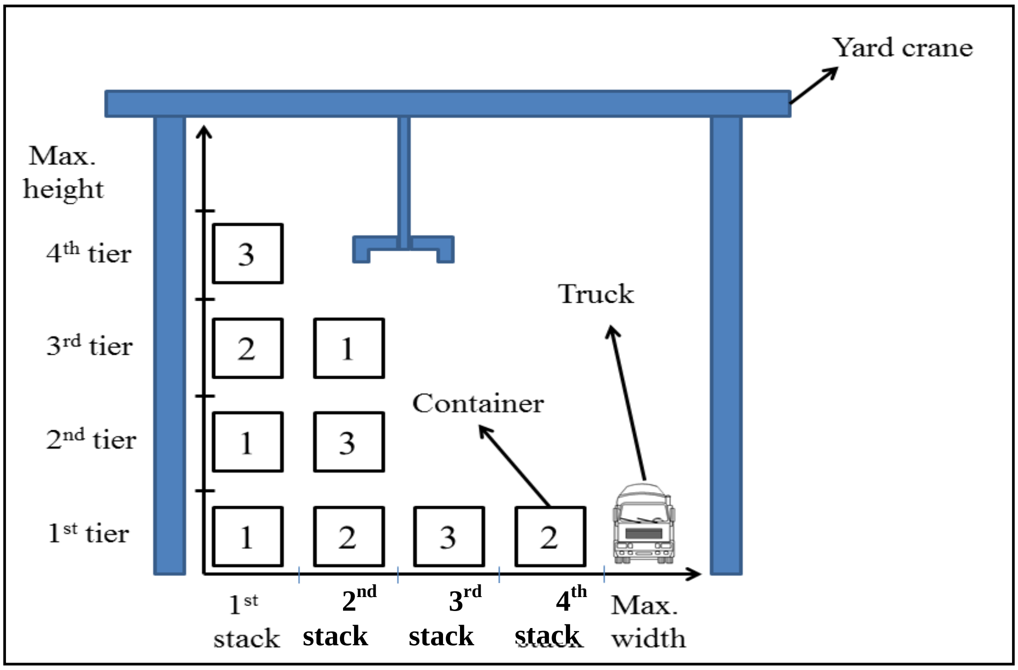

Figure (2) Characteristics of the container pre-marshalling problem

SOLVING THE CONTAINER PRE-MARSHALLING PROBLEM [2]

Solving the container pre-marshalling problem to optimality is typically done using mathematical programming. On one hand, this method is very effective, on the other hand, it is not efficient and very complicated to use. An example of a mathematical model is provided below:

Sets and parameters

$Time: set\ of\ time\ periods, Time = \{1,2,..,T\}$

$Cont: set\ of\ container's\ priority\ or\ categories, Cont = \{1,2,..,C\}$

$Slots: set\ of\ bay\ slots, Slots = \{1,2,..,S\}$

$N: number\ of\ containers$ in the bay

$n: maximum\ width\ of\ the\ bay\ (number\ of\ stacks)$

$H: maximum\ height\ of\ the\ bay\ (number\ of\ tiers)$

DECISION VARIABLEs

$$x_{ij}^{ct} = \begin{cases} 1, if acontainerwithprioritycismoved \\ fromslotitoslotjattimeperiodt, \\ wherei \neq j(movementarc) \\ 0, otherwise \end{cases}$$

$$y_{ij}^{ct} = \begin{cases} 1, if acontainerwithprioritycremainedinitslocation \\ attimeperiodt, wherei = j(no - movementarc) \\ 0, otherwise \end{cases}$$

$$f_{cj} = \begin{cases} 1, if acontainer \text{ with } prioritycisinslotjinthefinallayout \\ 0, otherwise \end{cases}$$

Objective function and constraints

$$Minimize \sum_c \sum_i \sum_{j \neq i} \sum_t x_{ij}^{ct}$$

$y_{ii}^{c1} \leq 1, \quad \forall c \in Cont, i \in Slots$ [1]

