

Paper:

Performance Analysis of Container Unloading Operations at the Port of Suva Using a Simplified Analytical Model (SAM)

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Time has fast become one of the most important factors in global trading. While little can be done to reduce the travel time of ships, significant effort can be put into improving the efficiency of container terminal. This paper presents a simple analytical model (SAM) for predicting container dwell times and determining equipment utilization. The paper exemplifies the operations of the Port of Suva and presents an analysis of its operations. To improve the current performance, a cooperative control schema is proposed. It is shown in this paper that the prediction model and performance measures are a useful tool for container terminal planners.

Keywords: container dwell times, simple analytical model (SAM), equipment utilization, performance measure, cooperative control

1. Introduction

Recent data reveals that approximately 18 million containers make more than 200 trips per year on ships [1]. This is strengthened by the fact that 90% of the world's trading items move through container terminals globally [2, 3]. Container terminals are therefore the trading interface of coastal nations.

The dynamic interactions between sections in a container terminal are complex [4]. Botti [5], when analyzing the container terminal operations using the multi-agent approach, classified the container operations into ship, stevedoring, service, transfer and gate agents. Fig. 1 illustrates this classification.

The daily container handling operations is summarized by Fig. 2. The containers, once unloaded by cranes, enter the shore based material handling system. They are then transferred and placed in storage yards until the shipping agent of the customer collects them. The outbound containers follow an opposite cycle, leaving the material handling system when the containers are loaded on a ship.

Present day container terminals must increase terminal throughput, ensure firm utilization of equipment and space, and reduce container re-handling times in order to remain competitive [6]. Each of these improvements lead

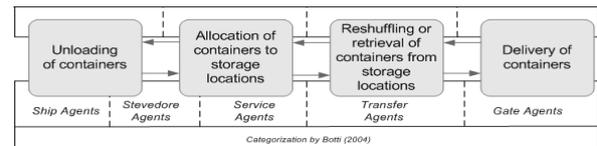


Fig. 1. Classification in sections by [5].

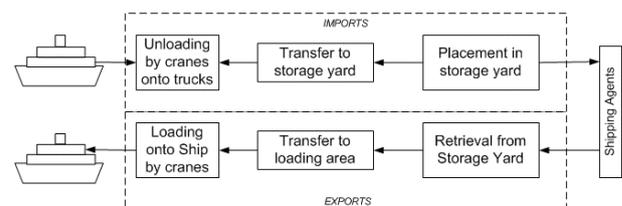


Fig. 2. Container handling operations.

to reduced ship turnaround times and maximum operational efficiency.

This paper therefore presents a simplified analytical model (SAM) to determine the operation time of a non-automated container terminal, as well as a cluster of performance management schemes. Based on data from June 2006 to June 2007, performance and equipment utilization of the Port of Suva, Fiji, are discussed. The paper identifies operational inefficiencies and presents recommendations for improvement.

2. The Process Model

The operations of the container terminal at the Port of Suva, situated in the Fiji Islands, are modeled in this paper. It supports the economy of a growing nation but is not equipped with state of the art equipment which most global ports use. Hence there is an immediate need to enhance the efficiency of current operations in order to compete internationally. Incoming ships unload containers on the wharf using their own deck (ship) cranes. Most ships come equipped with two to three cranes. These cranes are operated by local staff. All of the unloaded contain-

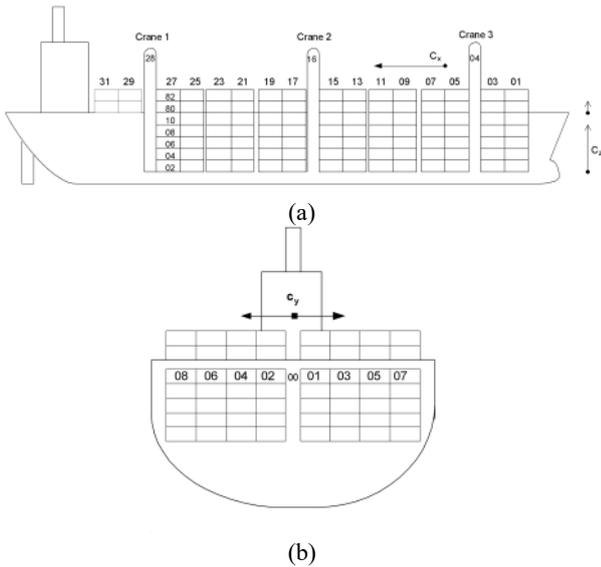


Fig. 3. Container location index (a) Side elevation of a container vessel (b) rear elevation of a container vessel.

ers need to be hooked and unhooked from the crane (done by two to three men). Containers on the wharf are then loaded onto shuttle trucks using forklifts. These trucks deliver containers to the heavy container handlers that are in the storage blocks. Each ship is assigned a storage block, and upon receiving containers, the heavy container handlers place containers in the designated storage location of that block. Port of Suva had just commenced the use of two Gottwald HMK 300E shore mobile cranes when the data collection was being carried out.

