

Determining the Best Fleet Sizing of a Container Terminal for a Given Layout

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Abstract

Container handling sea Ports are the hearts many supply chains which are dependent on exports and imports. The overall operations productivity of the container terminals (CT) directly links with the efficiency of the supply chains. Normally in CTs inward and outward containers from/to vassals are handled in two different cycles as unloading and loading. Once a ship arrives to the berth, unloading will take place first and this is followed by the loading operations. In order to handle these activities, three types of equipments are used: Query Crane (QC) is used for (un)loading containers from a ship, Prime movers are used to move containers from/to QC to yard or vice versa. Yard cranes are used to (un)load to/from yard. Since number of different equipments operating in a constraint environment this leads to traffic congestions at buffer zones, intersections of the route network of the terminal etc. Due to these phenomena overall efficiency of the terminal reduces. Therefore, this research is focused on determining the most effective layout arrangement and respective fleet size of prime movers by considering external and internal aspects of a given CT. This problem is modelled and solved in analytically and tested in Arena simulated environment. The proposed approach is able to minimize idle times of CT equipments and minimize resources consumption.

Keywords

Container terminal operations, productivity, fleet sizing, simulation with Arena

1. Introduction

Container trade worldwide has grown 9.5% per year during the last decade and will continue with the growth rate of 8% in the coming years (Lu Chen, 2007). Responding to this demand increase in containerization, in ports point of view, is important to enhance the levels of services. It could only be done by handling materials (containers) more efficient ways in side of the port. It is because; a port's efficiency is often measured in terms of its throughput and typical ship turnaround time (i.e. a ship's time at berth plus any delay caused by the port). Container terminal is the facility in port where all the material handling activities are been carried out. Daily various types of cargos and vassals ships come to the port and so to container terminal, the allocation of those to certain berths in the CT is done according to a certain priority level. Unloading and loading of containers is done using quay cranes (QC). At the storage blocks in the yard, yard cranes (YCs) carry out a number of operations that include lifting and placing. Yard vehicles are used for transporting containers between and quayside and the yard, servicing both quay cranes and yard cranes as prime movers. Once they have transported to the stacking area unloading and placing is done by stacking cranes and lifting vehicles.

There are many factors that affect the operational efficiency of a Container Terminal. Basically the efficiency of the Container Terminal depends on the layout configuration which provides high performance of the material handling equipments, proper arrangement of buffer zone, optimum traffic route, usage of optimal number of prime movers etc.