$\sum_c y_{ij}^{ct} + \sum_c \sum_{j \neq i} x_{ij}^{ct} \leq 1, \quad \forall t \in Time \setminus \{1, T\}, i \in Slots$ [2]

$\sum_c y_{ij}^{ct} + \sum_c \sum_{i \neq j} x_{ij}^{ct} \leq 1, \quad \forall t \in Time \setminus \{1, T\}, j \in Slots$ [3]

$$y_{ij}^{c1} - y_{ij}^{c2} - \sum_{i \neq j} x_{ij}^{c2} \leq 0, \qquad \forall c \in Cont, j \in Slots \qquad [4]$$

$$y_{ij}^{c(T-1)} + \sum_{j \neq i} x_{ij}^{c(T-1)} - y_{ji}^{cT} \leq 0, \forall c \in Cont, j \in Slots \qquad [5]$$

$$y_{ij}^{ct} + \sum_{i \neq j} x_{ij}^{ct} - y_{ji}^{c(t+1)} - \sum_{i \neq j} x_{ij}^{c(t+1)} \leq 0,$$
$$\forall t \in Time \backslash \{1, T-1\}, c \in Cont, j \in Slots \qquad [6]$$

$$\sum_c \sum_i \sum_{j \neq i} x_{ij}^{ct} \leq 1, \qquad \forall t \in Time \backslash \{1, T\} \qquad [7]$$

$$\sum_c y_{(i-1)j}^{ct} + \sum_c \sum_{j \neq i-1} x_{(i-1)j}^{ct} - \sum_c y_{ij}^{ct} - \sum_c \sum_{j \neq i} x_{ij}^{ct} \geq 0,$$
$$\forall t \in Time \backslash \{1, T\}, i \in Slots \backslash \{1, H+1, 2H+1, \ldots, (n-1)H+1\} \qquad [8]$$

$$\sum_c y_{(i-1)j}^{ct} - \sum_c y_{ij}^{ct} \geq 0$$
$$\forall t \in Time, i \in Slots \backslash \{1, H+1, 2H+1, \ldots, (n-1)H+1\}$$
[9]

$$\sum_c y_{i(j-1)}^{ct} + \sum_c \sum_{i \neq j-1} x_{\mathrm{i(j-1)}}^{ct} - \sum_c \sum_{i \neq j} x_{ij}^{ct} - \sum_c y_{ij}^{ct} \geq 0,$$

$$\forall t \in Time \backslash \{1, T\}, j \in Slots \backslash \{1, H+1, 2H+1, .., (n-1)H+1\} \qquad [10]$$
$$f_{cj} - y_{ij}^{cT} = 0 \qquad \forall c \in Cont, j \in Slots$$
[11]
$$\sum_c c * f_{c(j-1)} - \sum_k k * f_{kj} \geq 0,$$
$$\forall j \in Slots \backslash \{1, H+1, 2H+1, \ldots, (n-1)H+1\}, k \leq \mathrm{c} \qquad [12]$$

Other ways are also exist to solve the container pre-marshalling problem effectively and efficiently are based on heuristics [3]. One of these methods is based on Genetic programming. A software was developed based on genetic algorithm. The interface of the software is as shown in figure 3.