SAM provides the port planners a simple tool to understand the cause and effect of their decisions. In the absence of a proper planning tool for a manual container terminal, SAM provides a clearer understanding of strategic decisions that will achieve the previously mentioned goals of a present day container terminal. It uses the operational specifications of individual sub-processes to determine the total process time.

2.1. Unloading

Consider the unloading process of a ship laden with C containers. The location of containers is given by the widely accepted bay, row and tier system that is represented here using (c_x, c_y, c_z) , as shown by **Fig. 3**. The gang responsible for the unloading of the ship follows a planner, commonly termed the manifest, and it consists of an array (c_x, c_y, c_z) for containers and the order in which they will be unloaded. The model uses the information from the manifest to determine the processing times for each container.

Unlike modern container terminals where quay cranes unload containers, in the Port of Suva, containers are unloaded by the deck crane closest to it. The crane closest to the container is determined by taking the crane with the minimum separation distance between the container

of concern and the deck crane. The separation distance, x_{sep} is determined from the following heuristic:

$$x_{sep} = L \left(\frac{|c_x - s|}{2} \right) \dots \dots \dots (1)$$

The distance a container is transferred after lifting is determined by using the geometry of the travel path of the crane. This is given by Eq. 2.

$$\Delta z = \begin{cases} H \left(\frac{c_z - 80}{2} \right) + h_c + h_d & \text{if } c_z > 80, \\ H \left(\frac{c_m - c_z}{2} \right) + h_c + h_d & \text{if } c_z < 80. \end{cases} \dots (2)$$

Typical storage systems on ships have two sections. One is on the deck while the other is in the hatches. The labeling system begins from 80 for containers over the deck, and from 00 for containers in the hatches. In the above equation, the first part determines the container movement distances for containers above the deck (labels > 80), while the second part computes container movement distances for containers in the hatches. The clearance, h_c and the height of the deck, h_d is dependant on the dimensions and geometry of the ship.

Containers that have been elevated are moved over the deck of the ship towards the wharf. The containers are then placed a safe distance away from the edge of the wharf. The following equation provides the distance traveled by the container in this direction.

$$\Delta y = \begin{cases} L \left(\frac{b - c_y}{2} \right) + y' & \text{if } c_y \text{ is even,} \\ L \left(\frac{c_y}{2} \right) + \frac{w_s}{2} + y' & \text{if } c_y \text{ is odd.} \end{cases} \dots (3)$$

The above equation is also divided into two, and is based on the standard numbering of rows adopted by ships. It provides the distances if the ship berths on its port side. Containers with even row numbers are closer to the berth (left side of the ship), and traverse a shorter distance over the ship compared to the containers with an odd row number, which traverse an additional half ship width.

Since the ship cranes are not of the gantry type, they do not traverse in x and y directions separately, but instead rotate about the z axis. Given the translation of the container, the angle that the crane rotates horizontally is given as follows:

$$\theta_h = \sin^{-1} \left(\frac{\Delta y}{x_{sep}} \right) \dots \dots \dots (4)$$

Hence, the time taken for a container to be unloaded from the ship to the wharf, including the hooking and unhooking time, is given as:

$$t_u = \frac{\theta_h}{\dot{\theta}_h} + \frac{\Delta z}{\dot{z}} + t_{hk} + t_{uk} \dots \dots \dots (5)$$

2.2. Transfer to Storage

Unloaded containers from the wharf are loaded by forklifts onto trucks parked alongside the containers. In a coordinated sequence of forward and backward motion,

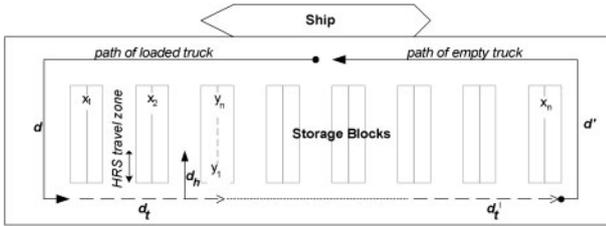


Fig. 4. Storage section layout of the Port of Suva.