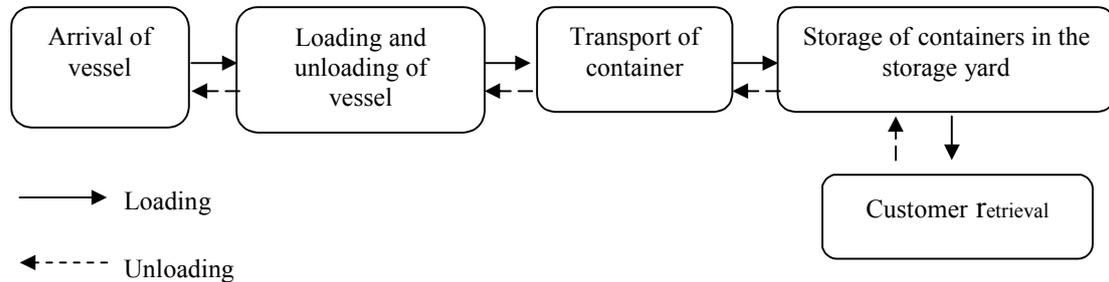


Figure 1: The interaction between Container Terminal processes

Crane clashing and collation of prime movers also can be minimized with a proper Container Terminal layout. There are number of decision problems such as the design of storage policies in the yard according to the specific requirements of the container (size, weight, destination, export/import etc.), allocation of containers to prime movers, routing and scheduling of yard cranes, the design of re-marshalling policies for export containers in order to achieve a proper layout configuration. Number of researches has done in recent past [1-4] with respect to CT operations. However, it is rare to find many researches linking layout configuration and optimal fleet sizes with overall operational efficiency of CT. However, some works involved to find best fleet sizes [5] and even to decide best layout topology to minimize traffic and delay etc. [6, 7]. Since the demand for operations equipments varies over the time due to number of ships that are being serviced at a port in any given time interval, optimal number of operation equipments needed also varies with time. Therefore this research is focusing on deciding the best fleet size once layout of the CT is evaluated for efficient operations. Rest of the paper is arranged as follows: section 2 presents the methodology and the respective mathematical models adapted in the research. Case study is presented in Section 3 and results are given in section 4. This is followed by conclusion and discussion in section 5.

2. Methodology

The methodology proposed in this paper is two folded. In the first stage, given layout of the CT is evaluated for overall operational efficiency analytically and perform necessary changes to the layout and tested new layout in simulation model using Arena simulation package. In the second stage, best prime mover fleet size is decided for the modified layout of the CT by analytical mode and later validates it using Arena simulation package.

2.1 Stage 1: Finding the optimum layout from the given layout

The layout of the flow path can be designed in various ways, initially the facility layout, the layout of the flow path and the location of pick-up and delivery points can be determined simultaneously. Secondly, the design of the flow path and the location of pick-up and delivery points can be determined by considering the layout of the facility as an input factor. Finally the flow path can be designed, considering the layout of the facility and the location of pick-up and delivery point. In order to reduce the cost of operation, the no of shifts as well as fuel usage should be kept at a minimum. For increase the efficiency of the layout, the ship delay should be minimized. [8]

$$\text{Ship Time} = (\text{sum of loading and unloading time}) + (\text{slack time of the QCs})$$

Therefore, it is essential to minimize the total transportation time between the QC and storage location.