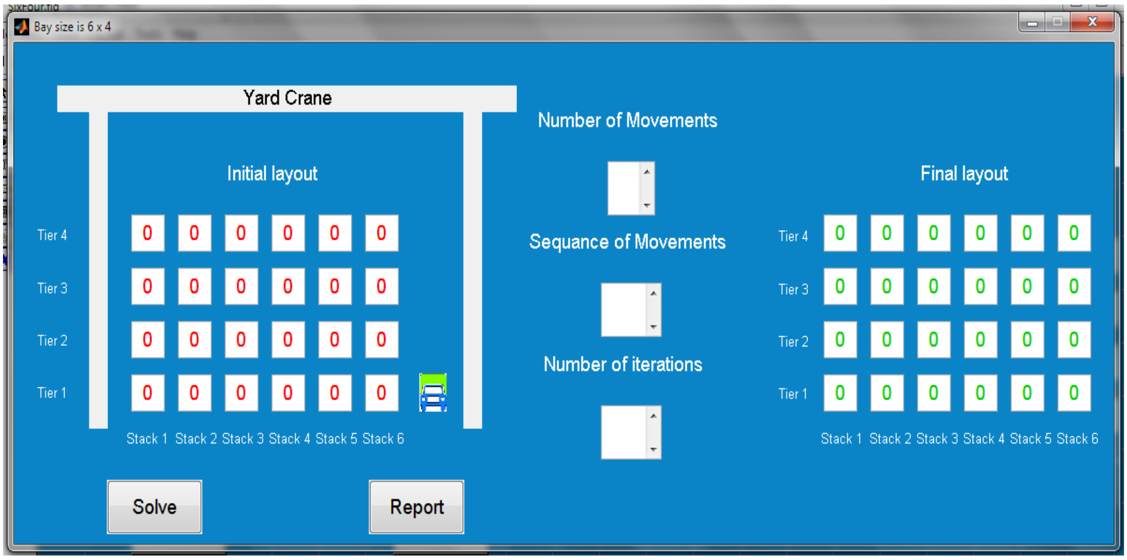

Figure (3) Interface of the software

In this software, the used just enter the initial layout of the bay, and once he click on solve, the final layout of the bay appears with the number and the sequence of movements required to reach such layout. After that, the user click on report button to make the software develop a report with all the information needed for the crane operator to execute the movements.

The software was used to solve a case study in Alexandria Container & Cargo Handling Company (ACCHC) which is located in Alexandria, Egypt. The results turns to be competitive. In the next section a detailed description of the applied case study.

Alexandria Container & Cargo Handling Company (ACCHC) is the first specialized container handling company in Egypt. It was established in 1984 to exercise all the activities related to container handling. The total throughput of the company in terms of TEU in the last 10 years is as shown in figure 4.

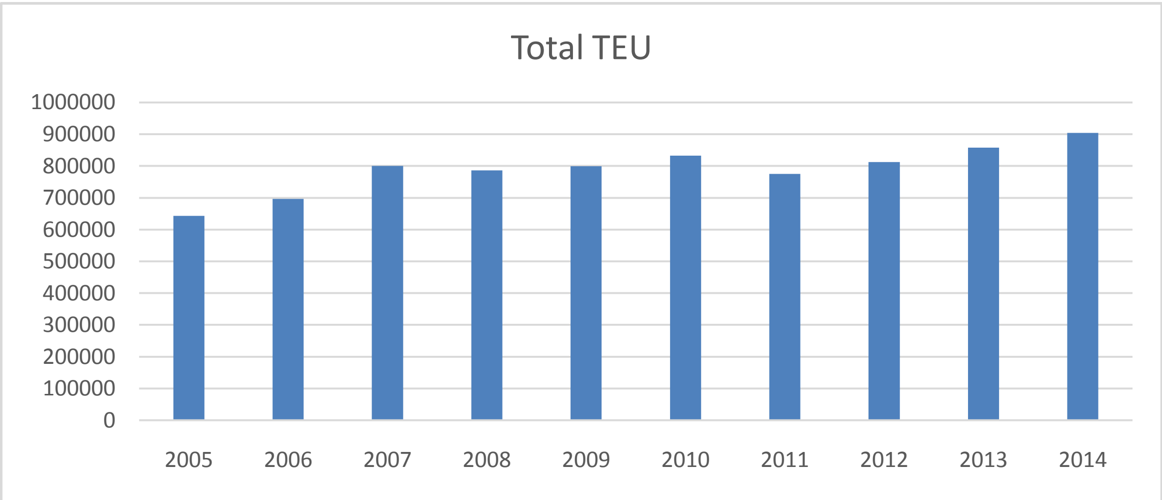

Figure (4) Company throughput in the last 10 years

The company operates two major terminals, the first is the Alexandria container terminal at the port of Alexandria and the second is El-Dekheila terminal at the port of Dekheila. Alexandria terminal has three berths for container vessels and one berth for RO-RO vessels. El-Dekheila terminal started operating in 1996 with one berth which accommodate 3 vessels at a time. The company obtained the ISO9002 certificate in February 1998 and the ISO9001-2000 QMS in 2003. It was also granted the certificate of Occupational Health & Safety Assessment Series Q.H.S.A.S-180001/99 in 2004.