combined with the elevation of the container, the forklift loads the container on the truck. The time taken for this process is given as follows:

$$t_f = \frac{f_{sep}}{s_f} \dots \dots \dots (6)$$

Once loaded, the trucks leave for the designated storage block. At present, the storage policy dedicates a complete storage block for a ship. The layout of the storage section is illustrated in Fig. 4. All trucks travel to the same storage block from the wharf, and the time they spend traveling is given as follows:

$$t_t = \frac{[x_s(2W + \delta)] + d}{s_t} \dots \dots \dots (7)$$

An assigned heavy container handlers then unloads the container off the truck and takes it to the pre-assigned storage location in the storage block. The time that the container spends on the high reach stacker is given as follows:

$$t_h = \frac{Ly_s}{s_y} + \frac{(z_s - z_h)H}{s_z} \dots \dots \dots (8)$$

2.3. Empty Travel Times

Equations 1 to 8 have so far presented models for the container travel times. These are times when the container is in motion and equipment is in use. Since the operation of the container handling equipment is cyclic, their repositioning times (times when equipment does not displace containers) must be noted for full modeling of the operations.

Hence, after unloading a container, the ship crane returns to the deck to pick up the next container. It is assumed that the drop off position of all the containers is approximately the same. Hence, the distance the crane travels empty to collect a container is the same as the distance the crane travels when it brings that particular container down. A difference is, however, seen in the speed of the cranes during their loaded and empty operations. A ratio, r_c that reflects the relationship between the loaded and empty time, therefore helps model the empty travel time of the crane. Therefore:

$$t'_u = \left[\frac{\theta_h}{\theta_h} + \frac{\Delta z}{z} \right] r_c \dots \dots \dots (9)$$

For simplicity, the notation ‘ t' ’ refers to the empty travel or the repositioning time for any container handling equip-

ment.

A similar approach is taken for the travel times of the forklift and the heavy container handlers, with ratios r_f and r_h used for the two equipment types respectively. Hence:

$$t'_f = r_f \left[\frac{f_{sep}}{s_f} \right] \dots \dots \dots (10)$$

$$t'_h = r_h \left[\frac{Ly_s}{s_y} + \frac{(z_s - z_h)H}{s_z} \right] \dots \dots \dots (11)$$

Since the trucks follow a mono-directional path, their empty travel paths are different from the loaded travel paths. The empty travel time of the truck is given as:

$$t'_t = r_t \left[\frac{[(x_n - x_s)(2W + \delta)] + d'}{s_t} \right] \dots \dots \dots (12)$$

2.4. Total Dwell Times of a Container

The container dwell times can therefore be summarized as:

$$t = t_u + t_f + t_t + t_h \dots \dots \dots (13)$$

3. Total Operating Times of the Equipment

The total operating time of the crane, inclusive of the empty travel time, is given by:

$$t_{crane} = \sum_{i=1}^n (t_{u_i} + t'_{u_i}) \dots \dots \dots (14)$$

The total operating time of the forklifts is given as:

$$t_{forklift} = \sum_{i=1}^n (t_{f_i} + t'_{f_i}) \dots \dots \dots (15)$$

The total operating time of the trucks, inclusive of the empty travel time, is given by:

$$t_{truck} = \sum_{i=1}^n (t_{t_i} + t'_{t_i}) \dots \dots \dots (16)$$

The total operating time of the HRS, inclusive of the empty travel time, is given by:

$$t_{truck} = \sum_{i=1}^n (t_{h_i} + t'_{h_i}) \dots \dots \dots (17)$$

The general formula for determining the utilization index for all equipment is given as follows:

$$U_{equip} = \frac{t_{working} + t_{empty}}{t_{working} + t_{empty} + t_{waiting}} = \frac{t_{equipment}}{t_{equipment} + t_{waiting}} \dots \dots \dots (18)$$

4. Performance Analysis

Data collection at the Port of Suva was carried out from June 2006 till July 2007. Fig. 5 illustrates the distribution

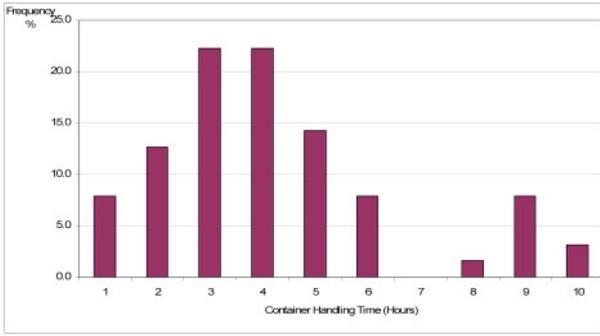


Fig. 5. Ship turnaround time distributions for Port of Suva between January and June 2007 [mean = 15.6 hours, median = 14.3 hours].