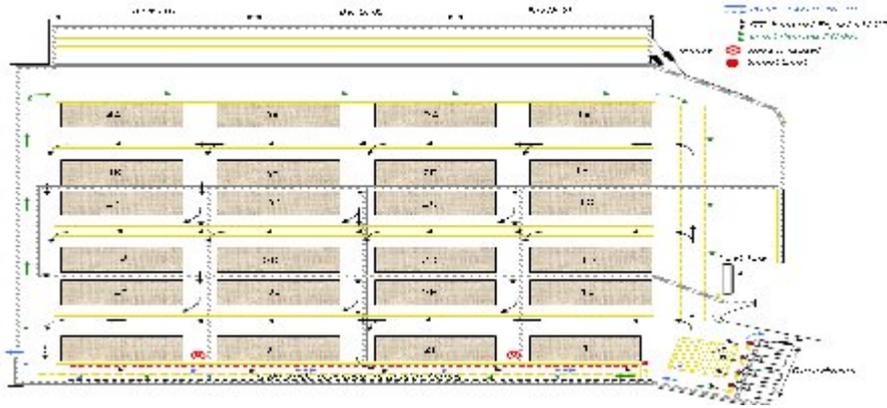


Figure 2: Given layout

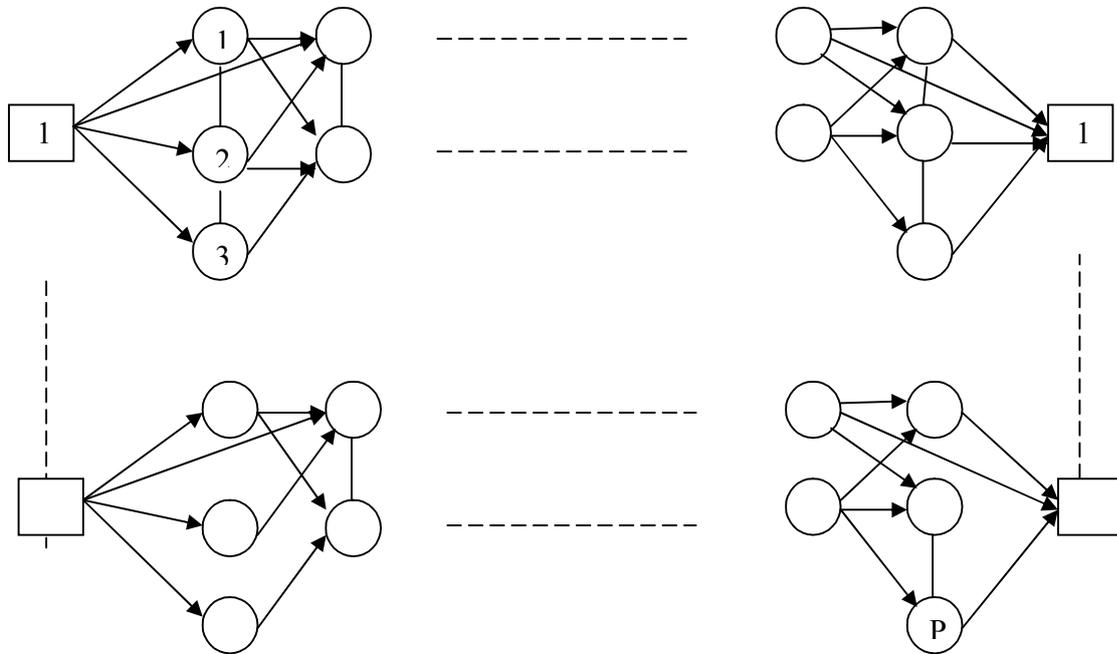


Figure 3 : Graph representation of the container terminal problem. Ship nodes are denoted

$s = 1 \dots S$, position nodes $p = 1 \dots P$ and vehicle nodes are denoted $v = 1 \dots V$. A set of directed arcs connect all ships with all positions and, correspondingly, a set of directed arcs connect positions with vehicles. All positions within each block are connected with in directed arcs. The illustrated graph is repeated for each container c , including only the ship and vehicle nodes, compatible with c .

Assumptions considered are; Only one ship is considered for allocation, All prime movers operate at the same speed, The ship length is negligible (the storage location in the yard has the same distance from any of the QCs), Loading cannot start until unloading of the ship is completed, Loading/unloading sequence and the storage location in the yard are predetermined.

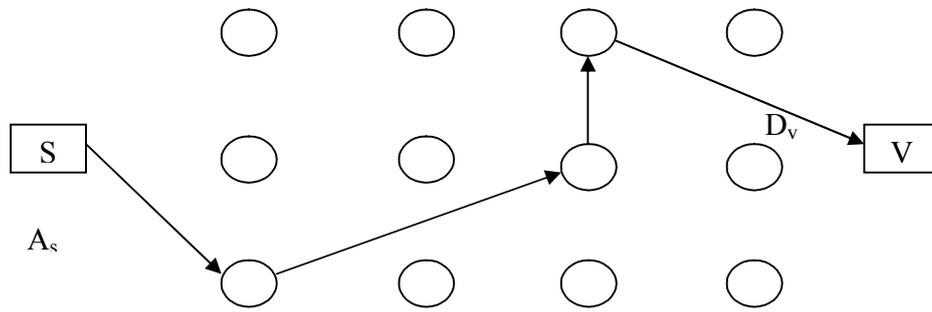


Figure 4: Direction of traveling

The objective function is to minimize the total transportation time for containers through the terminal. $\sum T_{ij}$ $c \in C, i \in (SUP), j \in (PUV)$ Where, $c = \{1, 2, 3, \dots, C\}$ containers, $s = \{1, 2, 3, \dots, S\}$ container ships $p = \{1, 2, 3, \dots, P\}$ positions in the yard, $v = \{1, 2, 3, \dots, V\}$ prime movers $A_s, s \in C$: arrival time for ship $S, D_v, v \in V$ departure time for vehicle $V, T_{ij}, i \in SUP, j \in PUV$ transportation time between nodes i and j ($i \neq j$), $x_{cij} = 1$ if container c is moved directly from node i to j