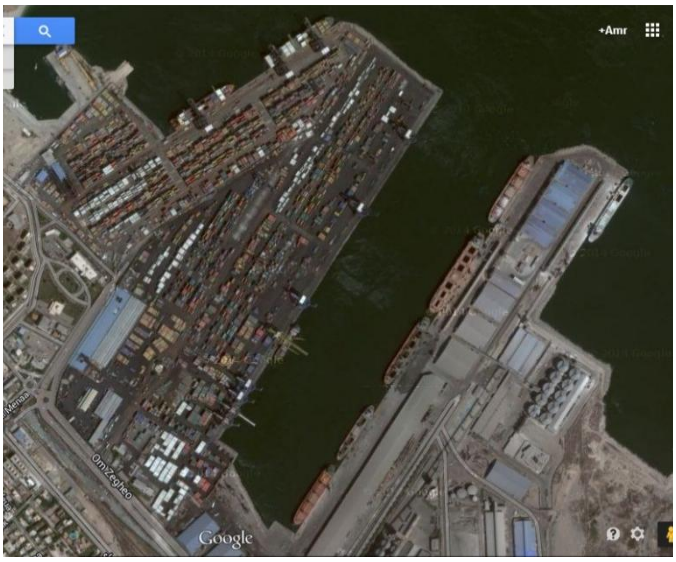

Figure (5) Eldekheila Terminal Arial Photo

The terminal is one of the largest terminals in Egypt, with a total area of 406,000 m2, storage capacity 18,000 TEU, container quay length of 1040m, water depth 12-14m. The infrastructure and the equipment of the company are summarized in the following tables.

Table (1)1 Yard cranes characteristics

Yard Cranes	
Quantity	12
Capacity in Ton	40
Number of stacks	5+1
Number of rows on land	(6+1) / (7+1)
Length between rails (m)	22.5 / 26

Table (2) Quay cranes characteristics

	Panamax	Super Post Panamax	Super post Panamax
Quantity	5	2	1
Capacity in Ton	45	60	60
Boom length	45	51	56
Under handling framework	33	38	38
Back reach length	17.5	19.5	19.5
Vessel width (number of container)	17	19	21

Table (3) Heavy, light and mobile cranes and trucks

Type	Quantity
Heavy top lift truck	16
Empty handler side spreader	5
Terminal tractors	45
Terminal trailers	45
Mobile crane capacity 100 Ton	1

The layout of El-Dekheila container terminal is shown if figure 6.

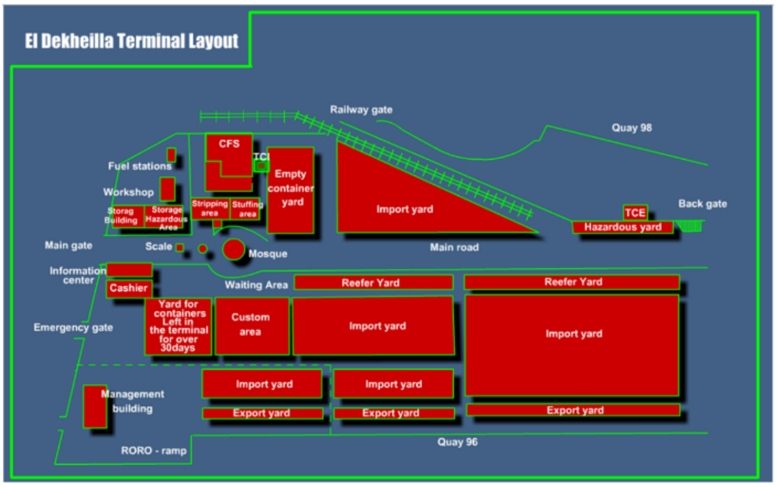

Figure (6) ACCHC layout in El-Dekheila terminal

The company uses "Navis" software for the container terminal operations management. Navis provides mathematical models and solution algorithms to solve some of container terminal. The company uses NavisExpert Decking for Automated Yard Planning. Navis Expert Decking Optimization Module automates yard planning, distributing containers throughout the yard based on predefined business rules. This comprehensive yard allocation module facilitates real-time, accurate and optimized stowage of containers in the yard and allows users to spend less time observing yard allocations and more time managing the yard.