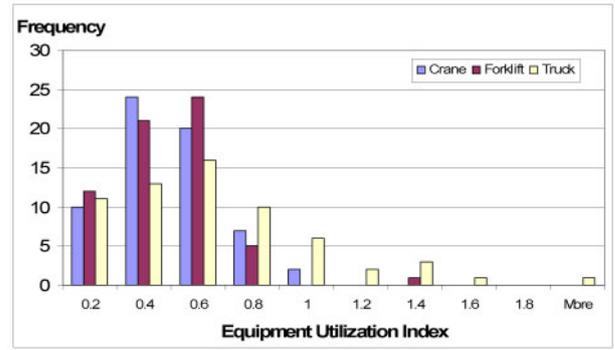


Fig. 6. Equipment utilization in Port of Suva .

Table 1. Individual process data collected from the Port of Suva between June and December 2006.

Process	Mean Process Time
t_{crane}	3.24 mins
$t_{forklift}$	3.60 mins
t_{truck}	4.43 mins

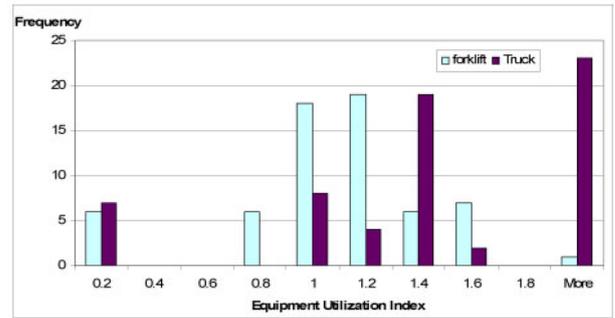


Fig. 7. Equipment utilization in Port of Suva without waiting time.

of the container handling operations time between February and June 2007. The individual process times, given in **Table 1**, were taken from data collected from the Port of Suva.

Data collection was carried out at two different levels. At the global level, data was extracted from the Port of Suva database. Here, overall performance figures, such as arrival times of ships, time when operations commenced, number of import and export containers and other similar times were available. At the local level, stop watches were used to time individual processes. It is extremely difficult to time an entire process sequence, due to the complex nature of the process. Hence, processes were broken down into sub-processes for data collection. Sub-processes included hooking and unhooking times, equipment movement times and waiting times.

Using previously presented equations and collected data, the utilization of individual equipment was determined. This is shown by the plot in **Fig. 6**. The mean utilization factor for the crane, forklift and trucks are 38.5%, 37.6% and 54.7% respectively. These results suggest under utilization of equipment, with utilization figures closer to 100% being better. In this case, 61.5%, 62.4% and 55.3% of the time, the respective equipment and their operators are idle. For the company, these are irrecoverable losses, especially when equipment operators are being paid for this period.

Given that the crane has the primary operation of unloading containers, other individual process times should ideally be the same as this in order to achieve a perfectly balanced container flow. Presented statistical data does

not show a flow balance, and hence the low equipment utilization index can be attributed to waiting times. To prove this, an analysis with the cranes operating time as reference, was performed.

Here it was assumed that the crane operates with 100% utilization (i.e. the crane does not have any waiting times). The operational times of the other equipment were then compared with the operational time of the crane. The results are presented by **Fig. 7**.

Comparing the above assumption with the actual operations, utilization drastically increases when it is benchmarked with a crane with no waiting times. There is a shift of the plot to the right and on a number of occurrences and the individual equipment are operating at more than 100% utilization. Representing a blocked system from the viewpoint of the crane, these results indicate that the machines are struggling to meet the demand of the crane if the crane works at 100% utilization. Trucks always find a container when they arrive at the wharf, and so do the forklifts. There is a non-stop demand for the containers to move and hence the trucks and forklifts have to overwork.

From this simple test, it can therefore be inferred that the possible cause of the underutilization of equipment is waiting time. It was also noticed during data collection that the waiting delays trigger a chain reaction across the process sequence, and these get amplified with recurring delays. The problem is caused by a lack of coordination

between the tasks. A few of the many events instigated by lack of process synchronization and affecting the utilization are listed below.