2.2 Step 2: Designing the optimal number of prime movers for a Container Terminal

Number of assumptions were considered in this stage also: only unloading process is taken in to account during the simulation, four separate cyclic paths considered there are four queues of unlimited number of transporter vehicles in front of each and each path. (But due to limitations in students version this number is taken as 100), Loading time near a QC is considered as a constant value for each and each path. These values differ from path to path but same for the transporters in a one particular path, Unloading time near a stacking crane is considered as a constant value for each and each path. These values differ from path to path but same for the transporters in a one particular path, Delays caused due to traffic congestion are considered as a constant value for each and each path. These delays differ from path to path but same for the transporters in a one particular path, Transporters are assumed to have a one particular speed when they're loaded and comparably higher speed when they travel freely

In order to find the best feet size of prime movers for the above proposed layout, a simplified version of the layout design is considered and it is converted into a network diagram, it is shown in Fig 5.

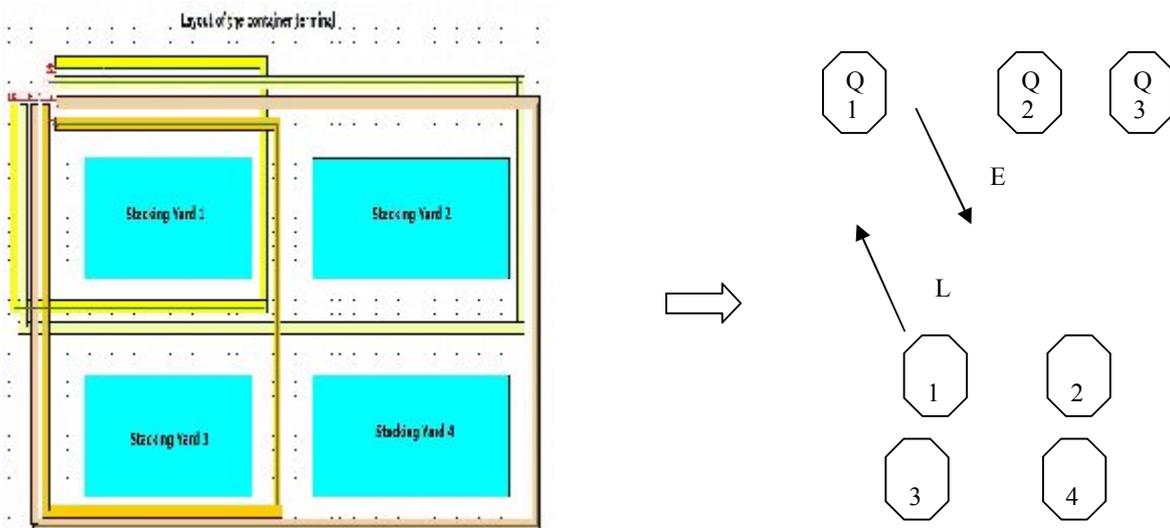


Figure 5: Simple layout design with converted network diagram

Where Q1, Q2, Q3 are Quay cranes of the terminal, 1, 2, 3 and 4 are stacking stations, and L - Path of loaded prime movers and E - Path of emptied prime movers, L_{ij} – Path of prime movers with loads of i^{th} Quay crane to the j^{th} station Where; $1 \leq i < 4$ and $1 \leq j < 5$

$$\begin{bmatrix} L1,1 & L1,2 & L1,3 & L1,4 \\ L2,1 & L2,2 & L2,3 & L2,4 \\ L3,1 & L3,2 & L3,3 & L3,4 \\ L4,1 & L4,2 & L4,3 & L4,4 \end{bmatrix}$$

There is a matrix for a unloading path as well.