In normal conditions, the company uses Navis to manage the storage yards effectively and efficiently. It provides a position for each incoming container, the position is provided in order to minimize future rehandles. But, during the times of port closure because of storms and bad weather, or in case there are sudden changes due to liner requirements, the containers are not stacked in their optimum positions, and the yard operator may need to reshuffle the containers to reduce the time needed for vessel loading. Navis does not provide a solution for the container pre-marshalling problem.

For export containers, the process of loading starts by obtaining the loading plan from the vessel as a list of target containers (As shown in table 4), and the associated stowage plan.

Table (4) Example of target Containers to be loaded on the vessel

Yard position	Container no.	iso code	weight	shipping line	Container Size	destination	full
PA103003	TRKU2036126	22G0	26	TRK	20'	BEY	FCL
PA122001	SOCU1101664	22G1	24.2	TAR	20'	IST	FCL
PA122002	GETU3004543	2200	24.2	TAR	20'	IST	FCL
PA122003	NOCU0052489	2200	24.2	TAR	20'	IST	FCL
PA122004	ARKU2396205	2200	26.1	ARK	20'	TRM	FCL
PA121001	GETU3030917	22G1	24.2	TAR	20'	IST	FCL
PA121002	CAXU6194490	22G1	24.2	TAR	20'	IST	FCL
PA291002	GESU2730532	22G0	5	TRK	20'	BEY	FCL
PA291003	TRKU2200163	22U1	5	TRK	20'	BEY	FCL
PA311001	TRKU2200137	2250	5	TRK	20'	BEY	FCL
PA323001	TRKU2040384	22G0	5	TRK	20'	BEY	FCL
PA323002	CRSU1184830	22G0	5	TRK	20'	BEY	FCL
PA322002	CRSU1147986	2210	5	TRK	20'	BEY	FCL
PA322003	TRKU2039001	22G0	24.9	TRK	20'	BEY	FCL
PA322004	TRKU2034545	22G0	5	TRK	20'	BEY	FCL