- Crane unloads a container, but trucks have not returned from the delivery of the previous container. The crane has to wait for the truck before unloading the next container.
- Truck arrives to collect a container from the crane, but the crane is still repositioning. The truck has to wait for the container to be brought down.
- The forklifts are loading the first truck, keeping a number of other trucks in queue. The trucks have to wait to be loaded.
- Forklifts are ready with containers, but trucks are not in sight. The forklift has to wait.

Waiting times are a natural phenomena in manual handling operations and its effect becomes obvious in large complex systems like container handling operations. Delays at one sub-process initiate a chain reaction with accumulated delays. A machine waiting for another, either during pick-up or delivery, is usually the initiator. A system to centrally coordinate the individual sub-processes is therefore likely to make a significant difference to performance.

5. Cooperative Control Schema

Waiting times can be significantly reduced if the operations of the individual equipment can be coordinated centrally. Such a system is termed cooperative control. The entire material handling operations can then be embedded into a cooperative framework; utilizing either a centralized or decentralized architecture.

A centralized architecture is one where a central server communicates with all the equipment in its colony and allocates tasks with deadlines. It requires a very reliable decision maker (similar in function to that of the airport control towers). In a decentralized architecture, the equipment are given more autonomy, making decisions and solving task allocation problems amongst themselves.

Researchers like [7–10] have considered the implementation of cooperative control schema for automated systems in container terminal operations. However, limited effort has been made to centrally control non-automated container handling systems. Experiences from the research of [10, 11] on managing multiple vehicles in a single workspace can be used to develop rules for the individual equipment such as trucks and forklifts.

6. Conclusions and Recommendations

The paper has presented a simple analytical method for predicting container dwell times and measuring the performance of a container terminal. Using a simple

and less computationally intensive tool, the processes are split into sub-processes and their individual performances compared. Through this, the equipment utilization and throughput can be measured.

Results from the Port of Suva indicate inefficiencies caused by an imbalance in the container flow, and resulting in high waiting times. A cooperative control schema is proposed to overcome the waiting times and attempt to reduce process delays.

While cooperative control schema has proved beneficial for automated systems, its impact on manual or semi-automated systems is unexplored. As further work, research will therefore develop ways to use cooperative control tools to eliminate waiting times and increase equipment utilization, without the need for investment in new container handling equipment.

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Appendix A. Nomenclature

c_x location of the container on the ship referencing the bay.

c_y location of the container on the ship referencing the row.

c_z location of the container on the ship referencing the tier.

s location of ships crane on the ship referencing the bay.

L length of containers. W width of containers. H height of containers.

w_s width of the ship.

x_{sep} the distance between the container and the crane closest to it.

y' clearance distance from the edge of the wharf where the container will be placed.

Δy total distance the container has to move in the y direction over the ship.

Δx distance the container has to move in the x direction.

a estimate of the distance the container moves to achieve Δy and Δx .

θ_h horizontal rotation angle of the crane to achieve Δy and Δx .

$\dot{\theta}_h$ horizontal rotation speed of the crane.

b bay reference of the furthest container on the ship.

Δz total distance the container has to move in the z direction over the ship.

\dot{z} speed of the crane in the z direction.

h_c additional height that the crane gains to move container over the ship.

h_d distance the container moves along the ship side to reach the wharf.

t_u time taken for a container to be unloaded.

δ distance between two adjacent container storage blocks.

x_s the number of the storage block in which the containers will be stored.

y_s exact location of the containers in the y direction.

z_s exact location of containers in the z direction.

z_h average height at which heavy container handlers transport containers.

t_f the time taken for the container to be loaded on the truck by the forklift.

f_{sep} separation distance between a truck and the forklift.

s_f mean speed of the forklift during the loading of a truck.

t_t total time container spends traveling to the storage yard on the truck.

t_h time the container is transferred from the truck to its storage location.

r_c the ratio of loaded travel speed of the deck crane to its empty travel speed.

n number of containers unloaded.

t_{crane} total time taken by the crane.

$t_{forklift}$ total time taken by the forklift.

t_{truck} total time taken by the truck.

t_{hrs} total time taken by the heavy container handlers.

GP Global Productivity.

U_{equip} Utilization of individual equipment.

t_{hk} time taken for hooking the containers to the crane hook.

t_{uk} time taken to take the hook off the containers.



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