Mathematical equations were developed for the vehicle operations for material handling in container terminals. The time for a typical delivery cycle in the operation of a vehicle transport system consists of (1) loading at the pickup station, (2) travel time to the drop off station, (3) unloading at drop-off station and (4) empty travel time of the vehicle between distances

Cycle time per delivery (T_{cij}) is given by

$$T_{cij} = T_L + \frac{L_{dij}}{V_{loading}} + T_U + \frac{L_{eij}}{V_{empty}}$$

Where, T_{cij} - cycle time of a prime mover with loads of i^{th} QC to the j^{th} station, T_L - time to load at a QC, L_{dij} - distance between i^{th} QC and j^{th} station unloading point, $V_{loading}$ - Velocity of the prime mover once it is been loaded, T_U - Time to unload at a stacking crane, L_{eij} -Distance between j^{th} station and i^{th} QC, V_{empty} - Velocity of the prime mover once is been unloaded

Total cycle time per delivery (T_c) is given by

$$T_c = \sum_{i=1}^3 \sum_{j=1}^4 n_i P_i C_{ij}$$

Where, n_i - jobs handled by the i^{th} QC, P_i - percentage of total jobs handled for the j^{th} station, C_{ij} cycle time per delivery. The total cycle time can be used to determine certain parameters of interest in the vehicle based system such as Rate of deliveries per vehicle and Number of vehicles required to satisfy a specified total delivery requirement.

The hourly rate of deliveries per vehicle (R_d) is

$$R_d = \frac{60 \text{ minutes}}{T_{cij}}$$

Adjusting of any time losses during the hour should be taken in to account. Possible time losses are availability (reliability factor), Traffic congestion, Efficiency of prime movers

Available time (AT) is $AT = 60 AT_f E$

Where, A - Availability factor, T_f - Traffic factor to indicate traffic congestion, E - Worker efficiency, now the hourly rate of deliveries equation can be modified as follows

The hourly rate of deliveries per vehicle (R_d) is $R_d = \frac{AT}{T_{cij}}$

Optimal number of vehicles (n_c) needed to satisfy a specified flow rate of deliveries in the system can be estimated by dividing the total workload by available time per vehicle.

$$n_c = \frac{WL}{AT}$$

Workload (WL) is given by,

$$WL = R_f T_c$$

Where, R_f - Specified flow rate of total deliveries for a system (delivery/hour), T_c - Delivery cycle time (minutes/delivery)

Therefore, **Optimal number of vehicles (n_c)** is,

$$n_c = \frac{R_f}{R_d}$$

Where, R_f - Specified flow rate of total deliveries for a system (delivery/hour), R_d - Hourly rate of deliveries per vehicle

3. Case study

A case study has been carried on the given layout, considering the critical factors best optimal layout is created (Figure 6).