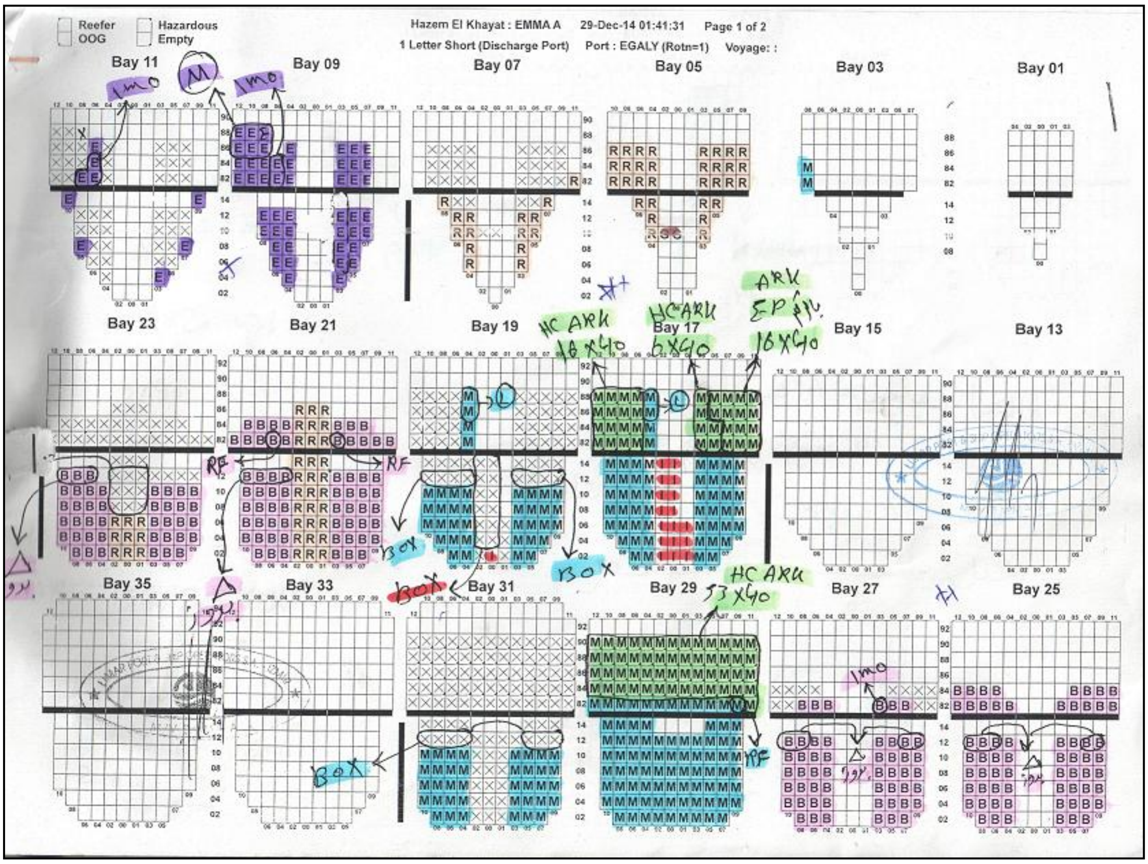

Figure (7) Example of the Vessel Stowage Plan

Then the terminal operators designate which containers will be stowed in which hatch according to the destination port, size and weight. This looks like the graph illustrated in figure 4. Then the quay crane foreman carries out the actual sequence of loading the target containers on the vessel.

A case study in El-Dekheila container terminal

In order to carry out pre-marshalling effectively, many conditions need to match, including:

- The containers are not stacked in their optimum loading order.
- The loading and stowage plans of the vessel are available before hand by a minimum of 24 hours.
- There is at least one transtainer crane (yard crane) available for executing the pre-marshalling.

These conditions were not all available during the case implementation, hence, the study team simulated these conditions by collecting the containers location information from a certain vessel, and measuring the time needed to make different container movements from another vessel, and then calculating the time needed to retrieve the target containers before and after pre-marshalling and comparing these two conditions with each other.

A case study was conducted in El-Dekheila container terminal, the available data were for "Mira" vessel with about 1000 containers to be loaded on the vessel. Three bays were selected to apply the proposed solution methodology. Also, the timing data were collected during loading the vessel "Ever Unicorn" operating for the Ever Green Line, on Saturday 24th , Jan 2015.

Figure (8) The Vessle Evergreen When Berthed in el-Dekhelia Terminal

Figure (9) Time Study Data Collection During Container Handling

Three bays were selected as the test case as shown in the following figures 7, 8 and 9. Each bay has seven stacks excluding the stack left for the carrying for the truck (Mavi), and five

tiers in height. The containers are classified into two categories, one for the containers which will be loaded on the vessel, and two for the other containers. All the containers have the same size and the same weight range. For each bay, the time of retrieval of the containers before pre-marshalling, as well as, the time of retrieval after pre-marshalling are calculated.
The data about the container which will be loaded on a specific vessel are usually known two days in advance, but in practice (and according to the container terminal operators statements) this information is made available about few hours in advance which leaves a very short time for yard preparation.