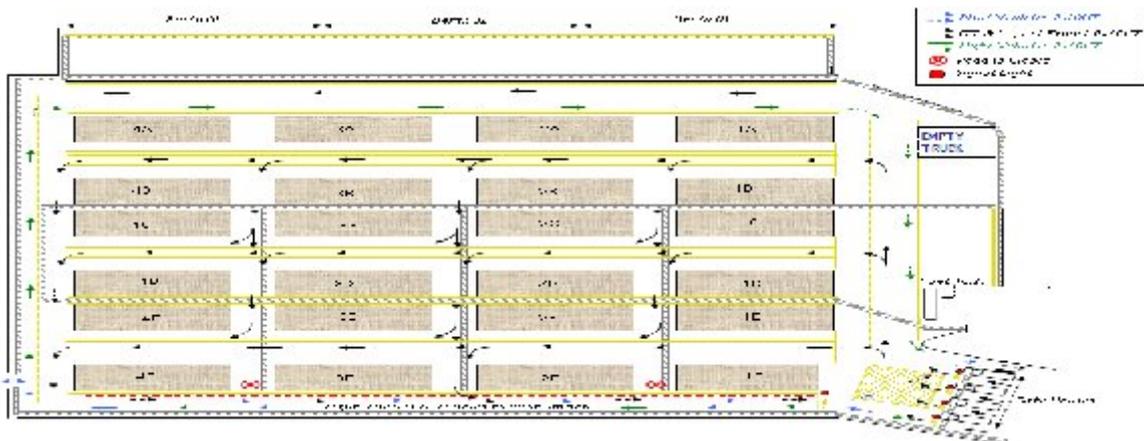


Figure 6: Modified version of the layout

3.1 Analysis and evaluation of performance of the Container Terminal on modified layout

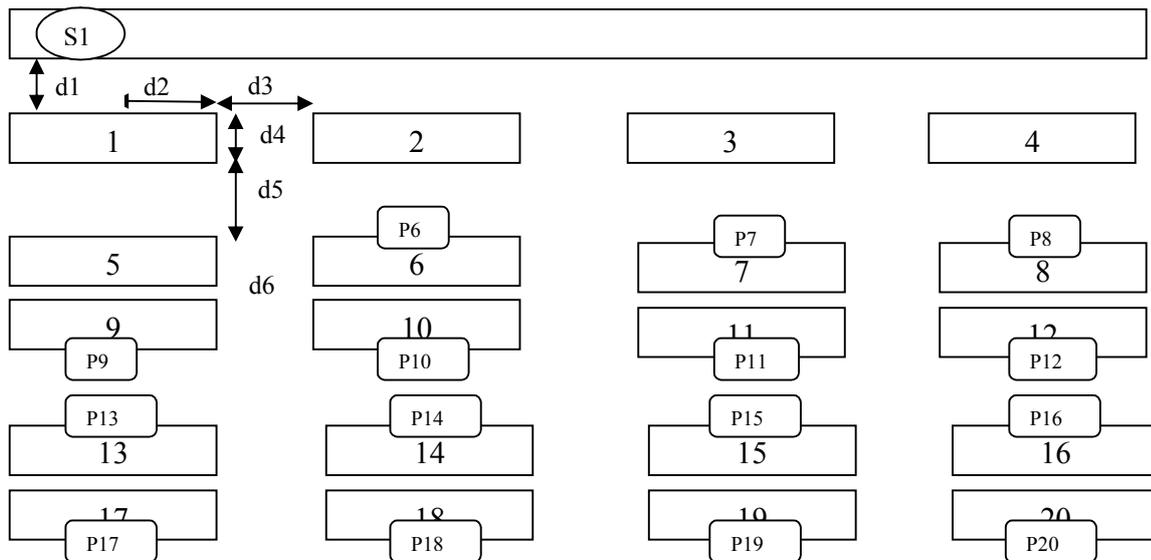


Figure 7: Analysis and evaluation of performance of the Container Terminal on modified layout

Here the optimal paths and minimum distances for each block can be defined, for an instance optimal path for blocks 5, 6, 7 paths and distances are given in Table 1. But, if there is traffic on transportation, the next best alternative paths are to be considered

Table 1 : Alternative traveling paths

Block number	Path	Distance
5	S1-P1-P2-P6-P5	$d1+6d2+2d3+d4+d5$
6	S1-P1-P2-P3-P7-P6	$d1+8d2+3d3+d4+d5$
7	S1-P1-P2-P3-P4-P8-P7	$d1+9d2+4d3+d4+d5$

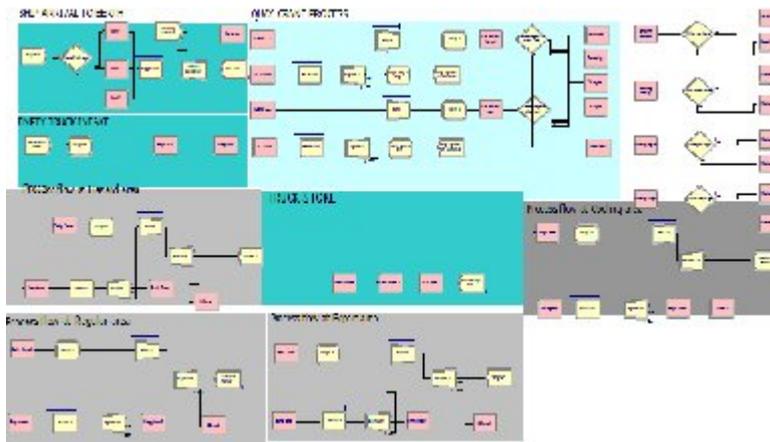


Figure 6: Arena Simulation Model

Simulation of the CT was done with traffic rules for prime movers and without traffic rules. The simulation model consist of ship arrival to berth, quay crane process, process flow of hazardous area, cooling area, regular area and export area sub modules. Simulations were carried out for several times with different batches and value added time, waiting time and total times were measured for all batches with and without traffic rules. In addition, above time measurements were calculated for ships and prime movers separately.

In this stage one quay crane and for four stacking stations are modelled in the Arena software. Container allocation for QC's was modelled as given in the variation of Figure 6. Mainly two scenarios considered.

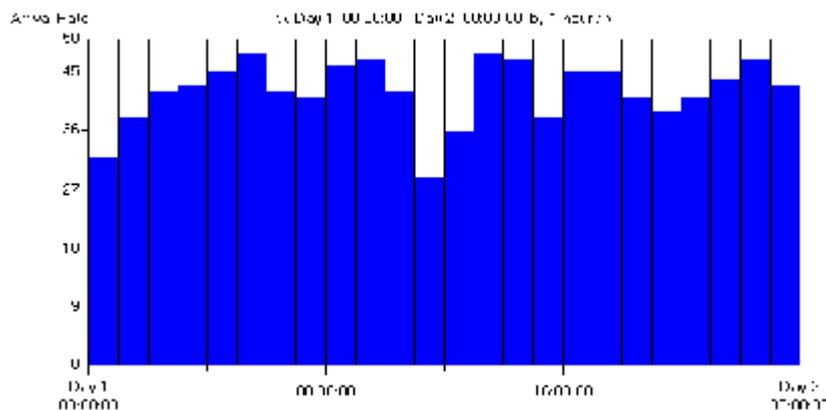


Fig 7: Schedule of the containers assigned to a specific QC

In the first scenario we have compared the effect of traffic congestion on the optimal number of vehicles that are to be assigned to each and every considered path. A,

4. Results

Simulation of the CT was done with traffic rules for prime movers and without traffic rules. The simulation model consist of ship arrival to berth, quay crane process, process flow of hazardous area, cooling area, regular area and export area sub modules. Simulations were carried out for several times with different batches and value added time, waiting time and total times were measured for all batches with and without traffic rules. In addition, above time measurements were calculated for ships and prime movers separately. These results are presented in Table 2 and Figure 8 and Figure 9.

Table 2: Simulation results for the layout 5

		Without traffic rule		With traffic rule	
		Trucks	Ships	Trucks	Ships
Entity	Value added time/mins	15.0489	17.7651	17.4135	14.3210
	Wait time/mins	512.03	700.45	485.56	680.75
	Total time	910.16	523.87	875.40	450.65
Queue	Batch10.Queue	12.23		10.34	
	Batch 11	32.45		28.70	
	Batch 3	4.09		3.50	
	Batch 5	10.83		7.94	
	Batch 6	15.55		14.87	
	Batch 7	15.26		13.92	
	Process 11	2.99		1.43	
	Process 12	2.18		2.04	
	Process 7	5.35		4.34	
	Process 9	5.85		4.93	

This clearly shows that for a traffic congestion situation the modified layout gives the optimum results, hence it is more efficient. The next step is to find the optimum no of prime movers for the modified optimum layout in order to achieve higher efficiency.