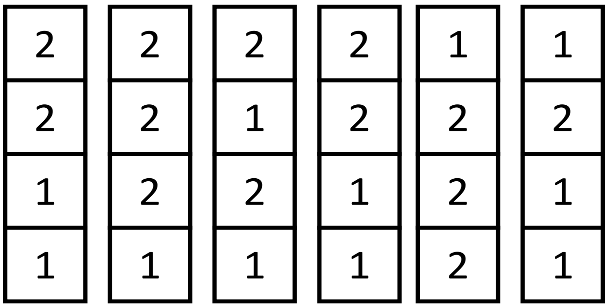

Figure 1 Initial layout of bay 1

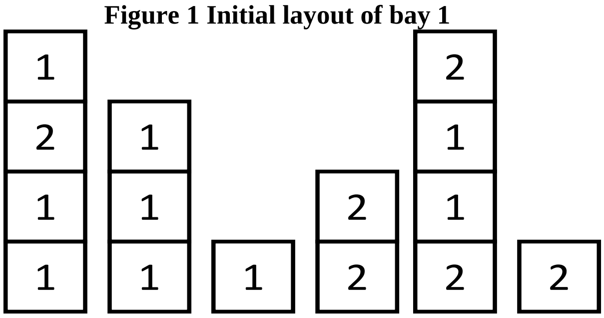

Figure 2 initial layout of bay 2

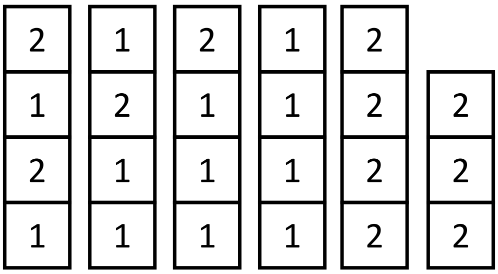

Figure 3 Initial layout of bay 3

Based on the executed time study, the upward, downward, leftward, and rightward movements' times are measured and then the average times are calculated as follows:

- Average upward movement time = 6.4 S
- Average downward movement time = 31.8 S
- Average leftward movement time = 16.2 S

- Average rightward movement time = 11.7 S
- All times including setup times

In the next section the moves are described as *(x y)*, i.e. from top of stack *x* to top of stack *y* or from.to Truck *T*

Bay (1)

- **In case of retrieval before pre-marshalling**

T = Truck

Total time = 2136.9 S ~ 36 min

Movements of retrieval = 5 T, 6 T, 6 5, 6 T, 6 T, 1 6, 1 6, 1 T, 1 T, 4 6, 4 6, 4 T, 4 T, 2 4, 2 4, 2 4, 2 T, 3 4, 3 T, 3 2, 3 T.

- **In case of retrieval after pre-marshalling**

Figure (10) illustrates bay #1 layout after pre-marshalling.

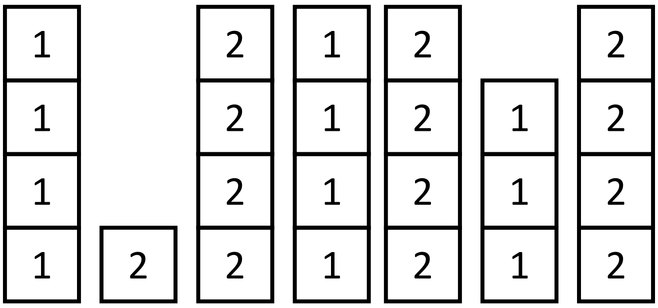

Figure 4 Final layout of bay 1

Movements of Pre-marshalling =

4 7, 4 7, 6 4, 5 4, 3 5, 6 7, 3 6, 3 7, 3 6, 2 3, 1 3, 1 3, 2 3, 6 1, 2 6 2 1, 6 2

Time of pre-marshalling = 28.6 min

- **In case of retrieval after pre-marshalling**

Total time = 1097.9 S ~ 18 min

Movements of retrieval = 1 T, 1 T, 1 T, 1 T, 4 T, 4 T, 4 T, 4 T, 6 T, 6 T, 6 T

Bay (2)

- **In case of retrieval before pre-marshalling**

T = Truck

Total time = 977.35 S ~ 17 min

Movements of retrieval = 1 T, 2 T, 2 T, 2 T, 1 T, 1 T, 1 T, 5 4, 5 T, 5 T.

- **In case of retrieval after pre-marshalling**

Figure (11) illustrates bay #2 layout after pre-marshalling.