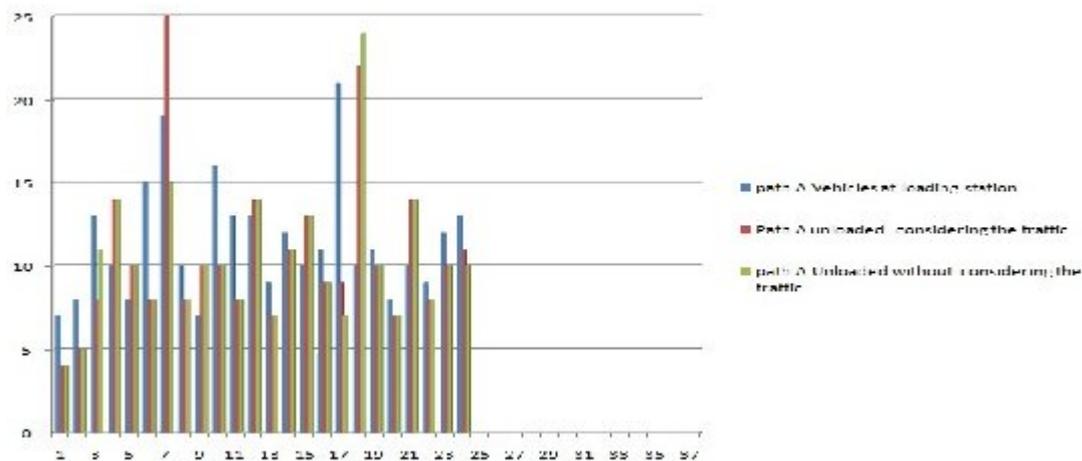


Figure 8 : Comparison of the effect of traffic on the jobs being served in path A (Traffic congestion is considered, $\rho = 0.95$)

This clearly shows the effect of the traffic congestion on the jobs being served and the number of prime movers that are to be applied to path 'A'. Here we can observe that the jobs are being more efficiently served when there is no

traffic (Obvious truth). However we can see that as the number of prime movers loaded at the QC increases the jobs delivered to the stacking yard are significantly decreasing when there is traffic.

In addition to above parameters prime mover acceleration and deceleration, break downs, accidents etc. are other parameters what determines the efficiency of the operation. Specified flow rate of total deliveries for a system is the other crucial parameter that determines the efficiency of the operation. Since we have considered a single cargo carrier problem we outrun the possibilities of fluctuating supplies.

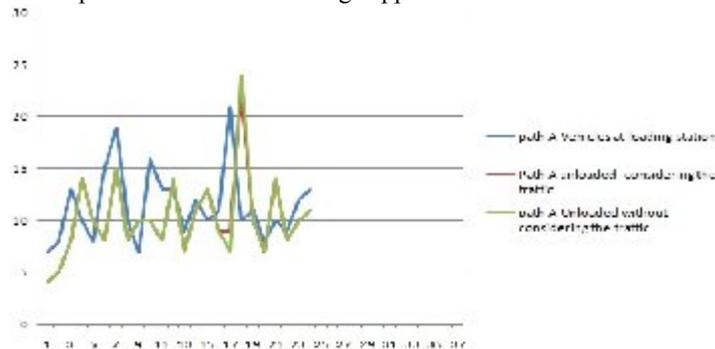


Figure 9 : Comparison of the vehicles left from loading station and vehicles reached to the unloading station

5. Discussion and Conclusion

In this research we tried to investigate the factors that are associated with the layouts to improve the productivity of the container terminals. The summarized results shows that it is needed to consider the traffic congestion and minimum distance paths to achieve the high productivity of the container terminal. According to the sizes of the seaport material handling equipments and travelling paths, marshalling area should be arranged to improve the efficiency. In order to minimize re-handling time and traffic congestion it is compulsory to have a pre determined careful planning of storage locations. The distance of path and the velocities of prime movers are the main parameters that determine the prime mover cycle time. Therefore the number of prime movers that are sent after loading (near QC) can be considered as essential.

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