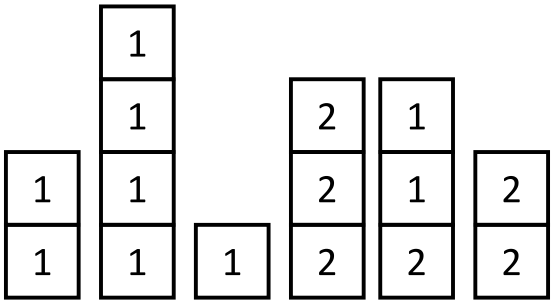

Figure (14) Figure 6 Final layout of bay 2

Movements of Pre-marshalling = 1 2, 5 4, 1 6.
Time of pre-marshalling = 4.3 min

- **<u>In case of retrieval after pre-marshalling</u>**
  Total time = 784.9 S ~ 13 min
  Movements of retrieval = 1 T, 1 T, 2 T, 2 T, 2 T, 3 T, 5 T, 5 T, 5 T.

<u>Bay (3)</u>

- **<u>In case of retrieval before pre-marshalling</u>**
  T = Truck
  Total time = 1714.55 S ~ 28 min
  Movements of retrieval = 1 T, 2 T, 2 T, 2 T, 1 T, 1 T, 1 T, 5 4, 5 T, 5 T.
- **<u>In case of retrieval after pre-marshalling</u>**
  Figure 12 illustrates bay #3 layout after pre-marshalling.

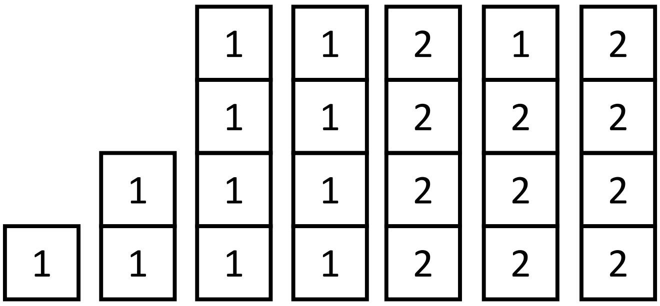

Figure 5 Final layout of bay 3

Movements of Pre-marshalling = 2 6, 17, 3 7, 1 3, 1 7, 2 7.
Time of pre-marshalling = 5 min

- **<u>In case of retrieval after pre-marshalling</u>**
  Total time = 1202.3 S ~ 20 min
  Movements of retrieval = 1 T, 2 T, 2 T, 3 T, 3 T, 3 T, 3 T, 4 T, 4 T, 4 T, 4 T, 6 T.

Table 5 summarizes the results of the case study. As it is shown there are potential savings in time needed for container retrieval ranging from 24 to 50%. This is a very large achievement when applied to loads reaching a 1000 container that need to be loaded on some vessels. Also, it important to note that the pre-marshalling activity is usually done during the idle time of the equipment when loading empty containers or when unloading import containers from the vessel. Which means that the pre-marshalling time is not lost time but it is important to improve the loading efficiency and reduce the berthing time of the vessels.

Table (5) Summary for the results of the three bays

	Bay	Retrieval before pre-marshalling	Pre-marshalling	Retrieval after pre-marshalling	Potential % Savings
Time (min)	1	36	28	18	50%
Movements		21	17	11	48%
Time (min)	2	17	4.3	13	24%
Movements		10	3	9	10%
Time (min)	3	28	5	20	29%
Movements		16	6	12	25%

CONCLUSIONS

- A full comprehensive pre-marshalling case was not possible due to the lack of needed conditions. In order for a full implementation, the vessel stowage plan and the container list must be available before hand and the target containers are not stacked in their optimum loading order.
- Instead, a simulated case was carried out. In this case actual time study was collected and three actual bays were considered.
- The results of the case shows promising potential time savings reaching 50% reduction in container retrieval time in heavily stacked bays with unordered containers.
- In general, pre-marshalling is more useful in transit terminals more than export terminals.

RECOMMENDATIONS

- The study team is ready for a full case implementation give the needed conditions are satisfied.
- It is believed that a full implementation in suitable conditions will have a significant effect on the terminal performance as shown by the study results.

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